Accelerator Aspects of the Cancer Therapy Project at the GSI Darmstadt

H. Eickhoff, B. Franczak, U. Krause, C. Riedel, R. Steiner
GSI Darmstadt

1) Introduction

At the GSI-Heavy-Ion research accelerator complex an experimental cancer treatment program is under development. The duration of this program is five years and will start with the first patient treatments near the end of 1996. In total about 350 patients will be treated.
This experimental program with a novel treatment scheme shall be the basis of a dedicated, hospital based therapy accelerator.

The advantages of heavy ions for cancer therapy are the enhanced radiobiological efficiency, the precise localisation of the energy deposition within the tumor at the 'Bragg-peak', and the extremely reduced damages of healthy tissue outside the tumor in comparison to photon- electron- and neutron radiation [1].
At present a few dedicated proton- (e.g. Loma Linda in the United States, PSI in Switzerland) and light- ion accelerators (e.g. HIMAC in Japan) for cancer treatment exist. These accelerators produce a beam with constant beam-parameters (energy, intensity, optics) over the treatment interval. Necessary beam manipulations are performed near the treatment place by means of devices for spreading and shaping the beam and sophisticated mechanical range manipulators in order to perform a 3d-conformal irradiation.
At GSI a novel treatment concept will be realized, that is based upon the 'rasterscan'-method and an active energy- and intensity-variation within the treatment time. Fig. 1 shows the principle of the rasterscan-method [2].

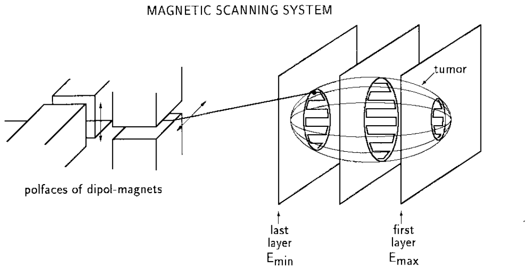

Fig. 1: Rasterscan-Method

The accelerated and slowly extracted beam enters 2 fast scanner magnets, that deflect the beam both in horizontal and vertical direction to cover the lateral dimensions of the tumor. An ionization chamber in front of the patient measures the number of ions at a specific irradiation point and controls the scanner excitation. Fast multiwire proportional counters control the position and beam width at each scanning point.
The required range sequence of the ions inside the tumor tissue are achieved by active energy variation of the beam. The range and dose of the ion beam is supervised by a PET-camera.
In order to minimize the treatment period in addition a variation of intensity and beam size is demanded.

2) Therapy requirements

For accelerator operation the GSI Therapy program requires reliable, fast, active variations (within a few seconds) of:

- beam energy
- beam intensity
- beam-size

within the treatment sessions. In the following table the essential beam parameters are summarized, which are the basis for the definition of the accelerator performance:

- **Ion-species :12 C (6+)**
- **Ion-source : High charge.-state Inj.**
- **Ion-energy : 80 - 430 MeV/u**
- **Extraction-time : 2 s**
- **beam-diameter : 4 - 10 mm (hor., vert.)**
- **max. pos. error : 1 mm**
- **Intensity-Variation : 10^6 to 10^8 Ions/spill**

- **No. of energy-steps : 255**
- **No. of intens.-steps : 15**
- **No. of focusing-steps : 7**

Table. 1: Therapy requirements

These requirements in connection with the enhanced safety demands implies a major change of the accelerator operation in all accelerator sections in comparison to the usual physics research mode.
A second demand is the possibility of performing therapy treatment and various physic experiments sequentially within short time intervals.
Whereas the accelerator operation of the established experimental program is determined by a large amount of flexibility in order to reach the specific beam parameters at the experiment, the Therapy project demands fixed and proven settings that for safety reasons may not be changed by operators. These two

contradictory operation modes have to be combined, as beside the Therapy program also experimental physics has to be possible.

The necessary parameter variations of the accelerator components have to be performed with a high degree of reliability and reproducibility.

In addition for safety reasons arbitrary changes of set values have to be prohibited during the treatment time ('lock' of the accelerator during the treatment interval).

3) Modifications of controls

The required large amount of parameter variation can only be handled by a major modification of control-hard and -software. Due to the tight schedule of the therapy project a concept had to be found to achieve this goal within the existing frame of accelerator operation and without influence on the experimental program. This concept is based upon the following essential features:

- the set parameters of the accelerator components have to be defined for all required parameter variations,
- the experimentally validated parameters are permanently stored within non-volatile memory of the component's control hardware,
- the reproducibility of beam parameters for identical set parameters is verified,
- during the therapy irradiation times parameter manipulations are excluded on component's level.

Within the present 'normal' accelerator operation a maximum number of 16 'virtual accelerators' (VA) can be provided for the experimental physics program. These VAs represent a complete set of different accelerator parameters, that allow a change of beam parameters (energy, intensity,..) from pulse to pulse.

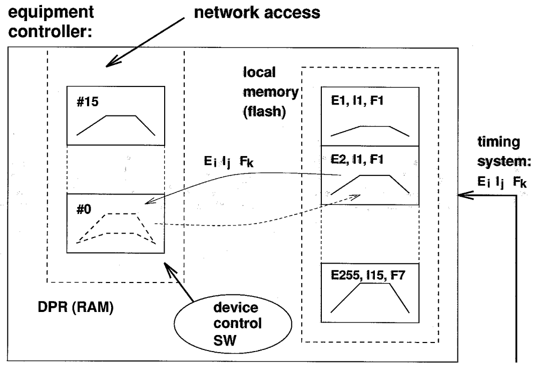

Fig. 2: Substructure of the 'Therapy'-VA

The Therapy requirements largely extend this maximal number of parameter variations (255 * 15 * 7 individual steps, see Table 1). Fortunately most components only depend upon one parameter (either energy or intensity or focusing); thus the variation possibilities are drastically reduced. Nevertheless an upgrade of memory capability was necessary. The existing Equipment Controllers (ECs) could be reused by replacing the existing memory piggi-back by a new one, providing 2 MByte of flash EPROM for the set parameters and 2 MByte of RAM for storing the actual component's parameters. [3]

Only the 'therapy accelerator' can activate subcycles within one VA for the demand of various energy-, intensity- and focus-steps. To provide the beam parameter information for the ECs in real time, there is no other means in the GSI control system but the timing system. It is connected to the irradiation place by a dedicated hardware link to receive, besides some status informations, the request for the next therapy beam according to the specific irradiation plan (see Fig. 2)

4) Experiments

In 1995 few machine development shifts were used to perform both in the Synchrotron and the high energy beam line systematical investigations concerning the dependence of various beam parameters as a function of extraction energy.

These experiments led to additional energy-dependent corrections for few accelerator components in order to achieve beam properties (position, spill time,..) that are almost independent from the beam energy.

As in July 1995 the first beam was delivered to the newly installed beam line to the irradiation place ('Cave M') these tests were done with this beam line in the second half of '95.

In Nov. the first therapy 'test cycle', consisting of 30 different energies in the range from 430 to 80 MeV/u was successfully tested after the described extensions of the control system had been installed and a new program for the data generation had been developed [4]. For all required parameter variations this software calculates the set parameters for the synchrotron and the Cave-M beamline and sends them to the devices. In addition programming of the non-volatile memories and activation of different test conditions are possible.

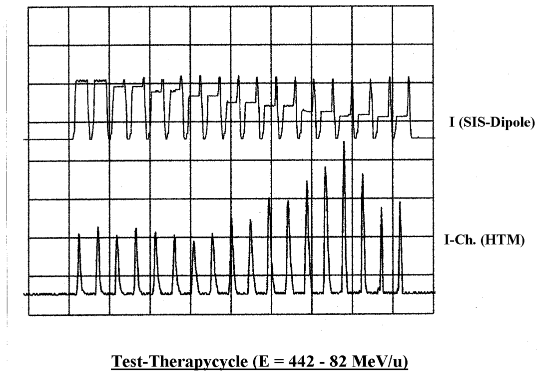

Fig. 3: Measurements of a Therapy test cycle

Fig. 3 shows in the upper trace the SIS-Dipolefield for such a predefined test cycle; the lower trace shows the measured spill signal of the slowly extracted beam in Cave-M.

All parameters were calculated on the basis of a theoretical model and corrections, found in previous beam times. Nevertheless the beam could be delivered to the irradiation place for the total energy range (see the ionization-chamber signal at the lower trace) without manipulating any set values.

To cope with magnetic hysteresis effects in the SIS an additional magnet ramp after beam extraction was introduced for the therapy cycles in order to generate a constant magnet cycle that is independent from the extraction energy.

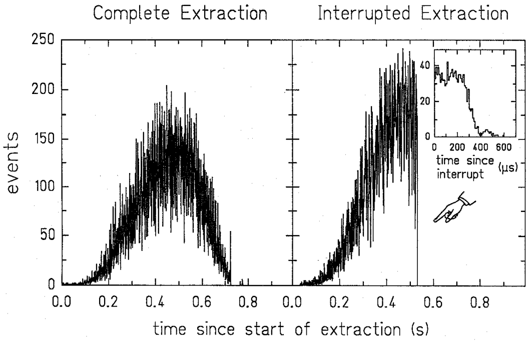

Fig. 4: Fast Spill-interruption

When a required dose limit has been reached the beam extraction can be interrupted very fast (0.5 ms) by locking the power supply of the two 'resonance'-quadrupoles, driving the beam smoothly into the 1/3 order betatron resonance. For safety reasons this procedure, that is well established at the synchrotron, will be extended by a second redundant spill-abort system.

In Fig. 4 the time-structure of an interrupted, slowly extracted beam is shown, measured with a particle counter in the high energy beam line.

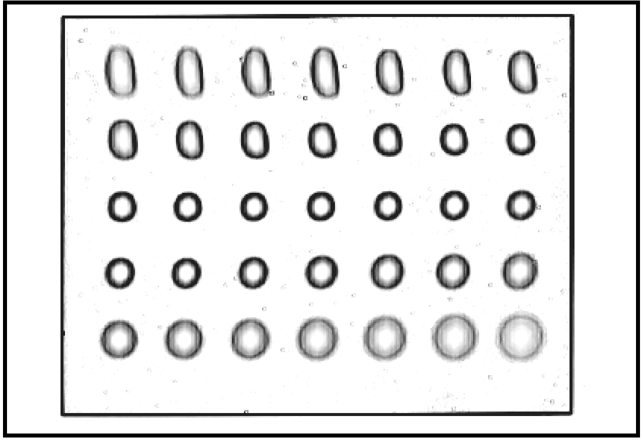

Fig. 5: Beam cross-section at the iso-centre for different beam energies (430 - 80 MeV/u)

Fig. 5 shows the beam coss-section for 35 energy steps within the required energy range at the ISO-center. By a special scanning-program each individual spill is deflected to different points, starting at a high energy value (430 MeV/u) at the upper left posistion down to the lowest energy (80 MeV/u) at the right position of the bottom trace. The energy variation between each point is 10 MeV/u; the programmed distance between the points is 15 mm both in horizontal and vertical plane. The beam extensions were measured by exposing a film located at the iso-center to the beam.

Whereas for medium energies (centre line) the beam profile has the demanded shape and size at lower energies the beam is spread out due to straggeling effects of foils ('vacuum-window', ionization chamber). It is also obvious that the vertical focusing at high energies (top line) has to be improved.

5) Status and Outlook

Within the last 18 months the specific accelerator requirements of the GSI Cancer Therapy project were detailled, the major part of the necessary extensions were installed and various beam tests have been performed within short machine development periods.

As the first patient treatment is scheduled near the end of '96, a lot of preparation tests are planned within dedicated accelerator test shifts. The major tasks are:

- Optimization of all dependencies (energy, intensity, focus) to reach the required beam parameters and tolerances.
- upgrade of beam-diagnosis software for automatically control of the large amount of data for the therapy 'subcycles'
- realization and test of component's lock both in the low- and the high energy accelerator sections
- development of information exchange processes between the accelerator and the Therapy Technical control room

A major fraction of beam time will be needed to check the reliability of the system after all modifications have been finished and a complete set of accelerator parameters is available.

Simulations of therapy operation with a phantom irradiation are scheduled for summer '96.

References:

[1] G. Kraft, G. Gademann, GSI-Report 93-23
[2] Th. Haberer et al, Nucl. Instr. Meth. A330, 296 (1993)
[3] U. Krause et al., ICALEPS 1995
[4] B. Franczak, 'Data Generation for SIS and Beam Lines for the GSI Therapy Project', this conference