COMPUTER CONTROLLED BEAM DIAGNOSTICS FOR THE HICAT FACILITY

M. Schwickert, A. Peters

Gesellschaft für Schwerionenforschung (GSI), Planckstr. 1, 64291 Darmstadt, Germany

Abstract

A set of 92 diagnostic devices for beam diagnostics in the heavy ion cancer therapy facility (HICAT) at the university hospital in Heidelberg is currently under development at GSI. For the HICAT facility that is presently under construction, all beam diagnostic devices will be fully computer controlled and will allow an automated detection of all relevant beam parameters. The HICAT rasterscan 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 and the intensity measurement of both the DC and AC beam in the different parts of the accelerator facility are reviewed. Additionally, the timing and control of the diagnostic devices are described.

INTRODUCTION

After the first technical proposal for HICAT had been presented in 1998 [1], as a next milestone the Feasibility Study was finished by the end of 2000. More recently the excavation activities for the accelerator building started in November 2003 and the corner-stone ceremony was held in May 2004. 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, 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). A detailed description of the HICAT facility is given in ref. [2].
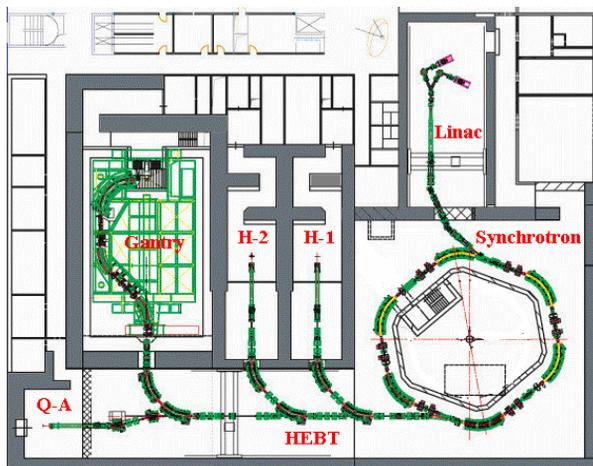

Figure 1: Layout of the first underground floor, housing the accelerator complex [5].

BEAM DIAGNOSTICS AT HICAT

After an unsuccessful search for an industrial contractor to produce the complete system of beam diagnostics (hard- and software), it was decided in June 2003 that the beam diagnostics group at GSI will act as contractor for HICAT beam diagnostics. The mechanical parts, such as detector housings, stepping motors, pneumatic drives etc., are produced by GSI. For the software and the electronic devices, however, industrial solutions were preferred.

Table 1: Overview of beam diagnostic devices for HICAT

Device	Qty.	Position	Device class
Faraday-cup	7	Linac	DC/AC-beam current
Profile grid	10	Linac	Profile measurement
El.-static pickup	4	Linac	Phase probe
DC-transformer	3	Lin/Sync	DC-beam current
AC-transformer	4	Lin/Sync	AC-beam current
Position monitor	6	Sync	Beam position
Beam loss monitor	6	Sync	Event counting
Ionization chamber	13	Sync	Event counting
Viewing screen	10	Sync/ HEBT	Optical diagnostics
Scintil. counter	5	HEBT	Event counting
Multi-wire proport. chamber	13	HEBT	Profile measurement
Isocenter-diagnostic screen	4	T1-T4	Optical diagnostics
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 meet the requirements of the therapy accelerator [3]. Concerning the layout of the electronic hardware the basic idea was to observe industrial standards to a maximum degree (e.g. PXI, IEEE1394), 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 performed using 11 separate PXI-controllers, as will be

described later. To collect maximum information about all relevant beam parameters (intensity, energy, beam profile, position and phase information) it has been decided to use state-of-the-art measurement solutions (e.g. LabViewRT, [4]).

Table 1 summarizes the beam diagnostic devices of HICAT. The devices are listed in the order of their position in the accelerator complex and beam transport system (Linac, Synchrotron, HEBT (High Energy Beam Transport)). Mainly due to the unification of the software layout, the beam diagnostic devices were subdivided into seven device classes, referring to the measured physical properties of the ion beam. In addition to the devices that perform active measurements 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 eighth device class, labelled "command devices".

In the following sections we briefly describe examples where beam diagnostic components have been newly developed or updated, with the aim of finding commercial solutions and of unifying the data acquisition process.

Linac Beam Diagnostics

HICAT is equipped with two ECR-ion sources to produce a stable dc-current of p, He, C and O ions. In this dc-regime DC-transformers [6] are used for an online measurement of the beam current in each source branch. Profile-grids are mounted at the entrance and exit of each of the two spectrometer-magnets and are used to measure the beam profile and the alignment of the beam. As an example Fig. 2 shows a profile grid produced for the HICAT project, with 64 horizontal and 64 vertical wires together with the ADC- and multiplexer-unit. A new control device was developed [7] adapting the existing GSI front-ends, with which up to eight profile grids can be addressed and read out using a single I/O-bus.
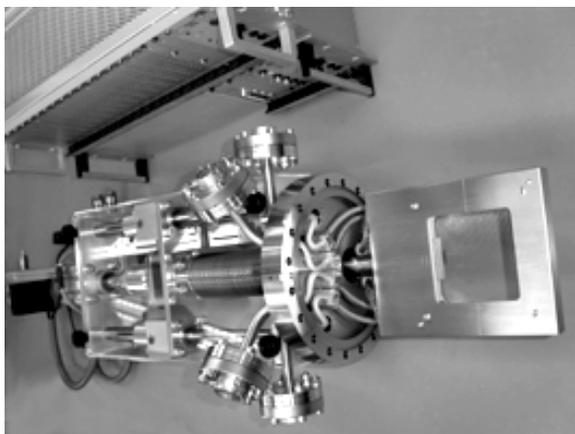

Figure 2: Profile grid with drive and control unit.

In the Linac section an RFQ accelerates the ions to 400 keV/u and the following IH-structure accelerates the 300 μs-macropulses to the injection energy of 7 MeV/u. In this section the beam current is measured via AC-

transformers [8]. Electrostatic pick-ups are used to determine both the energy and the phase structure of the linac macropulses. The pre-amplified pick-up signals are readout using compact-PCI digitizer boards with a sampling rate of 4 GSa/s [9]. By this means a minimum of instrumentation is included in the signal path. For an exact measurement of the beam energy two successive pick-ups are used as a time-of-flight (TOF) setup.

Beam Position Monitors

Each of the six synchrotron periods is equipped with a beam position monitor (BPM) [10] to determine the horizontal and vertical position of the bunched beam during the synchrotron cycle. The BPM-detector consists of a shoe-box like linear-cut pick-up. Pre-amplification of the pick-up signal is performed using purpose-built FET amplifiers, complying with all requirements of the BPM. The position sensitivity of the BPM depends on the beam intensity. Therefore, adequate amplification stages are used for low beam currents. Since the beam intensity is varied from pulse to pulse during the therapy cycles, a relay-free switching of the amplification of the BPM signals is needed. Additionally, a high input impedance of 1 MOhm is necessary to match the pick-up signals, because of the relatively low revolution frequency of the bunched beam of 1-7 MHz. Another pre-requisite for high-resolution position measurements is the exact synchronization of the amplifier pairs for the horizontal and vertical direction, respectively. Because there were no commercial solutions available at that time, GSI initiated a hardware development with an industrial partner [11]. The new type of amplifier is precisely adjusted to the needs of the position measurement. After pre-amplification near the detector, the BPM signal is converted to the beam position by commercially available log-ratio BPM-electronics [12] in the facilities' electronic room and connected to the data acquisition system.

Optical Diagnostics

Altogether 10 viewing screens are mounted in the synchrotron and HEBT sections of HICAT. One viewing screen is mounted in the first period of the synchrotron for the measurement at the end of the first turn and a second viewing screen is placed in the extraction channel to monitor the beam position and profile during the extraction. Additional viewing screens are installed along the HEBT beamline and behind the dipoles deflecting the beam to the horizontal treatment places. For all devices the screens are coated with P43 [12] with an active area of 100 mm diameter. The properties of the scintillating material have been subject to many studies at GSI [13] and P43 was found to be the best choice, concerning optical decay times and light output. The wavelength of 545 nm is ideal for the CCD cameras, which capture the image of the viewing screen. These cameras are connected to four firewire-network-hubs (IEEE 1394) and optical fibres are used to bridge the long distance to the electronic room. Thus, at this point again state-of-the-art industrial standards (IEEE1394, DCAM) are used and a

complete digital data path without loss of information is achieved.

DATA ACQUISITON CONCEPT

The basic concept of data acquisition with beam diagnostic devices at HICAT consists of three layers: the detector layer, the digital I/O-layer and the command-device layer, which is logically separated from the first two layers. The detector-layer and the digital I/O-layer are of course closely connected and build up a hierarchy of devices: one or more detectors are connected to one data acquisition system (DAS, digital I/O-layer) and one or more DAS are in turn logically grouped to "device classes" (cf. table 1). The concept has been developed in collaboration with the company responsible for the whole accelerator control system [14].

Detector-Layer

The components of the detector-layer consist of passive electronics, i.e. signal detection, pre-amplification and range settings. Except for the electrostatic pick-ups and the beam position monitors all components have a built-in test and/or calibration function. For example the current transformers (DC, AC) and the Faraday-cups are provided with stabilized current sources to allow an immediate calibration of the detector and, as well, a test of the signal path starting at the pre-amplifier.

Digital I/O-Layer

This logical layer contains the DAS, which controls the underlying detector-layer, digitizes the data and communicates with the process control of the accelerator control system. At this point the overall accelerator timing system is connected to the measurement process. Timing-signals are transported via a facility-wide real-time bus and are converted to trigger signals for the DAS by so-called timing-DCUs (Device control units, see next section). A real-time operating system (LabViewRT) is working on the PXI-controllers representing this layer. From the perspective of the accelerator control system the DAS is the abstraction layer for the connected beam diagnostic devices.

Command Devices

The electro-mechanic and pneumatic drives of the beam destructive detectors (e.g. profile grids, ionization chambers etc.) are controlled by a dedicated OPC-Server. For the accelerator control system command devices are treated independently from the DAS.

System Integration

All components of the accelerator control system (e.g. process control, GUI, database etc.) are linked via 100 MBit ethernet. Fig. 3 gives a schematic overview of how beam diagnostics are integrated in the HICAT control system. The DAS communicates with the "process control"-part of the system, which manages the preparation of the DAS to collect data, as well as the transport of the data to the graphical user interface (GUI) or the databases. The trigger signals for the DAS and for the detector-electronics are generated by so-called "device control units" (DCU). These devices have been especially developed for HICAT by an automation company [14] and are connected to the real-time bus with a precision of better than 1 µs.
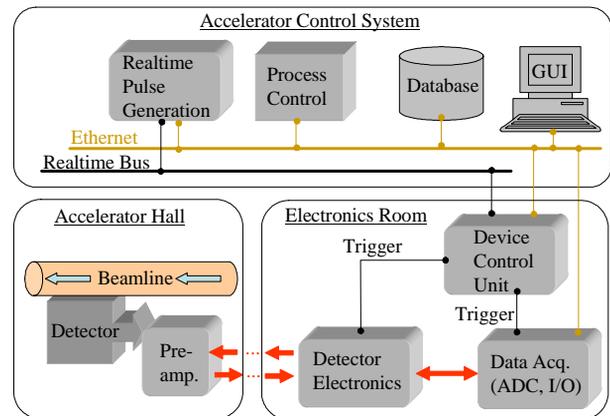

Figure 3: Schematic data acquisition layout.

SUMMARY AND OUTLOOK

We have shown that the development of a clinical facility for ion therapy has led to various scientific-industrial partnerships which had a big impact also in the field of beam diagnostics at GSI. Many existing diagnostic systems were technologically improved. A conclusive concept for standardized data acquisition has been worked out and is in the implementation phase at the moment. The structural layout is open for future extensions.

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