Safety and Control System for the GSI Therapy Project

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Abstract

This talk describes briefly the ideas of the tumor treatment with heavy ions, using the raster scanning technique. It gives a survey of the energy loss of heavy ions in matter (Bragg peak) as well as the biological efficiency of the heavy ions. A description of the concepts of the raster scanning technique follows. The physical parameters involved (energy, focus, intensity) will be discussed. The next section deals with the technical realization of the raster scanner control system. It is concerned with the communication with the GSI accelerator SIS and with the handling of the process data stipulated by the treatment planning. These data are: the position of the beam within the tumor, the applied dose for a single pixel, the scanner magnet settings and the beam request mechanism. In addition the control system handles other technical parameters like high voltage, pressure and temperature of the ionization chamber detectors, the position of the patient couch, vacuum valves, etc. An important part of the control system is the beam shut off system. Another subsystem of major concern is the interlock system. This system takes care for the safety of the patient and manages the correct execution of the treatment. The last paragraph describes the means of cross checking and overall system monitoring.

1 Basic concepts of the GSI therapy project

The energy loss of heavy ions in matter is characterized by a sharp "Bragg Peak". The penetration depth depends on the energy of the beam.

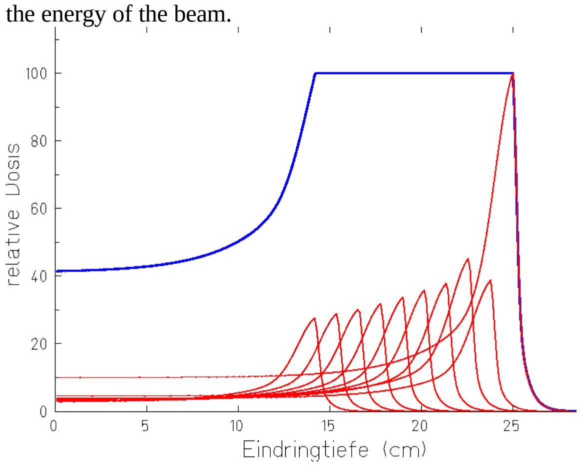

Fig.: 1 Energy Loss of Heavy Ions in Matter

Varying the energy of the beam and its intensity, leads to a superposition of "Bragg Peaks" which yields to a dose distribution shown in Fig.: 1. Therefore the dose is mainly deposited in a region defined by the energy range of the beam. This results in a biological efficiency shown in Fig.: 2.

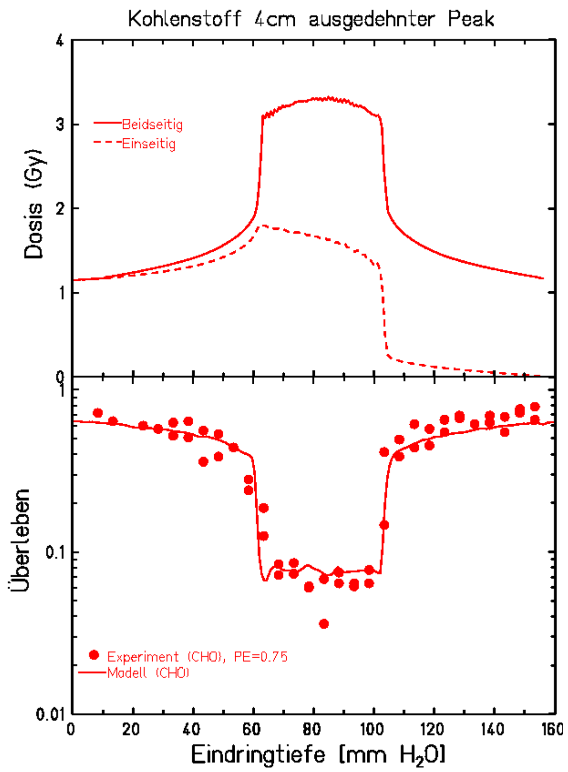

Fig.: 2 Biological efficiency

This behavior of heavy ions led Th. Haberer et. al. [1] to the design of the intensity controlled raster scan treatment method. Fig.: 3 shows the principles of this method. The volume of the tumor is divided into slices irradiated with constant energy. Irradiation starts with the highest energy E_{max} and ends with the lowest energy E_{min}. Each of these slices (Iso Energy Planes IES) contains a number of pixels depending on the shape of the tumor. Two dipole magnets deflect the beam to the first pixel. The beam remains at this pixel as long as the stipulated number of particles for the current pixel is reached. After that, the beam is deflected to the next pixel. This process lasts as long as the last pixel of the IES is irradiated. At the end of the irradiation of one IES, the control system stops the beam, requests the next energy and starts with the first pixel of the next IES.

The process stops when the last pixel of the last IES is irradiated.

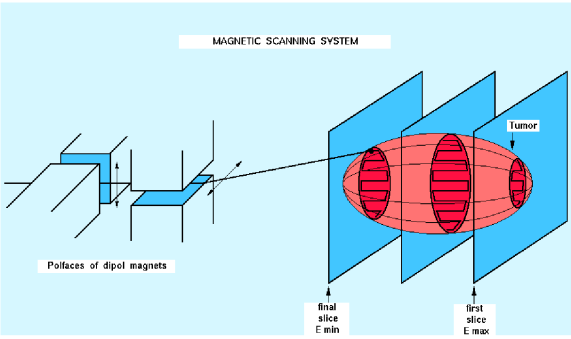

Fig.: 3 The Principles of the Raster Scan Method

2 The physical parameters

The safety and control system has to deal with the following physical parameters:

- Heavy ions used for the therapy project: ($_{12}C^{6+}$)
- Energy range: 80 - 400 MeV/u in 253 steps
- Focus of the beam: 7 steps
- Intensity of the beam (particles / spill): 15 steps
- Position of the beam in the tumor
- Size of the beam at this position in the tumor
- Number of particles at this position in the tumor.

These parameters are defined and stipulated by the treatment planning.

3 Control system overview

The Treatment- and Technical Control Room

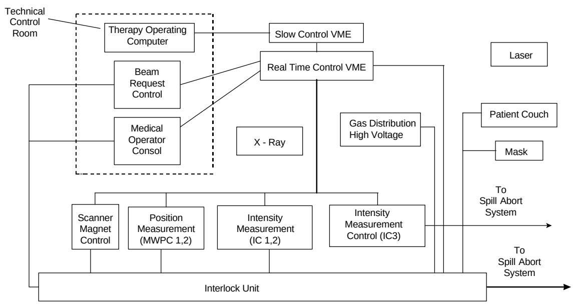

Fig.: 4 Treatment- and Technical Control Room

The Therapy Operating Computer

- handles the treatment plan,
- prepares the data to be processed,
- loads and verifies these data,
- displays status information,
- performs the graphical user interface (Factory Link).

The slow control VME system communicates with the therapy operating computer and the real time VME system. It receives status information about the current irradiation, particularly information about interlocks. Also the slow control VME system performs the control of temperature and pressure of the detectors.

The real time VME system is the heart of the safety and control system. It handles the process data and controls the peripheral electronics, like beam request control, scanner magnet control, position measurement, and intensity measurement. Further parts of the safety and control system are: the spill abort system, an independent intensity measurement control, the patient couch, a laser system for positioning of the patient, a mask to fix the patient on the patient couch, a X-ray device to control the position of the patient, ionization chambers (IC1 - IC3) and two multi wire proportional chambers (MWPC1, MWPC2) with the according high voltage supplies and gas distribution system. The medical operator console performs all actions done by authorized staff; like start and stop of the irradiation, etc.

3.1 The real time control VME system

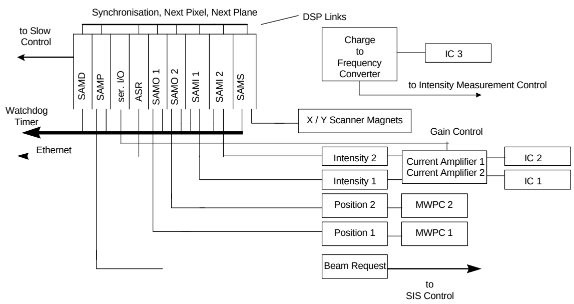

Fig.: 5 Real Time Control VME System Overview

The real time control VME system consists of a communication controller ASR and several dedicated DSP based controllers connected to the peripheral electronics. DSP links on the P2 connector of the VME crate synchronize these controllers.

3.2 Scanner magnet control

The controller SAMS drives the current of the vertical and horizontal magnets. It verifies the setting and observes the settling time.

3.3 Intensity measurement

The intensity measurement is redundant. Each branch consists of an ionization chamber (IC), a current amplifier, a digitizing unit, and a DSP controller SAMI. A serial I/O controller sets the gain of the current amplifier. Method: The current of the IC, which is proportional to the beam current, is amplified and converted into a voltage. This voltage is digitized by an ADC each 12.7 µs and summed up. This sum is constantly compared with the value stipulated by the intensity value for the current pixel. If this value is reached, the beam is deflected to the next pixel. The two branches are controlled for equal operation.

3.4 Position measurement system

The position measurement is also redundant. Each branch consists of a multi wire proportional chamber, a digitizing readout electronic, and a DSP controller SAMO. The task of this system is to measure the position and the width of the beam at the current pixel. This measured values are compared with the stipulated process data of the beam position. The method of this system is described in [2].

3.5 Beam request control

The beam control system consists of electronics for communication with the accelerator control system and a DSP controller SAMP. The system requests the corresponding energy step, the focus of the beam, and the number of particles per spill for each IES.

3.6 Intensity measurement control

The intensity measurement control consists of a third ionization chamber (IC3), a charge to frequency converter, and three preset counters. This independent system performs a maximum dose per pixel cut off, a maximum dose per IES cut off, and a maximum dose per total irradiation cut off.

3.7 Communication with therapy operating computer

A dedicated DSP controller SAMD sends all relevant data and status information of the real time control system to the therapy operating computer. This computer with its graphical user interface informs the operators about the status and progress of the irradiation of the patient.

3.8 Software time-out

All DSP based controllers must send a periodical signal to a watchdog timer to insure proper operation of the software running in the controllers.

3.9 Synchronization

All DSP controllers communicate with each other via a ring of DSP links. If one controller runs out of phase in processing of the data, the irradiation is stopped.

4 Data to be processed by the control system

The physical parameters derived from the treatment planing are transformed in the following data used by the control system:

- number of IES,
- number of pixels per IES,
- energy step (1 - 253) for each IES,
- intensity step for each IES,
- focus or each IES,
- Current of the scanner magnets for each pixel including tolerances and settling time,
- position and size of the beam per pixel,
- intensity per pixel,
- maximum intensity per pixel, per IES, and per total irradiation,
- high voltage of the detectors,
- gas flow, pressure , and temperature of the detectors,
- position of the patient.

5 Safety considerations

In case of a failure or an error the extraction of the beam must be stopped within 1 ms. This is done by deactivating a fast quadrupol and a bending magnet in the beam line. At the end of an IES only the quadrupol is deactivated.
In case of an irradiation of a patient this spill abort system is solely controlled by the safety and control system. It can not be influenced by other activities at GSI.

The spill can be aborted by the interlock unit (ILE) and the intensity measurement control system.

The failure or error information (30 inputs) is stored in the error register of the ILE. The signal to the spill abort system is the logical or of the outputs of this register. Only an intervention at the medical operator console by an authorized person clears and enables the ILE. The ILE also reserves the spill abort system for therapy irradiation. If this reservation fails no extraction of beam is possible.

5.1 Hardware

- Scanner magnet breakdown or failure

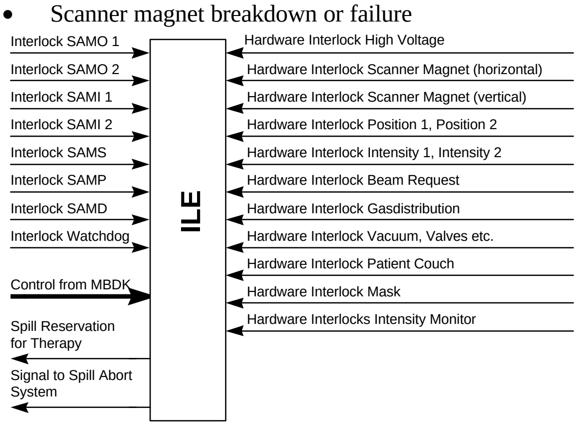

Fig.: 6 Interlock Unit ILE

Two groups of signals cause an interlock:

- High voltage is out of order,
- Gas distribution fails (no gas),
- MWP readout electronic fails,
- Digitizing electronic of the intensity measurement fails (ADC time-out, data overrun ,etc.),
- The beam request electronic fails (wrong energy step, e.g.),
- A valve in the beam line is closed or the vacuum is bad,
- The patient couch has moved during irradiation,
- The patient has opened the mask,
- The intensity measurement control detects too much radiation. This interlock is independently routed to the spill abort system.

5.2 Software

Each DSP based Controller is capable of sending an interlock signal to the ILE.

- The position measurement (SAMO1 or SAMO2) detects a wrong position or a wrong spot size of the beam,
- The intensity measurement controllers (SAM1 or SAMI1) detect an error (overshoot) in the intensity.
- The scanner magnet controller (SAMS) detects a failure in the current settings of these magnets or detects a time-out, e.g. too fast movement of the beam,
- The beam request controller (SAMP) detects an error in the communication with the SIS control system, e.g. the requested energy step is not correctly executed by the accelerator.
- An interlock is also generated if the communication with the therapy operating computer fails (SAMD).
- A software time-out of any controller leads to an interlock (watchdog timer).

6 Conclusion

All acceptance tests have been passed and the first patients will be treated at the beginning of December this year.

Acknowledgments

We would like to thank Prof. Dr. G. Kraft and his group for bringing up this project.

References

[1] Th. Haberer et. al., NIM A330 (1993) 296 - 305

[2] E. Badura, H. Essel et. al., Real-Time Beam Intensity and Position Control System, GSI, Workshop, August 1995.