STATUS OF THE LINAC COMPONENTS FOR THE ITALIAN HADRONTHERAPY CENTRE CNAO

H. Vormann, B. Schlitt, G. Clemente, C. Kleffner, A. Reiter, GSI, Darmstadt, Germany,
U. Ratzinger, IAP, Frankfurt University, Germany.

Abstract

A collaboration between the italian hadrontherapy project CNAO and GSI has been established. Within this collaboration GSI delivers technical support for manufacturing, assembly, tuning, tests and commissioning of the CNAO injector linac and its technical systems. The status of the linac activities is presented as well as the results of the RF tuning of the 20 MV, 216.8 MHz IH-type drift tube linac cavity. The start of linac installation and commissioning on site at CNAO is expected for autumn this year.

INTRODUCTION

The italian hadrontherapy centre CNAO (Centro Nazionale di Adroterapia Oncologica) is designed for the treatment of tumours with proton and light ion beams and to clinical and radiobiological research. It is presently under construction in Pavia [1][2]. The accelerator consists of a 7 MeV/u injector linac and a 400 MeV/u synchrotron. The linac is a copy of the linac of the Heidelberg Ion-beam Therapy centre HIT [3][[4][5] and consists of a 400 keV/u RFQ [6] and a 20 MV IH-type drift tube linac (IH-DTL) [7][8].

In 2004 a contract between CNAO and GSI was signed regarding the construction and commissioning of the CNAO linac. GSI delivers technical support in terms of all linac components [9]: copper-plating, assembly, RF tuning and pre-tests (together with IAP, Frankfurt University) of RFQ, IH-DTL and an additional debuncher cavity (used for the reduction of the momentum spread at synchrotron injection), pre-assembly of beam line sections with supporting frames, tests of RF amplifiers, linac sub-control system and power supplies. Furthermore, GSI has delivered various beam diagnostics components, to be used along LEBT, linac and MEBT [9][10]. The installation of all linac components on the CNAO site in Pavia as well as the commissioning will be supported.

STATUS OF LINAC COMPONENTS

Beam tests of the RFQ using proton beams have been performed at an RFQ test bench at GSI during 2006 in order to check the final beam energy of the RFQ and to adjust the gap voltage of the drift-tube rebuncher integrated into the RFQ tank [9][11][6].

Figure 1: RFQ test bench with CNAO RFQ at GSI.

The test bench was also used for beam tests of the beam diagnostics equipment delivered to CNAO by GSI using 8 keV protons from the ion source and 400 keV protons from the RFQ [9]. Overall, two AC transformers, four phase probes, seven profile grids and one Faraday cup had been constructed, vacuum tested, and prepared by GSI including two complete actuators and vacuum feed-throughs for all profile grids [10]. Besides the detectors, the corresponding pre-amplifier modules and the PXI data acquisition electronics (including manual operating software) have been tested at the RFQ test bench and have been delivered by GSI.

After additional low level RF verification tests of the RFQ and after the assembly and RF tuning of the IH tank (Fig. 2, 3) at GSI, all linac components (including additional steerer and quadrupole magnets and a foil stripper) have been pre-assembled at GSI on the final supporting frames. This includes the qualification of all components for the alignment at CNAO as well as the installation of vacuum pumps and of further vacuum equipment, and the accomplishment of vacuum leak tests.

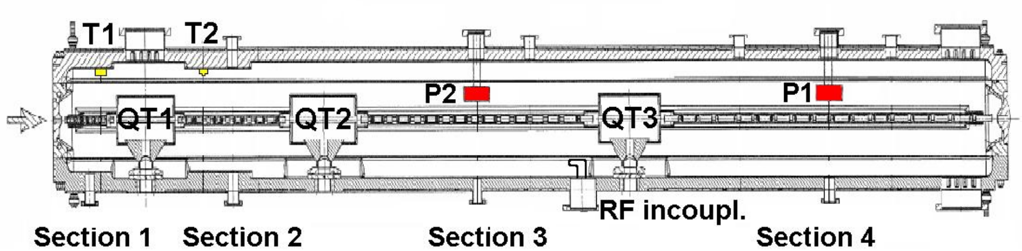

Figure 2: IH-DTL with four KONUS sections, three internal magnetic Quadrupole Triplett lenses (QT1 – QT3), movable RF plungers (red: P1, P2), and inductive tuning plates (yellow: T1, T2). The length of the cavity is about 3.8 m.

After completion of these preparations, all linac components have been delivered to CNAO in November 2007 and in April 2008.

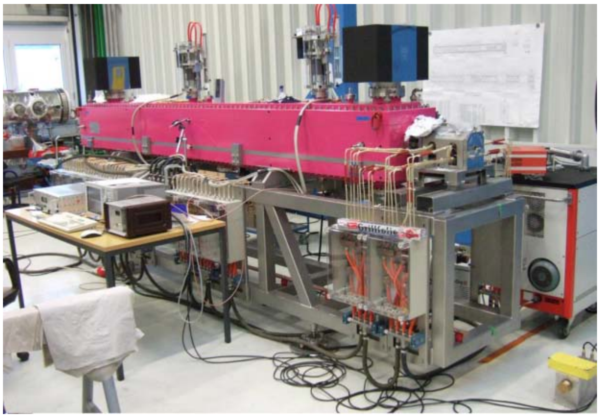

Figure 3: IH-DTL during low level RF tests at GSI.

After the last shipment, vacuum tests as well as low-level RF measurements of the IH-DTL and of the RFQ have been successfully performed at the CNAO site in Pavia in April 2008 (Fig. 1). High power RF tests of the linac cavities will be performed during commissioning in Pavia.

The debuncher cavity (designed for the HIT facility) has been optimized using Micro Wave Studio [12]. The resonator with redesigned spiral was assembled at IAP by the group of Prof. Schempp and finally tuned at GSI in January 2008 (Fig. 4).

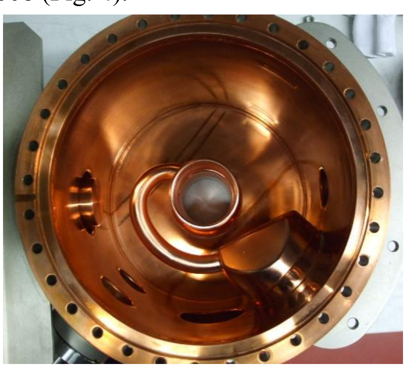

Figure 4: Open debuncher cavity with spiral and drift tube.

The remote control of the CNAO linac will be performed via a dedicated linac sub-control system which was adopted from the HIT project. This sub-control software has been linked to the main CNAO accelerator control system via a dedicated gateway that provides communication with all linac components (magnet power supplies, RF amplifiers and the beam diagnostics devices from GSI). After several integration tests of the linac sub-control system into the CNAO accelerator control system at GSI, installation and commissioning of the system in Pavia has been performed successfully in spring 2008.

Final factory acceptance tests of the three RF amplifiers for pulse powers of 1400 kW (IH-DTL), 200 kW (RFQ) and 4 kW (debuncher) have been performed at THOMSON Broadcast & Mulitmedia AG, Turgi, Switzerland, in April 2007. The amplifiers were installed on site in Pavia in November 2007; RF transmission lines and cables until February 2008. Commissioning of the RF amplifiers has started recently. The magnet power supplies for the linac were installed and cabled in Pavia by CNAO, first power supplies have been commissioned recently.

RF TUNING OF THE IH-DTL

The IH-DTL [7][8] is optimized for ion beams with a mass-to-charge ratio of $A/q = 3$ (Table 1). The drift tube structure is subdivided into four sections applying the KONUS beam dynamics scheme (combined zero degree structure, Kombinierte Null-Grad-Struktur) [13]. They are separated by three magnetic quadrupole triplet lenses integrated into the IH tank (Fig. 2). It requires a voltage distribution along all accelerating gaps that matches well the design distribution according to beam dynamics simulations.

Table 1: Major parameters and measured RF properties of the IH-DTL

Design Ion	$^{12}C^{4+}$
Tank Length	3770 mm
Number of Gaps	56
Injection Energy	0.4 MeV/u
Final Energy	7.0 MeV/u
Resonance Frequency	216.816 MHz
RF Pulse Length	≤500 μs
RF Pulse Repetition Freqency	10 Hz
Voltage Gain	19.8 MV
Averaged eff. Voltage Gain	5.25 MV/m
Unloaded Quality Factor Q_0	≈ 14700
Eff. Shunt Impedance	≈ 120 MΩ/m
Expected RF Pulse Power	≈ 880 kW

During 2007, RF tuning was performed. Bead pull measurements were done after every tuning step in order to investigate the voltage distribution [14][15] (Fig. 3). Two movable RF plungers are used which are influencing the voltage distribution as well as the resonant frequency. To achieve a sufficient voltage distribution at the design frequency, optimization is obtained by using two additional tuning methods:

- Inductively acting fixed tuning blocks are mounted at the plane surface of the upper tank half shell (Fig. 2).
- Capacitive tuning is used to increase the voltage at the ends of the drift tube structure: Drift tube holders with a higher base were mounted at the low energy end (Fig. 5) as well as some fixed capacitive tuning blocks between drift tube holders at the high energy end.

Once having achieved the optimum setting with fixed tuning bodies and plunger positions, frequency tuning by moving the plungers is possible only in a small range (± 100 kHz). As the RF duty factor is below 1 % and the thermal drift was estimated to be ≤1 kHz/K only, this tuning range is sufficient. On the other hand, the different dielectric constant under vacuum conditions causes a frequency shift of about 60 kHz and has been considered at the RF tuning.

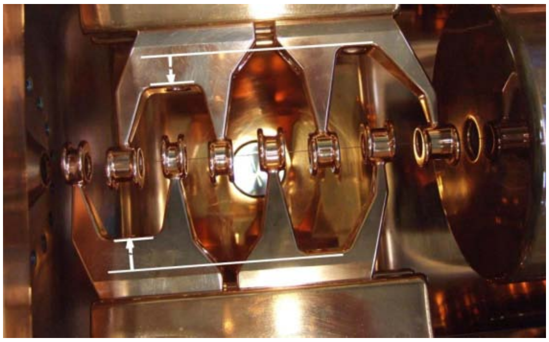

Figure 5: Drift tubes with a higher base (arrows) in section no. 1 (low energy end). To the right, the entrance part of the first internal triplett lense is visible.

With the final plunger setting, the IH-DTL was tuned successfully (Fig. 6). The deviations of the sum of the measured gap voltages in each drift tube section with respect to the design values are +0.5 %, +1.2 %, -0.5 % and -0.2 % only. It is recommended to keep plunger P1 in the last drift tube section fixed during operation in order to avoid a mismatch of the voltage distribution, while the RF frequency control should be performed with plunger P2 only. The tuning curve of this plunger is shown in Fig. 7 over a large frequency range. The working point is marked and the small gradient of the tuning curve allows stable operation around the design frequency.

The spectrum of higher frequency modes for the proposed plunger setting shows nearest neighbouring frequencies at 221.5 MHz and 233.1 MHz (Fig. 8), well separated from the operation frequency of 216.816 MHz.

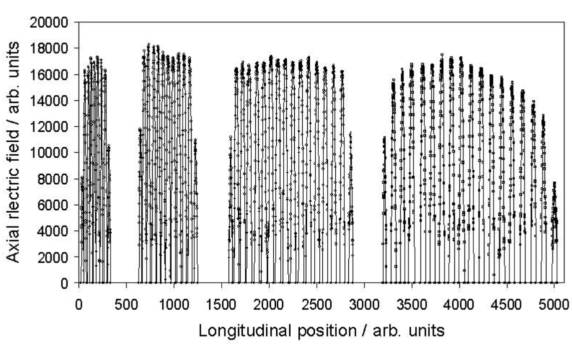

Figure 6: Measured final on-axis electric field distribution. The maximum corresponds to about 18 MV/m.

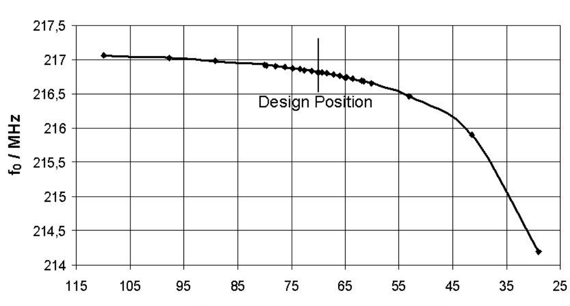

Figure 7: Resonance frequency vs. plunger position.

Figure 8: Frequency spectrum of the IH-DTL.

SUMMARY & OUTLOOK

The RF tuning of the IH-DTL has been finished successfully in 2007. The deviation from the design voltage distribution in each drift tube section is ≤1.2 %, the measured quality factor should lead to a moderate RF power consumption, and the proper mechanical preparation enables reliable operation.

The commissioning of the ion sources and the LEBT at CNAO is currently in progress. Linac installation will start after the LEBT commissioning in autumn 2008. After RF commissioning of the cavities, specific beam diagnostic test benches will be used for the successive beam commissioning of the RFQ and of the IH-DTL.

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