BEAM DIAGNOSTIC DEVICES AND DATA ACQUISITION FOR THE HICAT FACILITY

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Abstract

A set of 92 diagnostic devices for beam diagnostics in the **H**eavy **I**on **Ca**ncer **T**herapy facility (HICAT) at the university hospital in Heidelberg is currently under development at GSI. All beam diagnostic devices will be fully computer controlled and will allow an automated detection of all relevant beam parameters. The HICAT raster scan method with active variation of intensity, energy and beam size requires the exact knowledge of the time resolved and spatial structure of the ion beam. An overview of the integrated devices is presented, particularly the time-of-flight method for energy measurement using electro-static pick-ups in the Linac is described in detail. The real-time PXI data acquisition system is explained as well as the embedding of the diagnostic devices in the timing and control system of HICAT.

INTRODUCTION

A first technical proposal for the HICAT facility had been presented in 1998 [1], a more detailed description of the final HICAT layout is given in [2]. The building is under construction since November 2003 and the installation of the accelerator will start in the last quarter of 2005. Fig. 1 shows the final layout of the accelerator facility. The outer dimensions of the accelerator building are 60m x 70m. HICAT consists of a 7 MeV/u-Linac (including the LEBT – low energy beam transport – and the MEBT – middle energy beam transport – lines), a Synchrotron (magnetic rigidity Bρ=0.38-6.5 T·m), two horizontal treatment stations (H-1, H-2), a Gantry-Section for 360°-patient irradiation and additionally a section for Quality Assurance (Q-A).

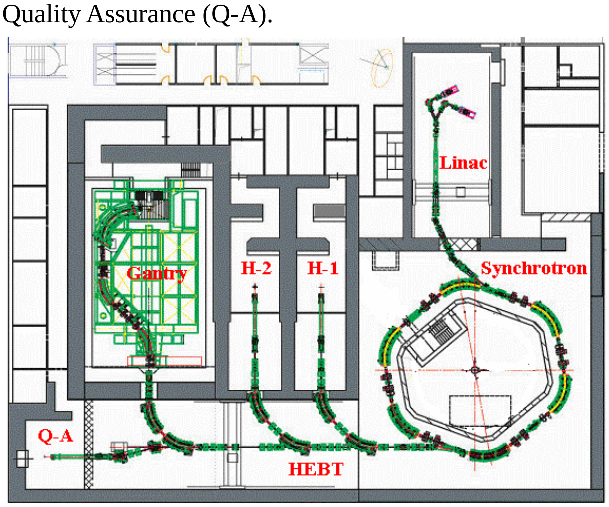

Figure 1: Layout of the first underground floor, housing the accelerator complex [2]

BEAM DIAGNOSTICS AT HICAT

Because no industrial supplier could be found, the beam diagnostics group at GSI was charged with the delivery of all measuring systems. The mechanical parts, such as detectors, linear vacuum feed-throughs, etc. are produced by GSI with sub-contractors. For the software and the electronic devices, however, commercial solutions with industrial partners were preferred.

Table 1: Overview of beam diagnostic devices for HICAT

Device	Qty.	Position	Device class
Faraday-cup (cooled/uncooled)	7	Linac	DC/AC-beam current
Profile grid	8	Linac	Profile measurement
El.-static pick-up	4	Linac	Phase measurement
DC-transformer	3	Lin/Sync	DC-beam current
AC-transformer	4	Lin/Sync	AC-beam current
Position monitor	6	Sync	Beam position
Beam loss mon.	6	Sync	Particle counting
Ioniz. chamber	13	Sync	Particle counting
Viewing screen	12	Linac/Sync/HEBT	Optical diagnostics (2D-Profile-Meas.)
Scintil. Counter	5	HEBT	Particle counting
MWPC	13	HEBT	Profile measurement
Isocenter-diagnostic screen	4	T1-T4	Optical diagnostics (2D-Profile-Meas.)
Slits	4	Linac	Command device
Foil stripper	1	Linac	Command device
Scraper	2	Sync/ HEBT	Command device

The 92 beam diagnostic devices were deliberately assorted to measure all relevant beam parameters (current, energy, beam profile, position and phase information) of the therapy accelerator [3]. Concerning the layout of the electronic hardware the basic idea was to use industrial standards to a maximal degree, in order to achieve a good maintainability of all devices and, as a consequence, to enhance the reliability of the HICAT facility. For example, all data acquisition is uniformly carried out using 11 separate PXI-controllers running LabViewRT [4], as will be described in detail below.

Table 1 summarizes the beam diagnostic devices of HICAT, listed in the order of their position in the accelerator complex and beam transport system – Linac, Synchrotron, High Energy Beam Transport (HEBT). Mainly due to the unification of the software layout, the beam diagnostic systems were subdivided into seven device classes, referring to the measured physical properties of the ion beam. In addition, also passive elements like slits, scrapers and the foil-stripper are included in the list, because these components are mounted on mechanic drives equal to the ones used for the active detector devices. These components build up the 8th device class, labeled as “command devices”.

In the following section the electro-static pick-up system for the Linac part is described as an example, where a well-known beam diagnostic component has been redesigned and updated for the use in a commercial therapy facility, with the aim of finding commercial solutions and of unifying the data acquisition process.

ELECTRO-STATIC PICK-UP SYSTEM FOR THE HICAT LINAC

Overview

In the Linac section an RFQ accelerates the 200 µs long macro-pulses to 400 keV/u and the following IH-structure speeds up the ions up to the injection energy of 7 MeV/u, both stages running at 216.7 MHz. The electrostatic pick-up systems are used to determine:

- The energy of the beam at the exit of both accelerating structures within one Linac macro-pulse using the time-of-flight (TOF) method.
- The function of the stripper – a defect of the foil will change the TOF measurement of the beam between the enclosing pick-ups.
- The phase angles of the pick-up signals with respect to the RF tank signals.

The maximum currents in the Linac section are in the order of 50 µA to 1 mA, but due to the intensity variation with I_{max}/I_{min} = 1000 in most cases during normal therapy operation the beam current will be very low. Together with the fact that very small installation space was available, it was decided to design the electro-static pick-ups for phase measurement only. A position monitoring capability would have needed 4 buttons per pick-up with a higher mechanical expense and very cost-intense electronics.

The analog system of the phase pick-ups was determined by the commercially available PXI digitizers from Acqiris (see below) with around 1 GHz bandwidth, which permits the bunch characterization up to the 4th harmonic (5th harmonic at 1.083 GHz attenuated by around 6 dB).

Layout and Properties of the Pick-up

Two different phase pick-up types were built, a special one for the inter-tank section and three identical detectors for the MEBT line between IH-output and synchrotron injection, see Fig. 2.

The phase pick-up is generally designed in 50 Ω geometry and the frequency response up to 1.2 GHz is constant within 0.4 dB. A grounded diaphragm is installed on the entrance side on the pick-up to avoid direct hitting of the beam in case of mismatched optics.

Figure 2: Phase pick-up for the MEBT section

Preamplifier Stage

For amplifying the signals directly behind the pick-up, a commercial amplifier from FEMTO [5], type DUPVA-1-60, is used. It ideally fits the system demands:

- Five gain stages from 20 – 60 dB in 10 dB steps, remote control via optocouplers included
- An analog bandwidth of 1.2 GHz with a flatness of 0.15 dB for all gain stages
- Independent transmission time for all gain settings – necessary for the TOF method

From these preamplifiers the signals are transmitted via coax cables directly to the DAQ stage outside the radiation protected areas.

Data Acquisition and Control System

As already mentioned high speed cPCI digitizer boards from Acqiris, type DC241 [6], were chosen instead of a standard oscilloscope, because it is designed for the integration in a real-time control system. Therefore all 4

Figure 3: 6U PXI crate from EKF with a 3U NI controller and four 6U Acqiris DC241 digitizer modules

digitizer boards were installed in a 6U PXI crate from EKF [7] with additional 3U slots for the NI PXI controller and an I/O board for the amplifier control, which was no problem due to the PXI standardization, see Fig. 3.

From the perspective of the accelerator control system a DAQ system is the abstraction layer for the connected beam diagnostic devices, because one or more detectors are connected to one DAQ system and one or more DAQ systems are in turn logically grouped to "device classes" (cf. table 1). This concept has been developed in collaboration with the company Eckelmann [8], responsible for the whole accelerator control system .

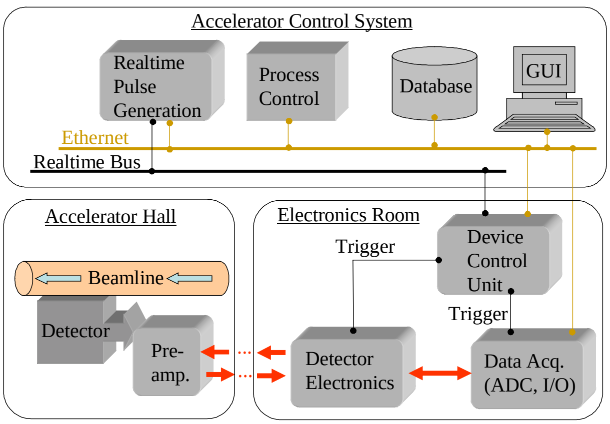

Figure 4: Schematic view of the DAQ systems embedded in the control system

All components of the accelerator control system (e.g. process control, GUI, database etc.) are linked via 100 MBit ethernet. Fig. 4 gives a schematic overview of the beam diagnostic's integration into the HICAT control system. The DAQ systems communicate with the "process control"-part of the system, which manages the preparation of the DAQ systems to collect data, as well as the transport of the data to the graphical user interface (GUI) or the databases. Timing-signals are transported via a facility-wide real-time bus and are converted to trigger signals for the DAQ systems by so-called timing-DCUs (Device control units) with a precision of better than 1 µs.

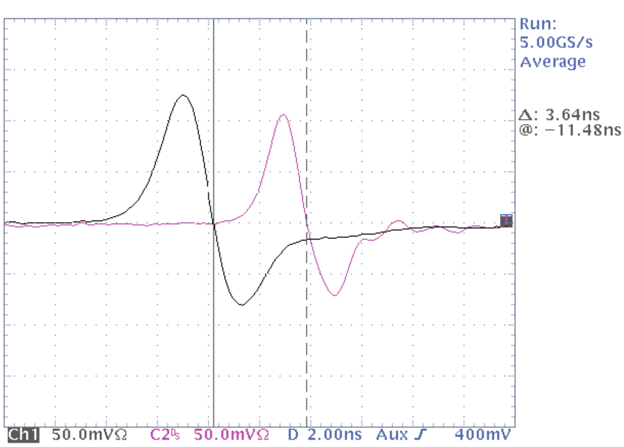

Figure 5: Time-of-flight signal from two pick-ups

Data evaluation and presentation

In Fig. 5 the acquired signals from two pick-ups separated by the distance L of typically some meters are shown. The bunch center-of-mass can be read from the signal data or – more precisely – the correlation function between the two signals can be calculated and evaluated.

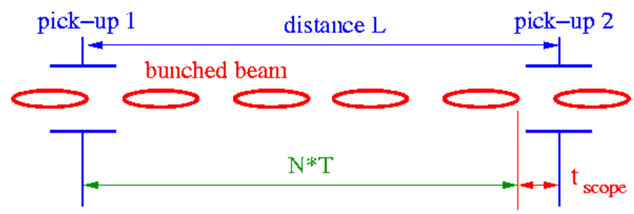

Figure 6: Principle of a TOF measurement using two phase pick-ups

As shown in the schematic (see Fig. 6), several bunches are between the pick-ups and a coarse estimate of the velocity is needed. This is normally known, but in case of trouble, a third pick-up has to be installed much closer to one of the others. The velocity is calculated for the measured time t_{scope} via

$$\beta c = \frac{L}{NT + t_{scope}}$$

with N bunches between the pick-ups and the bunch repetition time of $T = 1/f_{RF}$.

The precision of such a velocity measurement $\Delta\beta/\beta$ is given by the uncertainty of the distance L and the time estimation t to be

$$\frac{\Delta\beta}{\beta} = \sqrt{\left(\frac{\Delta L}{L}\right)^2 + \left(\frac{\Delta t}{NT + t_{scope}}\right)^2}$$

Assuming a precision of ΔL = 1mm and Δt = 100ps, an accuracy better than 0.1% can be reached for the energy spread $\Delta W/W=2*\Delta\beta/\beta$, if the distance between the two pick-ups is around 4 m like in the HICAT set-up downstream of the IH-structure at 7 MeV/u (β = 0.12). With the energy resolution given above it is possible to detect defects of the stripper foil which e.g. causes an energy loss of 16.2 keV/u for the passing Carbon beam.

Before commissioning of the Linac an intuitive GUI (Graphical User Interface) will be defined for the electrostatic pick system. Tests of the whole system including all software levels are foreseen in the next months at the test stand for the RFQ, which is currently built up at GSI.

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