

# ACCELERATOR CONTROL FOR THE GSI CANCER THERAPY PROJECT

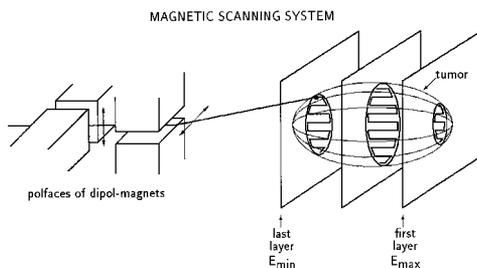
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## Abstract

At the Heavy Ion Research Institute GSI in Darmstadt an experimental cancer treatment program has started. A new method for cancer treatment with ions has been developed, using the intensity controlled rasterscan method in addition to an active pulse to pulse variations of the extraction energy, the beam intensity and the end focusing from the GSI heavy ion synchrotron SIS. The experiences within this experimental program with a novel treatment scheme will contribute to the design of a dedicated, hospital based therapy accelerator.

## 1 RASTERSCAN AND ACCELERATOR CONTROL

Whereas at presently existing therapy-dedicated proton- and light-ion accelerators for cancer treatment the beam-parameters (energy, intensity, optics) are constant over the treatment interval, at GSI a novel treatment concept is realized, that is based upon the 'rasterscan'-method (Fig. 1) and an active energy- and intensity-variation within the treatment time [1,2].



**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. Ionization chambers in front of the patient measure the number of ions at a specific irradiation point and control the scanner excitation. Fast multiwire proportional counters control the position and beam width at each scanning point. When the required dose limit for a tissue layer has been reached the beam extraction is interrupted very fast (0.5 ms) by locking the power supply of two 'resonance'-quadrupoles, that drive the beam smoothly into the 1/3 order betatron resonance.

In addition with the active energy variation to cover different ranges a 3d-conformal irradiation beam is achieved. Further beam manipulations (by means of devices for spreading and shaping the beam and sophisticated mechanical range manipulators) can be avoided with this method.

For accelerator operation the GSI therapy program requires reliable, fast (within a few seconds), step by step variations of :

- beam energy
- beam intensity
- beam-size

during 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-energy	: 80 - 430 MeV/u
• Extraction-time	: 2 s
• beam-diameter	: 4 - 10 mm (hor., vert.)
• Intensity-Variation	: $2 \cdot 10^6$ to $2 \cdot 10^8$ 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 imply a major change of the accelerator operation in all accelerator sections in comparison to the usual physics research mode. [3,4,5]

The necessary parameter variations of the accelerator components have to be performed with a high degree of reliability and reproducibility. The requested beam properties for all possible parameter variations have to be accurate in the (sub-) mm range.

A second demand is the possibility of performing therapy treatment and various physic experiments sequentially within short time intervals ('mixed operation').

The chosen solution to fulfill these requirements was to create for one (out of 16 existing) 'virtual accelerator' fixed set parameters of all relevant accelerator components for all demanded variation possibilities.

To realize this concept major extensions on all accelerating control levels had to be performed like the modification of the existing controls hardware to integrate non volatile memory for the set parameters and

the generation of operating tools to create these values and to record the beam properties.

Although the patients safety is guaranteed by the raster control system with redundant fast beam diagnosis and spill abort, additional precautions have been installed on the accelerator side to enhance operation reliability:

- During the treatment time the accelerator is in a 'locked' state, which prohibits any component access.
- An interruption of the therapy cycle by other virtual accelerators is prohibited.
- All passive beam affecting devices (profile-grids, cups, valves,..) will be removed automatically before a therapy cycle is activated.

## 2 EXPERIMENTAL RESULTS

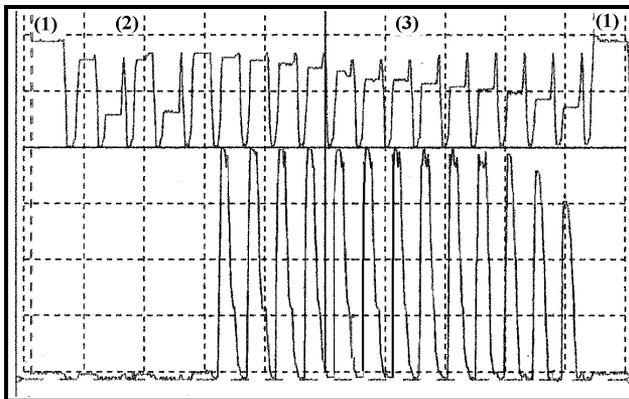
In July 1995 the first beam was delivered to the newly installed beam line to the irradiation place ('Cave M')

In Nov. '95 the first therapy 'test cycle' including a predefined sequence of extraction energies was successfully tested after the described extensions of the control system had been installed.

Such a test cycle is shown in Fig. 2 with the dipolefield of the synchrotron SIS in the upper and the signal of the SIS beam current transformer in the lower trace.

A (low intensity) experimental pulse (1) is followed by 5 therapy preparation pulses (2) and twelve therapy pulses with decreasing extraction energies (3).

The preparation pulses with varying magnet excitations are required to cope with magnetic hysteresis effects in the SIS and the high energy beam line (within these pulses no beam is injected into the synchrotron).



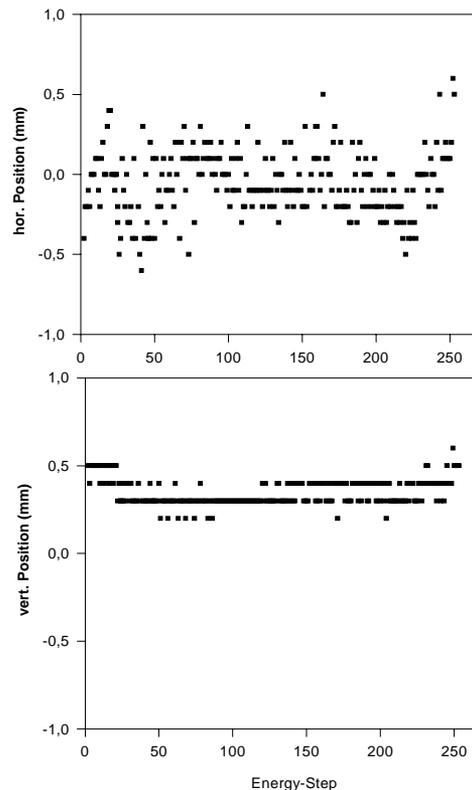
**Fig. 2** SIS-Dipole field (upper trace) and synchrotron beam current (lower trace) for a Therapy test cycle

For the same reason 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.

At the accelerator most of the available therapy test beamtimes were used to optimize the beam parameters in order to achieve the required specifications.

Fig. 3 shows for all energy steps both in horizontal and in vertical direction the center of gravity of a strongly focused beam at the position of the Cave M multiwire proportional chamber (MWPC) about 1 m in front of the patient. The variations of the horizontal position are close to 1 mm; that of the vertical positions are much better in the range of a few tenth mm.

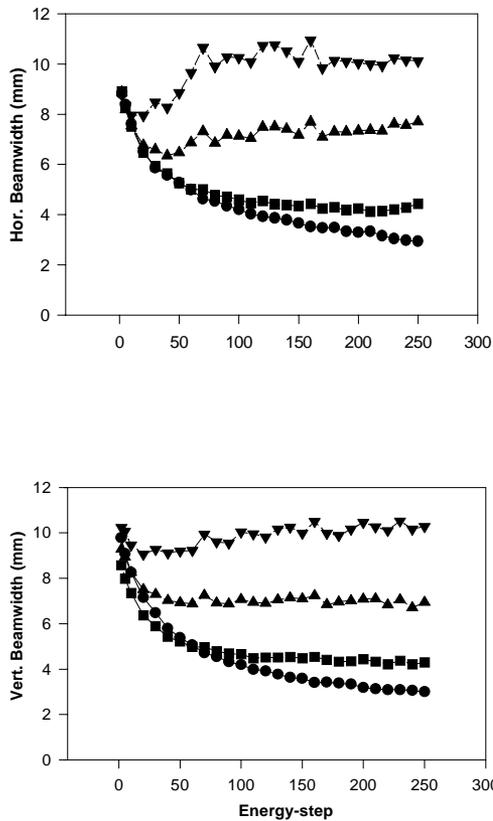
These beam properties were constant during several days without any corrections at the accelerator's set values



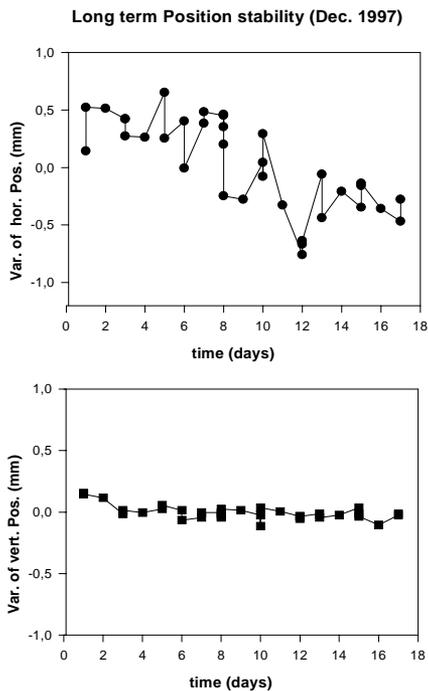
**Fig. 3** Beam-Position-Measurements (MWPC, all energies)

Due to the requirements of the treatment plan and the limited stepping speed of the scanning magnets the intensity of the extracted beam has to be varied at maximum by a factor of 100 between sequential accelerator cycles.

This intensity variation is performed within the low energy accelerator section by means of a bunch synchronized variable beam deflection in front of an aperture. The advantage of this method is, that the emittance after this section is intensity independent, which simplifies the data generation after the linac. The requested intensity tolerances are reliably realized from pulse to pulse.



**Fig. 4:** Horizontal and vertical beam widths (FWHM), measured with a profile grid at the ISO-center



**Fig. 5** Long-term position variations

The horizontal and vertical beam width (FWHM) at the treatment position ('isocenter'), measured with a profilegrid, is shown in Fig. 4 for the complete energy range and four focusing steps (4,5,8,10 mm). It is obvious, that in the low energy range the desired small spot sizes cannot be achieved due to straggeling effects within the different diagnosis components between the beam exit and the isocenter and mainly the mini ridge filter, used to smear out the bragg peak at low energies. These measured beam widths are taken into account in the treatment planning.

Fig. 5 shows the stability of the beam position over 18 days without corrections of the accelerator's set parameters. Each point of this measurement contains the mean horizontal and vertical beam position at the treatment place for a defined number of energy- and focusing steps.

At the treatment place the main tasks were the development and test of the control system including the rasterscan and the fast beam monitor system.

Although a relatively strong intensity modulation of the extracted beam within the spill is observed, homogeneous dose distributions are achieved due to the fast intensity control of the scanning system.

### 3 STATUS AND OUTLOOK

- All required modifications of the accelerator control to fulfill the therapy requirements were established and successfully tested. In addition the 'mixed operation', which means a change between therapy operation and physic experiments, was demonstrated.
- At the treatment place all hardware components are functional; the positron emission tomograph (PET) [6], which is used for 'treatment plan verification' has been installed and successfully tested in various experiments.

After intense quality assurance tests the first patients' treatment started in Dec. '97 [7]

As in the first three months of 1998 major alterations of the accelerator facility took place, treatments blocks are scheduled for August and November with an increased number of patients.

#### References:

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