

DESIGN AND BEAM DYNAMICS SIMULATION FOR THE ION-INJECTOR OF THE AUSTRIAN HADRON THERAPY ACCELERATOR

T. Strodl, TU Vienna, Austria

Abstract

MedAustron is an initiative for the construction of the Austrian hadron therapy centre. In 2004 the design study was presented. The basic design consists of two ion sources, an ion-injector, a synchrotron and a beam transfer line with five possible beam exits. The synchrotron is based on the proton ion medical machine study (PIMMS) design with some modifications. The injector is based on the GSI design of the Heidelberg ion cancer therapy accelerator with the original radio frequency quadrupole and IH-Linac. Modifications have been done in the design of the low energy beam transport and the medium energy beam transport lines. The impact of these modifications has been investigated, and several other beam scenarios have been simulated with different simulation codes.

INTRODUCTION

Status of the MedAustron Project

In June 2004 the design study of MedAustron was presented with a proposal for the technical layout of the facility [1]. In October 2004 the Austrian federal government together with the government of Lower Austria decided to financially support the project. Subsequently a project development company was founded in Wiener Neustadt to perform the call for industrial partners. [2]. The site for the construction of the complex is provided by the city of Wiener Neustadt. The overall financial support is around 46.6 MEur invest and 5.5 MEur running cost per year. The area of the site is 32 600 m² and is supported by the city of Wiener Neustadt [3].

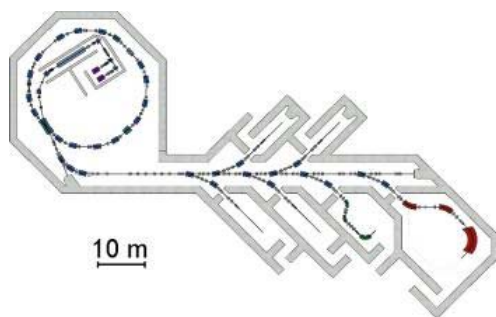


Figure 1: The MedAustron accelerator complex foresees an injector with two ion sources, a synchrotron, an extraction and transfer line, four treatment rooms (equipped with two fixed beam, one proton gantry, and one ion gantry), and two research rooms.[1]

The Accelerator Complex

The injection energy for the synchrotron is 7 MeV/u for both carbon ions and protons. At extraction the magnetic rigidity is 2.443 Tm for protons and 6.347 Tm for carbon ions. The average beam current is 3.81 mA and 1.06 mA, respectively. And the maximum extraction energy is 250 MeV/u for protons and 400 MeV/u for carbon ions. The synchrotron has a circumference of 77.64 m and a design radius of 4.231 m. The beam line consists of 16 dipoles and 24 quadrupoles. The design inherits from the PIMMS design with a few changes done by the CNAO/TERA group, e.g. an extension in the circumference.

The maximum average beam current at the transfer lines is 1.6 nA for protons and 0.38 nA for carbon ions. The extraction time for a spill varies from 1 s to 10 s.

The betatron core induces the extraction of the beam [4, 5]. For the transfer line from the synchrotron to the beam application and treatment rooms a modular system has been designed [6]. Each module of the system fulfils a certain task while leaving the other beam parameters unchanged. The philosophy of such a system is to provide a flexible system, where modules look very similar. Identical modules for the deflection to the treatment rooms will have identical magnet systems and controls. The system consists of 7 different modules: matching and chopper module, combined beam size control module, rotator module, extension module, deflection module for gantry rooms, combined deflection and scanning module for medical rooms, and combined deflection and scanning modules for research rooms

Treatment and Research Rooms

In the MedAustron design study six rooms are proposed. Four medical treatment rooms will provide particle beams for cancer therapy. Ideally a flexible therapy centre would consist of carbon ion gantries only. However, due to the overwhelming cost of such a gantry only a single ion gantry is proposed for MedAustron. A complementary proton gantry can also deliver proton beams. In the remaining two therapy rooms a fixed beam of either protons or carbon ions can be delivered.

The two research rooms will have fixed beams with scanning possibilities too. The application of these two lines is still under discussion and the possible fields are ranging from detector development to radio biology.

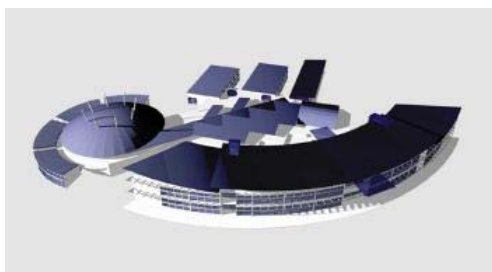


Figure 2: Bird-eye view of the visionary architectural design of MedAustron (design by Arno Hofmann): The synchrotron hall at the left-hand side, the offices and therapy facilities in the front and the research rooms in the back of the futuristic building. An extension of the main building to the right-hand side is possible.[1]

LAYOUT OF THE INJECTOR

The injection system is based on the design for the injector of the cancer therapy accelerator in Heidelberg. Due to the position within the synchrotron ring the layout of the medium energy beam line has been modified as well as the low energy beam line.

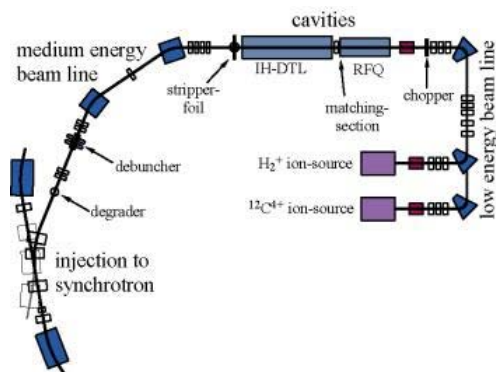


Figure 3: Layout of the injector.[1]

Basic design

For reasons of efficiency an existing layout was chosen for the design and modifications were applied. Candidates were the Frankfurt/GSI approach [8] on one hand and the HIMAC injector [7] on the other hand. The idea of two independent linacs for the two particles was dismissed because of cost reasons. The requirements for the linac were an easy to use machine, low maintenance, and low cost. Following the European trend one compact linac for both sort of particles was chosen to be studied in detail.

Ion Sources

There are two ion sources, the first one will provide an H_2^+ beam and the second one a $^{12}C^{4+}$ beam. The energy for the beam is 8 keV/u for both kind of particles. The required beam currents are 1 mA for H_2^+ and 0.18 mA for

$^{12}C^{4+}$, respectively. The Supernanogun ECR-ion source, which will be installed at the Heidelberg therapy accelerator, is a good candidate for both of the MedAustron ion sources as well. At extraction voltages up to 30 kV the required beam currents can be achieved [8].

Low Energy Beam Line

For the beam transport from the two ion sources to the accelerating structures a low energy beam line has been designed. Two independent lines select the specific ions from the ion sources. With the two independent dipoles the operation of one source can be observed while the other one is delivering the beam to the accelerator. This possibility of quality enhancement is very convenient for therapy purposes, because of the high demands for the quality of the beam. After a second equivalent dipole the beam is refocused and prepared for injection to the consequent radio-frequency quadrupole. A chopper system prepares beam pulses of 200 μ s. The kinetic energy in this section is 8 keV/u for both kind of particles. The design current is compatible with the ion sources requirements, 1 mA and 0.18 mA respectively.

Accelerating Structures

The proposed layout for the linear accelerating structures foresees the radio-frequency quadrupole, matching section and the IH-DTL from the injector of the cancer therapy facility in Heidelberg. A detailed discussion can be found in the references [9] and [10].

The RFQ accelerates the particle to the energy of 400 keV/u. The cavity has a total length of about 1.4 m and a diameter of about 0.25 m. At the high energy end a drift tube is inserted inside the tank. This integrated drift tube focuses the beam longitudinally. Thus the drift tube inside the matching section becomes no longer necessary.

The IH-DTL accelerates the particles to the injection energy of 7 MeV/u. The cavity has a total length of 3.77 m and a diameter of 0.32 m. The IH-DTL consists of four "KoNuS"-sections with three quadrupole triplet lenses. The complete injector system works an operation radio frequency of 216.8 MHz.[10]

Medium Energy Beam Line

At the stripper foil $^{12}C^{4+}$ becomes $^{12}C^{6+}$ and H_2^+ decays into two protons. The beam line consists of two dipole magnets one quadrupole triplet, two quadrupole duplets, a debuncher and a degrader. The debuncher smoothes the beam pulse longitudinally and thus reduces the momentum spread. The degrader reduces the intensity of the beam. Multi-turn injection during 10 to 20 turns avoids unnecessary high currents in the injector. By emittance-dilution one can form the phase space in such a way, that it leads to identical beams sizes for the extracted proton and carbon ion beams at the minimal extraction energy of 60 MeV and 120 MeV, respectively.

SIMULATION STUDIES

For the design of the beam lines and the beam dynamics simulation different codes have been used. LORASR simulations led to the design of the IH-DTL. PARMPRO was used with the RFQ. Both accelerating structures were simulated using Dynamion. Trace3D was used for designing the low and medium energy beam lines.

Front-To-End-Simulation

A crucial task for the commissioning of the injector is to compare the measurement results with particle simulations online. This goal could certainly be achieved easier having only a single code instead of a diversity of different simulation codes. The investigated candidate has been Dynamion, being capable of particle tracking through solenoids, dipoles, quadrupoles, DTL- and RFQ-sections. The code generates a data-file with particle phase space positions at every slice. One exemplary plot for the envelopes of the RFQ obtained from the data-file is shown in Fig. 4. The simulation was completed for the beam line from the RFQ to the stripper foil.

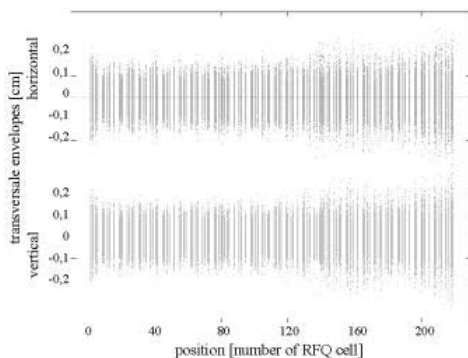


Figure 4: Result of Dynamion simulations for the envelopes of the RFQ.

Comparison of the DTL-simulations

Dynamion was originally designed for the simulation of RFQ-dynamics. Therefore, special investigation was needed for the simulation of the DTL with Dynamion. As shown in Fig. 5 the longitudinal phase space at the exit of the DTL is a factor of 1.5 larger and also the particle losses were higher than predicted by LORASR. Although, Dynamion is a very powerful tool the eventually better solution would be to stick with the design codes and to integrate interfaces.

LEBT and MEBT design

The impact of the modifications by the TERA/CNAO group in the low and medium energy beam transport lines have been investigated with Trace3D. The limiting geometry of the inner area restricts the design of the beam lines. Although the MEBT is shorter, simulations show that the

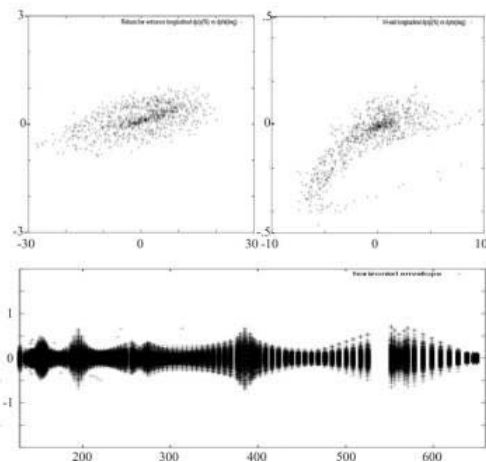


Figure 5: Dynamion Results for the IH-DTL: above shows the longitudinal phase space before the rebuncher and at the end of the DTL-section in units of dp/dp vs. $d\phi$, below is the horizontal envelope of the beam line from the rebuncher until the stripper foil in units of cm.

distance from the debuncher to the injection point is sufficient. Simulations of the LEBT have shown problems with the higher space charge forces. So a shorter beam line would be advantageous and the presented layout is probably not the final one.

REFERENCES

- [1] T. Auberger, E. Griesmayer, "Das Projekt MedAustron - Designstudie", Wiener Neustadt : Fotec - Forschungs- u. Technologietransfergesellschaft mbH, ISBN 3-200-00141-0, 2004.
- [2] PEG MedAustron Gesellschaft mbH, Viktor-Kaplan-Strasse 2, 2700 Wiener Neustadt. <http://www.pegmedaustron.at>
- [3] Federal Ministry for Education, Science and Culture, "Med Austron: Ausschreibung gestartet", Austrian Press Agency, 2005, October, OTS0204, 121350 Okt 05, <http://www.ots.at>
- [4] L. Badano, M. Benedikt, P. Bryant et al.: "Proton-Ion Medical Machine Study", CERN 2000-006, ISBN 92-9083-166-9, Geneva, 2000.
- [5] P. Knaus, S. Rossi, et al.: "A betatron core for optimised slow extraction in a proton/ion medical synchrotron", EPAC'98, 1998, Stockholm, p. 2368.
- [6] M. Benedikt, Nucl. Instrum. Methods Phys. Res., A 539 (2005) 25-36
- [7] S. Yamada, "Commissioning and performance of the HIMAC medical accelerator", PAC'95, 1995, Dallas, p. 9.
- [8] B. Schlitt, G. Hutter et al.: "Development of a 7 MeV/u, 217MHz carbon injector linac for therapy facilities", LINAC'02, 2002, Gyeongju, p. 781.
- [9] A. Bechtold, U. Ratzinger, A. Schempp, B. Schlitt, "Status of the Integrated RFQ-drifttube-combination for the medicine-synchrotron in Heidelberg", PAC'03, 2003, Portland, p. 1062
- [10] Y.R. Lu, S. Minaev, et al.: "The compact 20MV IH-DTL for the Heidelberg therapy facility", LINAC'04, 2004, Lübeck, p. 57