STATUS REPORT ON THE VINCY CYCLOTRON

N. NEŠKOVIĆ, V. VUJOVIĆ, B. BOJOVIĆ, P. BOJOVIĆ, D. ALTIPARMAKOV, P. BELIČEV, N. MAKSIMOVIĆ, A. DOBROSAVLJEVIĆ

VINČA Institute of Nuclear Sciences, P. O. Box 522, 11001 Belgrade, Yugoslavia

The VINCY Cyclotron is the main part of the TESLA Accelerator Installation, which includes also a heavy ion source, and a light ion source. It is a compact isochronous cyclotron. The diameter of the pole of its magnet is 2,000 mm. The sectors of the magnet are straight, and there are four of them per pole. The bending constant of the machine is 145 MeV, while its focusing constant is 75 MeV. The radiofrequency system of the machine consists of two λ/4-resonators with the eigenfrequency in the range from 17 to 31 MHz. The ions coming from the heavy ion source, or light ion source will be injected into the machine axially. They will be introduced into its median plane by a spiral inflector. The heavy ions accelerated in the machine will be extracted from it by a foil stripping system, or by an electrostatic deflection system. The light ions will be extracted from it by the foil stripping system.

1 Introduction

The TESLA Accelerator Installation is an ion accelerator facility consisting of a compact isochronous cyclotron - the VINCY Cyclotron, an electron cyclotron resonance heavy ion source - the mVINIS Ion Source, a volume light ion source - the pVINIS Ion Source, and a number of experimental channels.[1,2] The construction of this facility has been going on in the VINČA Institute of Nuclear Sciences.

2 VINCY Cyclotron

2.1 Magnetic Structure

The magnetic structure of the VINCY Cyclotron consists of the ferromagnetic elements - the yoke, poles, sectors and shimming elements, the main coils, and the correction coils - the trim coils and harmonic coils. It is shown in Figures 1, 2, and 3.

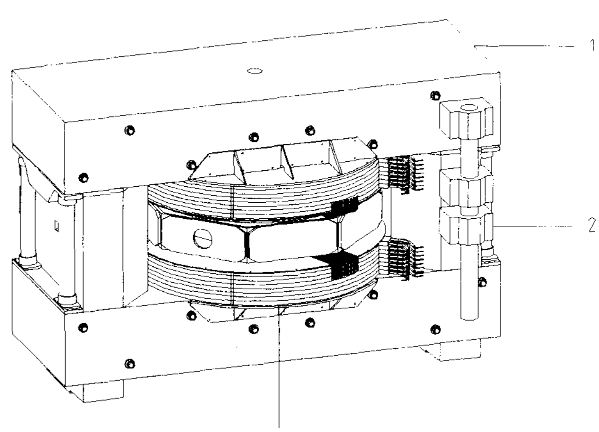

Figure 1. Magnetic structure of the VINCY Cyclotron: 1 - yoke, 2 - elevation system, and 3 - main coil.

The yoke consists of 2×9 cross rails, making its lower and upper parts, and 2×4 pillars, making its side parts. The poles consist of 2×4 circular plates. The diameter of the pole is 2,000 mm. The distance between the poles, i.e. the distance between the valleys of the magnet, V1-V4, is 190 mm. The sectors are straight, their angular span is 42°, their height is 46.8 mm, and there are four of them per pole. The distance between the sectors, i.e. the distance between the hills of the magnet, H1-H4, is 66.4 mm. The shimming elements are placed on the horizontal surfaces of the sectors seen from the median plane of the machine. With the shimming elements on the horizontal surfaces of the sectors taken into account, the minimal magnetic gap of the machine becomes 31 mm. The maximal magnetic induction at its center is 2.02 T.

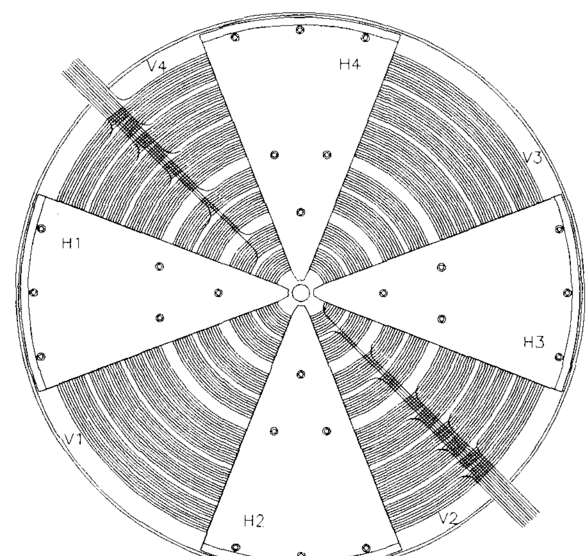

Figure 2. Trim coils of the VINCY Cyclotron.

The VINCY Cyclotron has two main coils. Each of them consists of eight identical segments, each segment has two layers, and each layer has sixteen windings. The inner radius of the main coil is 1,030 mm, its maximal radial dimension is 1,543 mm, and its height is 438 mm. The main coils are wound from a rectangular hollow copper conductor. The outer dimensions of its cross section are 22

$\times$28 mm^2. The segments of the main coils are powered in series, their maximal current is 1,000 A, and they are cooled by demineralized water.

The VINCY Cyclotron has ten circular trim coils per pole and they are placed between the poles and sectors. Each of them has one layer and its height is 15 mm. The trim coils are wound from a square hollow copper conductor with the magnesium oxide insulation in the copper sheath. The outer dimensions of its cross section are 8.8$\times$8.8 mm^2. The trim coils are powered independently of each other, their maximal currents are 200 A, and they are cooled by demineralized water.

The VINCY Cyclotron has eight quasi-trapezoidal harmonic coils per pole - four of them in the central region of the machine, lying on hills H1-H4, and four of them in its extraction region, lying in valleys V4 and V2. The harmonic coils are wound from the same conductor used for the trim coils. They are powered independently of each other, their maximal currents are 200 A, and they are cooled by demineralized water.

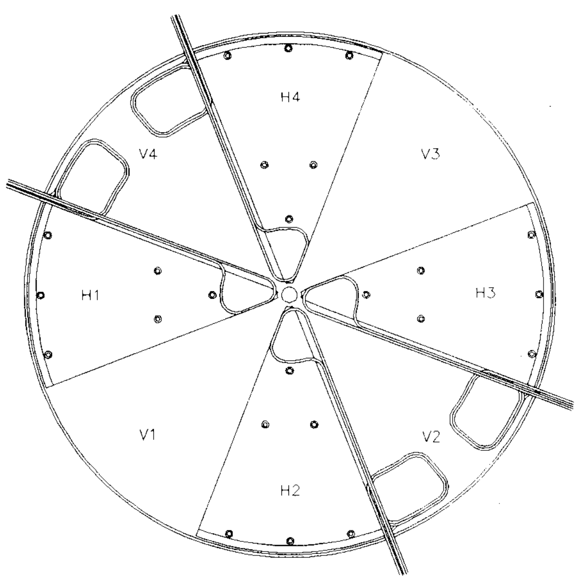

Figure 3. Harmonic coils of the VINCY Cyclotron.

The magnetic structure of the VINCY Cyclotron includes also the elevation system of its upper part, i.e. the upper part of the yoke, the upper pole with the sectors, main coil, and correction coils, the upper parts of the anti-dees of the radiofrequency (RF) system of the machine, and the upper horizontal side of its main chamber. This system is of the hydraulic type, its elevation capacity is 150 t, and its maximal height of elevation is 1,000 mm.

2.2 Radiofrequency System

The RF system of the VINCY Cyclotron consists of two $\lambda/4$-resonators with the eigenfrequency in the range from 17 to 31 MHz, two amplifier chains, the coupling lines and coupling loops, the control subsystem, and the safety subsystem.[3,4] The resonators are shown in Figure 4.

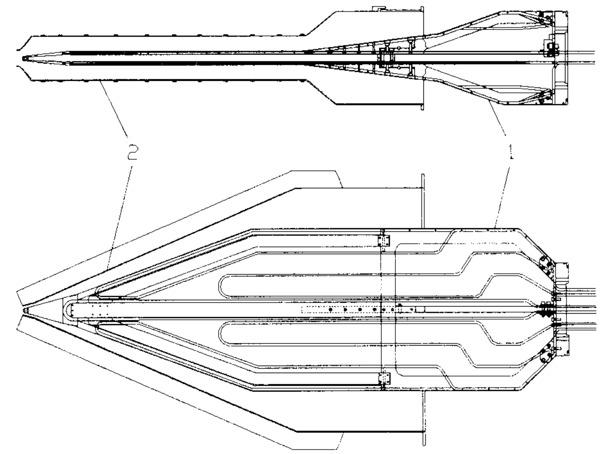

Figure 4. The horizontal cross section of the dee and anti-dee - 1 and 2, respectively, of the RF system of the VINCY Cyclotron defined by the median plane, and their vertical cross section defined by the symmetry plane of valleys V1 and V3.

Each resonator consists of a part being out of the main chamber, and a part penetrating the main chamber and lying between valleys V1 and V3. The inner electrode of the resonator consists of a cylindrical part of the outer diameter of 326 mm and the length of 1,350 mm, being partly out and partly in the main chamber, terminated by the dee. The outer electrode of the resonator consists of a cylindrical part of the inner diameter of 850 mm and the length of 1,850 mm, and a transition part of the length of 500 mm, being out of the main chamber, and a box, being in the main chamber, terminated by the anti-dee. The average angular span of the dee is 33°, and that of the anti-dee is 48°. The vertical dimension of the ion beam aperture of the dee is 22 mm. The coarse changes of the eigenfrequency of the resonator are performed by a sliding short, while its fine changes are achieved by a trim loop placed on the sliding short.

The amplitude of the dee voltage varies from 35 to 100 kV. The phase difference between the dee voltages is either 0 or 180°, depending on the harmonic number of the dee voltage, h. If h is even, the phase difference between the dee voltages is 0°, and, if it is odd, the phase difference is 180°.

The heat generated in the resonator is taken away by demineralized water flowing through a system of tubes soldered to the inner surfaces of its inner electrode, and to the outer surfaces of its outer electrode.

The amplifier chains begin with a frequency synthesizer, and each of them includes a predriver amplifier, a driver amplifier, and a power amplifier. The predriver amplifier is a 2 kW broad-band amplifier. The main element of the driver amplifier is a 20 kW tetrode in the grounded cathode configuration, while the main element of the power amplifier is a 50 kW tetrode in the grounded grid configuration. Both tetrodes are cooled by demineralized water, and they operate in class B or class C. The maximal amplitude of the anode voltage of the power amplifier is 10 kV.

2.3 Injection System

The injection system of the VINCY Cyclotron includes a spiral inflector, and the electrodes in the central region - four electrodes at the dee potential, and four electrodes at the anti-dee potential.[5,6] The spiral inflector is placed in the lower axial channel of the machine.

2.4 Extraction Systems

The VINCY Cyclotron has two extraction systems - a foil stripping system, and an electrostatic deflection system.

The low charge state heavy ions, and light ions accelerated in the VINCY Cyclotron will be extracted from it by the foil stripping system, which includes a foil stripper, and a magnetic channel. The foil stripper is placed between valleys V4, and its position can be adjusted in the radial and azimuthal directions. The magnetic channel is placed after the foil stripper.

The high charge state heavy ions accelerated in the VINCY Cyclotron will be extracted from it by the electrostatic deflection system, which includes an electrostatic deflector, and a magnetic channel. The electrostatic deflector is placed between valleys V2, and the magnetic channel between hills H1.

2.5 Vacuum System

The main chamber of the VINCY Cyclotron consists of a skeleton, whose horizontal cross section is an equilateral octagon, a lower horizontal side, an upper horizontal side and eight vertical sides. It is shown in Figure 1. The skeleton is made of stainless steel, while the horizontal and vertical sides are made of an aluminum alloy. The horizontal and vertical dimensions of the main chamber in the symmetry plane of hills H1 and H3 are 2,868 and 460 mm, respectively. The sides facing hills H2 and H4 are used to evacuate the main chamber. The monitors of the ion beam diagnostic system are introduced into the main chamber through the sides facing hills H1 and H3, the foil stripper, and the corresponding magnetic channel through the side facing valleys V4, and the electrostatic deflector, and the corresponding magnetic channel through the sides facing valleys V2, and hills H1, respectively. The ion beam is extracted through the side facing hills H4.

The main chamber will be evacuated by two cryogenic vacuum pumps and two turbomolecular vacuum pumps. The pumping speed of each of the cryogenic pumps is 10,000 l/s, while the pumping speed of each of the turbomolecular pumps is 1,100 l/s. In addition, the parts of the resonators behind the sliding shorts will be evacuated by two turbomolecular vacuum pumps with the pumping speeds of 1,100 l/s.

2.6 Operating range

The operating range of the VINCY Cyclotron in the B_0-T/A plane is given in Figure 5; B_0 is the magnetic induction at the center of the machine, T the energy of the ion at its exit, A the mass number of the ion, and η its specific charge. The maximal value of the magnetic induction at the center is taken to be 2.02 T, and the extraction radius of the machine is 860 mm. As a result, the bending constant of the machine is K_b = 145 MeV. Its focusing constant is K_f = 75 MeV. This means that for $\eta \leq 0.517$ the energy of the ion is limited by the bending ability of the machine, and that for $\eta > 0.517$ it is limited by its focusing ability. The former range includes the heavy ions, D^-, H_2^+, and H_3^+ ions, and the latter range includes the H^- ions. The low magnetic induction limit of the operating range is determined by the maximal power consumption of the trim coils. The three vertical lines appearing in this figure show how the range of the RF system covers the operating range. The heavy ions will be accelerated with the harmonic number of the dee voltage equal to 2 or 4, D^-, H_2^+, and H_3^+ ions with h = 2, and H^- ions with h = 1. The low energy limit of the operating range is determined by the low frequency limit of the RF system.

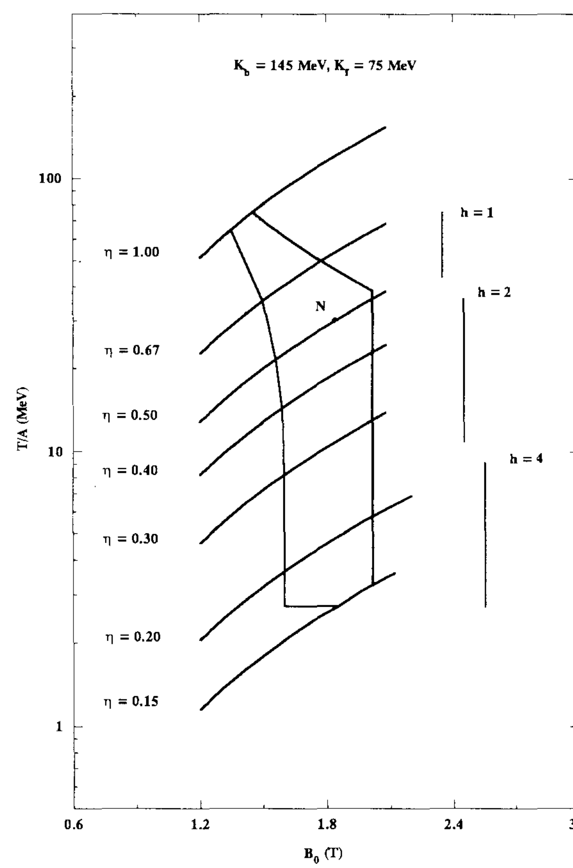

Figure 5. The operating range of the VINCY Cyclotron.

The first ions which will be accelerated in the VINCY Cyclotron will be the H_2^+ ions. The magnetic induction at the center of the machine will be 1.84 T, and the energy per nucleon of the ions at its exit will be 30.2 MeV. This is the nominal operating point of the machine, N - the isochronous profile of the average magnetic induction in the median plane is achieved with the zero power consumption of the trim coils. As it has been said, the acceleration of these ions will be performed with the harmonic number of the dee voltage equal to 2, the frequency of the dee voltage will be 28.3 MHz, and its amplitude will be 80.0 kV. With the intensity of these ions from the pVINIS Ion Source of 200 μA, the expected intensity of the protons at the exit of the machine is higher than 40 μA. The extraction of the first ion beam from the machine is planned for the beginning of 1997, and this ion beam will be used first for the production of radioisotopes for medical dignostics - in the first half of 1997.

The VINCY Cyclotron will be able to deliver, e.g., 4 μA of 26.6 MeV per nucleon N^{6+} ions, 5 μA of 11.0 MeV per nucleon Ar^{11+} ions, and 4 μA of 3.3 MeV per nucleon Xe^{20+} ions. It will be able to deliver also 2 μA of 66 MeV protons, 20 μA of 43-73 MeV deuterons, 40 μA of 22-36 MeV protons, and 60 μA of 11-16 MeV protons.

3 Ion Sources

3.1 mVINIS Ion Source

The mVINIS Ion Source is a multiply charged (heavy) ion source. It is a plasma machine with the magnetic confinement in which the plasma is generated by the microwaves using the effect of electron cyclotron resonance. The multiply charged ions are generated in their collisions with the hot electrons, and the heating of the electrons is performed using the effect of electron cyclotron resonance too.

The magnetic structure of the mVINIS Ion Source consists of two coils wound from a copper conductor, a ferromagnetic yoke placed around the coils, and a NdFeB permanent magnet hexapole placed inside the coils. The frequency of the microwaves in the mVINIS Ion Source is 14 GHz, with the possibility of raising it to 16 and 18 GHz.

The mVINIS Ion Source will be able to produce ions of gaseous as well as solid substances. It will be able to deliver, e.g., 40 μA of 150 keV N^{6+} ion beam, 50 μA of 275 keV Ar^{11+} ion beam, and 40 μA of 500 keV Xe^{20+} ion beam, with the emittances not exceeding 80 π mm mrad. It will be able to deliver also heavy ions of lower energies - above 10 keV. The first ion beam will be extracted from the machine in the beginning of 1997.

3.2 pVINIS Ion Source

The pVINIS Ion Source is a volume light ion source. The plasma is produced by the electrons emitted from a heated filament. The ions are generated using the effect of dissociative attachment of the electrons to the highly vibrationally excited molecules.

The magnetic structure of the pVINIS Ion Source consists of the SmCo permanent magnet rods in the cylindrical multicusp configuration.

The pVINIS Ion Source will be able to deliver H^-, D^-, H_2^+, and H_3^+ ion beams with the currents higher than 200 μA, and the emittances smaller than 50 π mm mrad. The extraction of the first ion beam from the machine is planned for the end of 1996.

4 Programs of use

The programs of use of the TESLA Accelerator Installation whose intensive preparations have already begun are the following: modification and analysis of physical properties of materials by ion beams, nuclear reactions with heavy ions at low and intermediate energies, radiation physics with light and heavy ions, radiolysis in condensed systems induced by heavy ions, physics of very thin crystals, production of radioisotopes and radiopharmaceuticals, and biological effects induced by irradiation with light and heavy ions.

The first experiments with the ion beams from the TESLA Accelerator Insatallation are planned for the first half of 1997 - in the field of modification of materials, with the ion beams from the mVINIS Ion Source, and in the fields of radiation physics, radiation chemistry, radiation bilogy, and production of radioisotopes, with the ion beams from the VINCY Cyclotron.

References

1. S. Koički et al., Accelerator installation at the Boris Kidrič Institute in Belgrade - conceptual and technical study, Bulletin de l'Academie Serbe des Sciences et des Arts No. 26 (1985), pp. 5-40.
2. N. Nešković et al., TESLA Accelerator Installation, Proceedings of the Third European Particle Accelerator Conference, Berlin, March 24-28, 1992 (Frontieres, Gif-sur-Yvette, 1992), Vol. 1, p. 415.
3. B. Bojović et al., Status report on the RF system for the VINCY Cyclotron, Proceedings of the Third European Particle Accelerator Conference, Berlin, March 24-28, 1992 (Frontieres, Gif-sur-Yvette, 1992), Vol. 2, p. 1310.
4. B. Bojović et al., The RF coupling system of the VINCY Cyclotron, Proceedings of the 13th International Conference on Cyclotrons and their Applications, Vancouver, July 6-10, 1992 (World Scientific, Singapore, 1992), p. 511.
5. Lj. Milinković et al., Injection and central region studies for the VINCY Cyclotron, Proceedings of the Third European Particle Accelerator Conference, Berlin, March 24-28, 1992 (Frontieres, Gif-sur-Yvette, 1992), Vol. 2, p. 1516.
6. D. Toprek and Lj. Milinković, Design of the central region for axial injection in the VINCY Cyclotron, Fourth European Particle Accelerator Conference, London, June 27-July 1, 1994.