FAST TRACK PHASE OF CONSTRUCTION OF THE TESLA ACCELERATOR INSTALLATION

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Abstract

Construction of the TESLA Accelerator Installation will be continued in three phases. The objectives of the first phase, called the fast track phase, are to complete construction of the VINCY Cyclotron, the main part of the facility, and to establish the routine production of radioisotope ^{18}F and radiopharmaceutical ^{18}FDG. The production of the radioisotope, with the 15 MeV H^+ ion beam, will be going on in the shielding vault of the machine. The objectives of the second and third phases are to construct the channels for production of radioisotopes, for radiation research and for proton therapy, and to commence their use. The ion beams that will be used in these phases are, e.g., the 65 MeV H^+, 30 MeV H^+, 7 MeV per nucleon $^4He^{2+}$ and 3 MeV per nucleon $^{40}Ar^{6+}$ beams. We shall describe the status of construction of the machine and mention the first programs of use of the facility.

INTRODUCTION

The TESLA Accelerator Installation, in the Laboratory of Physics of the Vinča Institute of Nuclear Sciences, consists of a compact isochronous cyclotron – the VINCY Cyclotron, a volume positive or negative light ion source – the pVINIS Ion Source, two similar electron cyclotron resonance heavy ion sources – the nVINIS Ion Source and the mVINIS Ion Source, and a number of low energy and high energy experimental channels [1, 2]. In the low energy channels ion beams from the mVINIS Ion Source will be used. In the high energy channels ion beams from the pVINIS Ion Source and the nVINIS Ion Source accelerated in the VINCY Cyclotron will be used. Programs of use of the facility include basic and applied research in physics, chemistry and biology, development of materials and nuclear technologies, production of radioisotopes and radiopharmaceuticals, and proton therapy.

Until May 1998 we had commissioned the pVINIS Ion Source, the mVINIS Ion Source and the channel for modification of materials. In June 1998 construction of the facility was stopped, due to the severe economic crisis in the country. It was resumed in small steps in September 2002, on the basis of a plan for continuation of construction of the facility approved by the Government of Serbia. The first phase of continuation of the construction, called the fast track phase, includes the completion of construction of the VINCY Cyclotron, and establishing of the routine production of radioisotope ^{18}F and radiopharmaceutical ^{18}FDG, to be used for positron emission tomography of tumors and other diseases. The second phase comprises construction of the nVINIS Ion Source, and of the channels for production of radioisotopes and for radiation research, to be used for routine and experimental production of other radioisotopes and radiopharmaceuticals, and for research in radiation physics, chemistry and biology, respectively. The third phase includes construction of the channel for proton therapy, to be used for routine treatment of eye tumors. These phases will be followed by the phase of development.

In June 2004 the Government of Serbia decided to use a part of the clearing debt of Russia to Serbia and Montenegro for the continuation of construction of the facility. The equipment will be delivered by the Joint Institute for Nuclear Research, Dubna, Russia, on the basis of a contract signed at the end of July 2004. It will ensure completion of the fast track phase of continuation of the construction – by the end of June 2006, and of the first part of the second phase, enabling the first experiments in the fields of production of radioisotopes and radiation research – by the end of December 2006.

MAGNETIC STRUCTURE AND RADIOFREQUENCY SYSTEM OF THE VINCY CYCLOTRON

The magnetic structure of the VINCY Cyclotron consists of the ferromagnetic elements – the yoke, poles, sectors and plugs, the main coils, and the correction coils – the trim coils and harmonic coils [3]. The diameter of the pole is 2,000 mm. The sectors are straight and there are four of them per pole. The minimal distance between the sectors is 36 mm. The machine has two main coils, 20 circular trim coils, placed between the poles and sectors, and 16 quasi-trapezoidal harmonic coils, eight of them in the central region and eight of them in the extraction region. The ferromagnetic elements and the main coils have been fabricated, assembled and tested. The correction coils have been fabricated and assembled, and their testing should be finished by the end of November 2004. The final shaping of the sectors and plugs should be completed by the end of November 2004 as well.

The radiofrequency system of the machine consists of two $\lambda/4$-resonators with the eigenfrequency in the range between 17 and 31 MHz, two coupling lines with coupling loops, two amplifier chains, the safety subsystem, and the control subsystem. Each resonator consists of a part that is out of the main chamber and a part penetrating it radially and lying between the magnet′s valleys. The vertical dimension of the ion beam aperture of the dee is 22 mm. The course changes of the eigenfrequency of the resonator are performed by a sliding short while its fine changes are performed by a trim loop attached to the sliding short. The maximal amplitude of the dee voltage is 100 kV. The coupling lines with coupling loops provide the direct coupling of the power amplifiers to the resonators. The coupling loop is fixed and the matching of the impedances of the primary and secondary circuits is achieved by varying the eigenfrequency of the power amplifier, with a variable condenser. The resonators, the amplifier chains, the safety subsystem, and the control subsystem have been fabricated. The coupling lines with coupling loops will be delivered by the Joint Institute, on the basis of the contract from July 2004.

The maximal value of the magnetic induction at the center of the machine is 1.97 T and its nominal extraction radius is 840 mm. The bending constant of the machine is 134 MeV while its focusing constant is 73 MeV. The minimal ion energy is limited by the power of the trim coils and the minimal eigenfrequency of the resonators.

INJECTION AND EXTRACTION SYSTEMS OF THE VINCY CYCLOTRON

The injection system of the machine includes the transport line – connecting it axially with the pVINIS Ion Source and the nVINIS Ion Source, the spiral inflectors with the system for their positioning and exchange, and the electrodes in the central region – three electrodes at the dee voltage, E1, E2 and E3, and one electrode grounded, E4 [4]. The inflector is placed at the end of the lower axial channel of the machine. The injection system will be delivered by the Joint Institute, on the basis of the contract from July 2004.

The machine has two foil stripping extraction systems – the back and front ion beam extraction systems, and an electrostatic deflection system [5]. The back extraction 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 includes a dipole and quadrupole magnet, BFM1, and a quadrupole magnet. The system will be fabricated within the fast track phase of continuation of the construction, and used first to extract the 15 MeV H^+ ion beam, and to transport it to the target station for production of radioisotope ^{18}F. The front extraction system enables the extraction of light and low charge state heavy ion beams at the front side of the machine, and their transport down to the channels for production of radioisotopes and for radiation research. It includes a dipole and quadrupole magnet, BFM2, a triplet of quadrupole magnets and a dipole magnet. The system will be fabricated within the first part of the second phase. Both foil stripping extraction systems will be delivered by the Joint Institute, on the basis of the contract from July 2004. The electrostatic deflection system will enable the extraction of high charge state heavy ion beams. It will be fabricated within the phase of development.

The test ion beams of the machine are: the 15 MeV H^+ ion beam obtained from the H^- accelerated beam, the 65 MeV H^+ beam obtained from the H^- beam, the 30 MeV H^+ beam obtained from the H_2^+ beam, the 7 MeV per nucleon $^4He^{2+}$ beam obtained from the $^4He^+$ beam, and the 3 MeV per nucleon $^{40}Ar^{15+}$ beam obtained from the $^{40}Ar^{6+}$ beam. The H^-, H_2^+ and $^4He^+$ ion beams will be produced with the pVINIS Ion Source, and the $^{40}Ar^{6+}$ beam with the nVINIS Ion Source. The H^- ion beam will be accelerated with the harmonic number of the dee voltage equal to 1, the H_2^+ beam with this parameter equal to 2, and the $^4He^+$ and $^{40}Ar^{6+}$ beams with this parameter equal to 4.We shall present here some of the results of calculations of the transport of the ion beams through the injection, central, acceleration and extraction regions.

Figure 1 shows the H^- ion horizontal trajectories in the central region, for the radii down to about 110 mm. The initial ion energy is 25 keV, the initial horizontal ion position, at the center of the grounded electrode gap, is 33 mm, the direction of the initial horizontal ion momentum relative to the direction perpendicular to the grounded electrode gap is 18°, and the initial ion phase is varied between –5 and 15°. The dee voltage is 75 kV.

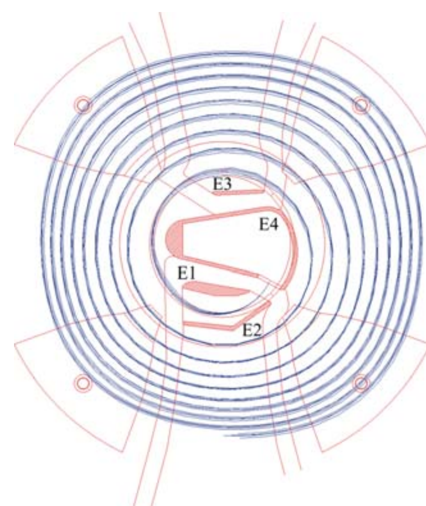

Figure 1: The H^- ion horizontal trajectories in the central region for the initial ion phase between –5 and 15°.

Figure 2 gives the central ion trajectories of the 15 MeV H^+, 65 MeV H^+, 30 MeV H^+, 7 MeV per nucleon $^4He^{2+}$ and 3 MeV per nucleon $^{40}Ar^{15+}$ ion beams in the extraction region. The initial parameters of the H^+ ion beam are: the horizontal emittance $\varepsilon_h = 5\pi{\cdot}mm{\cdot}mrad$, the vertical emittance $\varepsilon_v = 5\pi{\cdot}mm{\cdot}mrad$, the maximal horizontal half-width $h_m = 1$ mm, the maximal vertical half-width $v_m = 5$ mm, the maximal horizontal half-angle $h_m' = 5$ mrad, the maximal vertical half-angle $v_m' = 1$ mrad, and the relative energy spread $\Delta E/E = \pm3$ %. The initial parameters of the 65 MeV H^+ ion beam are: $\varepsilon_h = 5\pi{\cdot}mm{\cdot}mrad$, $\varepsilon_v = 5\pi{\cdot}mm{\cdot}mrad$, $h_m = 1$ mm, $v_m = 5$ mm, $h_m' = 5$ mrad, $v_m' = 1$ mrad, and $\Delta E/E = \pm1$ % while the initial parameters of the other beams are: $\varepsilon_h = 12\pi{\cdot}mm{\cdot}mrad$, $\varepsilon_v = 5\,\pi{\cdot}mm{\cdot}mrad$, $h_m = 2$ mm, $v_m = 5$ mm, $h_m' = 6$ mrad, $v_m' = 1$ mrad, and $\Delta E/E = \pm1$ %. In each of these cases it is assumed that the ion beam has initially a double waist. In the case of 15 MeV H^+ ion beam the radial position of the stripping foil (of the back extraction system) has to be 421 mm while in the cases of 65 MeV H^+, 30 MeV H^+, 7 MeV per nucleon $^4He^{2+}$ and 3 MeV per nucleon $^{40}Ar^{15+}$ beams the radial positions of the stripping foil (of the front extraction system) have to be 812, 824, 818 and 851 mm, respectively.

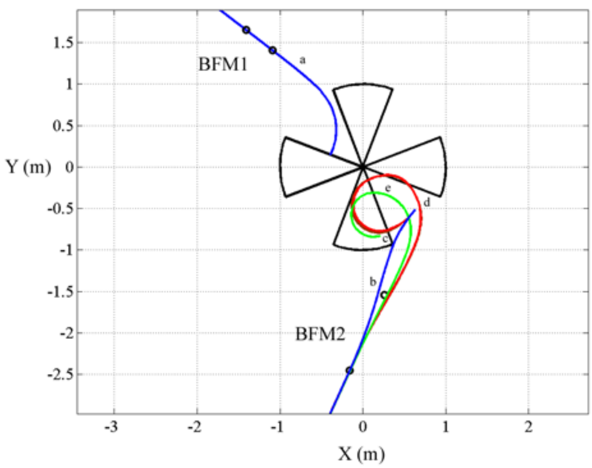

Figure 2: The central ion trajectories of the (a) 15 MeV H^+, (b) 65 MeV H^+, (c) 30 MeV H^+, (d) 7 MeV per nucleon $^4He^{2+}$ and (e) 3 MeV per nucleon $^{40}Ar^{15+}$ ion beams in the extraction region. The central points in the entrance and exit planes of BFM1 and BFM2 are shown too.

FIRST PROGRAMS OF USE OF THE TESLA ACCELERATOR INSTALLATION

Realization of the program of use of the channel for modification of materials, with ion beams from the mVINIS Ion Source, has been going on since May 1998. This program includes: (i) modification of surface properties of carbon materials by highly charged ion implantation and metal deposits, (ii) modification of electric, thermal and optical properties of polymers by highly charged ion irradiation, (iii) modification of surface layers of steels by hard coatings and ion implantation, (iv) synthesis of nanocomposite structures by implantation of metallic ions in polymer substrates, (v) *in situ* analysis of sputtered ions during ion bombardment, etc.

The first program of use of the VINCY Cyclotron will be routine production of radioisotope ^{18}F and radiopharmaceutical ^{18}FDG, to be used for positron emission tomography of tumors and other diseases. It will be followed by the programs related to routine and experimental production of other radioisotopes and radiopharmaceuticals, and to research in radiation physics, chemistry and biology. These programs will include: (i) development of novel radiohalogenated tracers for diagnostics, (ii) development of radiopharmaceuticals for alpha-endoradiotherapy, (iii) development of rapid techniques for separation and purification of radionuclides for radiopharmaceutical applications, (iv) heavy ion modification of insulators: surface and bulk properties of track recording polymers, (v) analysis of pollutants by high energy proton induced X-ray emission, (vi) determination of individual resistance to high-LET radiation, (vii) eradication of humane prostate cancer by proton irradiation, etc.

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