

STATUS OF THE 7 MeV/u, 217 MHz INJECTOR LINAC FOR THE HEIDELBERG CANCER THERAPY FACILITY

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Abstract

A clinical synchrotron facility designed by GSI for cancer therapy using energetic proton and ion beams (C, He and O) is under construction and will be installed at the university hospital in Heidelberg, Germany, starting in 2005. The status of the ECR ion source systems, the beam line components, the 400 keV/u RFQ and the 20 MV IH cavity as well as the linac RF system is reported. The production of most of the components is in progress. First devices have been delivered to GSI already. The RF cavities of the injector linac have been designed in close cooperation between GSI and IAP. A beam test stand for the RFQ using proton beams is presently being set up at the IAP. Two prototype magnets of the linac quadrupole magnets have been built at GSI and have been tested successfully. An 1.4 MW, 217 MHz cavity amplifier has been delivered by BERTRONIX recently. A test bench for this system has been installed at GSI including a 120 kW driver amplifier.

INTRODUCTION

A dedicated clinical Hevy Ion Cancer Therapy facility (HICAT) has been designed at GSI and will be built at the university hospital in Heidelberg, Germany [1][2]. The accelerator chain is designed to accelerate low-LET (linear energy transfer) ions (p, He) as well as high-LET ions (C, O) to cover the specific medical requirements. It consists of two ECR ion sources, a 7 MeV/u injector linac and a compact 6.5 Tm synchrotron to accelerate the ions to final energies of 48 – 430 MeV/u. Three treatment stations (two fixed horizontal beam lines and one isocentric ion gantry) as well as a quality assurance place for R&D activities are planned. The facility is designed to treat more than 1000 patients per year using the intensity controlled raster scan method, which has been developed at GSI and has been successfully applied with carbon ion beams to about 230 patients since more than six years within the GSI therapy project [3]. The requested maximum beam intensities at the treatment places are 1×10^9 $^{12}\text{C}^{6+}$ ions/spill and 4×10^{10} protons/spill. Only active and no passive beam manipulating systems are planned.

The layout of the injector linac is presented in Fig. 1 [4][5], major linac parameters are listed in Table 1. The low energy beam transport lines (LEBT) consist of two independent spectrometer lines and allow for a fast selection between two different ion species by a switching magnet. DC operation is planned for the ion sources. A short beam pulse with a length of up to about 300 μs will be formed by a macropulse chopper. The RF linac

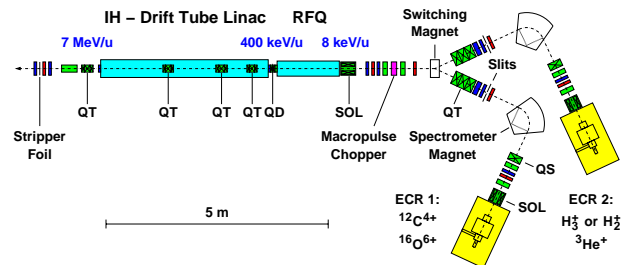


Figure 1: Schematic drawing of the injector linac. SOL \equiv solenoid magnet; QS, QD, QT \equiv magnetic quadrupole singlet, doublet, triplet.

Table 1: Selection of major linac parameters.

Ion species (from ion sources) and required ion source currents	$^{12}\text{C}^{4+}$: 130 μA $^{16}\text{O}^{6+}$: 100 μA	H_3^+ : 440 μA $^3\text{He}^+$: 320 μA
Ion mass-to-charge ratio	$A/q \leq 3$	
Final beam energy	7 MeV/u	
Operating frequency	216.816 MHz	
RF pulse length	$\leq 500 \mu\text{s}$ @ PRR ≤ 10 Hz	

consists of an 1.4 m long four-rod type RFQ for acceleration of the ions to 400 keV/u [6][7], a very compact intertank matching section [4] and a 3.8 m long 20 MV IH-type drift tube cavity [4][5][8][9]. The remaining electrons of the ions will be stripped off for all ion species in a thin stripper foil behind of the linac.

GENERAL STATUS

The components for the complete HICAT facility like vacuum chambers, magnets, power supplies, the RF systems and the accelerator control system have been ordered from industry in 2003. Most of the manufacturing drawings are completed and the production of the components is in progress. The first solenoid magnet for the LEBT has been delivered by SIGMAPHI to GSI last week.

Two complete 14.5 GHz SUPERNANOGAN ECR ion source systems have been ordered from PANTECHNIK [10]. Major components of the ion sources are fabricated and assembled already. Factory acceptance tests are planned for the fourth quarter of this year.

An overview of the beam diagnostics devices for the complete HICAT facility is given in Ref. [11]. The mechanical parts such as detector housings, stepping motor and pneumatic drives are produced or integrated by GSI whereas for the software and the electronic devices industrial solutions are preferred. The production of first

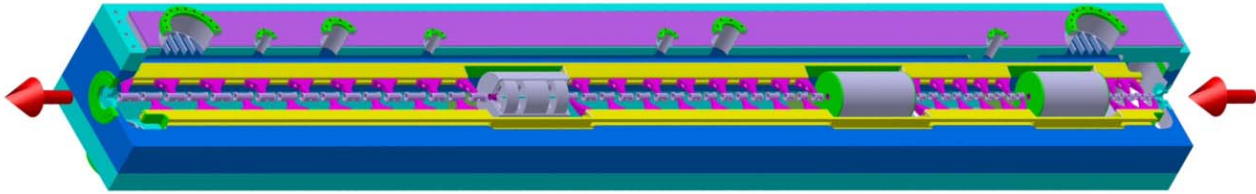


Figure 2: Design of the 20 MV IH cavity. The arrows mark the beam direction. In the drawing, the cavity is rotated around the beam axis for better visualisation. The view is diagonal from the top. In reality the small drift tubes mounted along the two opposing girders will be arranged in the horizontal plane. The three large drift tubes contain the magnetic quadrupole triplet lenses. The length of the cavity is about 3.77 m, the outer width of the center frame is 400 mm.

components at GSI has started in 2003, e.g. first SEM-grids for the LEBT have been produced already [11].

The excavation activities for the accelerator building in Heidelberg started in November 2003 and the cornerstone ceremony was held in May 2004. The work on the concrete ground plate and on the walls for the second underground floor is in progress. The beginning of the installation of the first accelerator components in Heidelberg is scheduled for the first half of 2005. A step-by-step commissioning of the accelerator facility and the treatment places is planned. First patient treatment is planned for 2006 / 2007.

RFQ

For longitudinal focusing of the ion bunches before injection of the ions into the IH structure, a drift tube set-up is integrated into the RFQ tank instead of using a separate rebunching cavity in the intertank section [6][7]. Major RFQ components like electrodes, stems, base plate and the tank have been fabricated by industry. Assembly and alignment of all components have been performed at the IAP. Basic RF properties have been measured [6][7]: The measured quality factor amounts to about 2500, the R_p value is about 30 k Ω . For the electrode design voltage of 70 kV, a power consumption of 165 kW is estimated. The total voltage along the two bunching gaps will be up to 140 kV for an electrode voltage of 70 kV.

Futhermore, a beam test stand has been set up at the IAP. First beam measurements behind the duoplasmatron ion source have been performed successfully as well as RF conditioning of the RFQ tank at 50 W continuous RF power [12]. Commissioning of the RFQ with proton beam is scheduled for September 2004.

IH CAVITY

The RF tuning of an 1:2 scaled cold model [4] of the IH structure has been completed successfully [8][9]. Microwave Studio simulations of the model and the power cavity have been also performed at the IAP [8][9].

The IH power cavity (Fig. 2) consists of three main parts: the center frame carrying 52 small drift tubes and the lower and upper half shells. Three magnetic quadrupole triplet lenses will be mounted in the lower half shell. The inner dimensions of the 217 MHz cavity are 260 mm in width and about 340 mm in height (see also Ref. [8]). The half shells as well as the center frame

are fabricated by milling from massive mild steel blocks. The manufacturing of the IH tank is in progress at PINK GmbH Vakuumtechnik, Wertheim, Germany [13]. The completion of the tank is expected for November 2004. The small drift tubes including the stems are milled from small copper blocks and have been fabricated already also at PINK GmbH Vakuumtechnik. They have been additionally copper-plated at GSI.

LINAC QUADRUPOLE MAGNETS

A set of four magnetic quadrupole triplet lenses (three integrated into the IH cavity and one subsequent to the IH tank) as well as a quadrupole doublet in the intertank section between the RFQ and the IH tank are required. Due to the small inner diameter of the IH tank, a new compact quadrupole magnet design has been developed at GSI [4][14]. Five magnet types with different lengths but with identical cross section have been designed. Some key parameters are listed in Table 2.

Table 2: Selection of key parameters of the linac quadrupole magnets. The maximum field levels are given for the design ion ($^{12}\text{C}^{4+}$). For further details see Ref. [14].

Yoke outer diameter	130 mm
Yoke lengths	42 / 49 / 67 / 81 / 97 mm
Yoke material	VACOFLUX 50
Magnet aperture diameter	20 mm
Number of turns per pole	5
Excitation currents	≤ 1050 A
Field gradients B'	≤ 110 T/m



Figure 3: Prototype quadrupole doublet built at GSI [14]. The yoke lengths are 42 mm and 81 mm. The distance between the yokes of the two magnets is 27 mm only.

Two prototype magnets of the most excited quadrupoles (42 mm and 81 mm yoke length) have been built at the GSI workshops (Fig. 3) [14]. Different measurements have been performed at GSI [14]. The measured field gradients B' as well as the integrated gradients $B' \times L_{\text{eff}}$ are shown in Fig. 4 for the quadrupole with 81 mm yoke length. The curves are linear up to about 800 A. With higher currents, increasing saturation effects are observed. The vertical lines at around 800 A and 900 A represent approximately the expected minimum and maximum operational values. They are close to the border of the linear region.

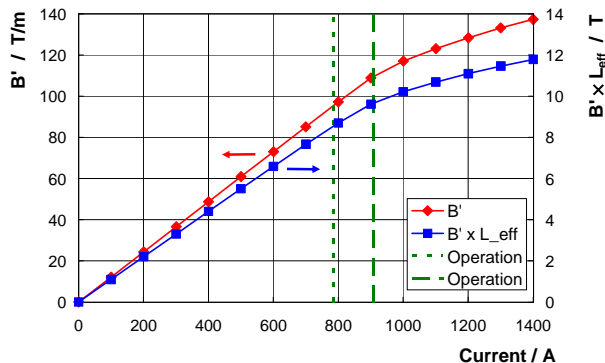


Figure 4: Measured field gradients (upper curve) and integrated gradients (lower curve) for the prototype magnet with a yoke length of 81 mm.

Production of the final linac quadrupole magnets including integration into the water-cooled drift tube housings for the internal triplet lenses is in progress at DANFYSIK. The yokes of the magnets are fabricated already. Delivery of the completed magnet units to GSI is scheduled for January 2005. Afterwards, the triplet lenses will be copper-plated at GSI and will be integrated into the IH tank.

RF SYSTEM

The linac RF system [4] covering three amplifier chains for 4 kW, 200 kW and 1.4 MW is under construction at THALES Broadcast & Multimedia AG in Turgi, Switzerland. The cavity amplifier for the 1.4 MW final stage for the IH cavity has been manufactured already at BERTRONIX Electronic GmbH, Munich, Germany [4] and has been delivered to GSI recently (Fig. 5). The stage can be equipped either with a TH 526 B tetrode from THALES Electron Devices or with an EIMAC 8973 from CPI using an adapter set. For high power tests of the BERTRONIX stage, an existing amplifier set-up at GSI has been modified to be used as a driver for the 1.4 MW stage. A commercial 4 kW transistorized amplifier from THALES B&M is used as the first stage of the driver amplifier. For the second stage, a THALES TH 18527 C cavity equipped with a THALES TH 571 B tetrode has been integrated into an existing GSI amplifier. A pulse power of 120 kW has been produced successfully at GSI with this driver set-up. High power commissioning of the 1.4 MW BERTRONIX stage is scheduled for September

2004. It is planned to use this set-up including the BERTRONIX stage also for high power tests of the RFQ up to 200 kW pulse power.



Figure 5: View on the 1.4 MW final stage cavity amplifier after delivery to GSI. The outer diameter of the system is 980 mm, the total height 2595 mm. (Photo by G. Otto, GSI; published with great acknowledgements to Dr. Klaus Berdermann, BERTRONIX Electronic GmbH, Munich, Germany.)

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