# THE GSI CANCER THERAPY PROJECT

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*Abstract*

At the Heavy Ion Research Institute GSI in Darmstadt an experimental cancer treatment program with a five years duration has been developed. A new method for cancer treatment with ions is applied, using rasterscan method in addition to an active pulse to pulse variations of ion beam properties, including the energy, intensity and focusing.
An overview of this Cancer Therapy Project is presented, that covers both accelerator aspects to provide the required beam variations within a short time and the installations at the treatment place for rasterscan control. In addition to a description of the technical design (controlhard- and software) experimental results will be shown, containing the achieved beam properties and measurements of rasterscan performance.

## 1 INTRODUCTION

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 and an active energy- and intensity-variation within the treatment time. With this method passive beam manipulations in order to perform a 3d-conformal irradiation (by means of devices for spreading and shaping the beam and sophisticated mechanical range manipulators) can be avoided [1, 2].
At the GSI in Darmstadt 350 patients will be treated within a five years experimental cancer treatment program; the first patient treatments are scheduled for this year.
The experiences within this experimental program with a novel treatment scheme will contribute to the design of a dedicated, hospital based therapy accelerator.

## 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** | **: ECR** |
| **• Ion-energy** | **: 80 - 430 MeV/u** |
| **• Extraction-time** | **: 2 s** |
| **• beam-diameter** | **: 4 - 10 mm (hor., vert.)** |
| **• Intensity-Variation** | **: $2*10^6$ to $2*10^8$ 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.
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.

## 3 MODIFICATIONS OF ACCELERATOR 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

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parameters, that allow a change of beam parameters (energy, intensity,..) from pulse to pulse.

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' (#0) 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.

Although the patients safety will be guaranteed by the raster control system with redundant fast beam diagnosis and spill abort, additional precautions have been installed on the accelerator side:

- The stored, verified set values for the accelerator components are signed with a unique identification code; this code has to be transfered in order to activate the EPROMs set values.
- During the treatment time the accelerator is in a 'locked' state, which prohibits any components 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.

## 4 THE INTENSITY CONTROLLED RASTERSCAN-METHOD

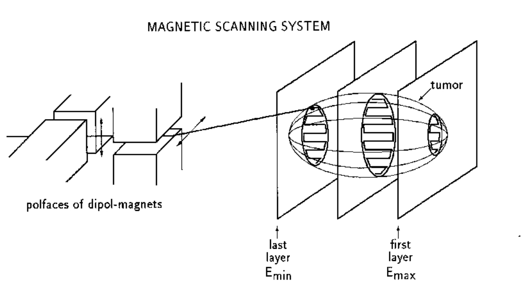


**Fig. 1** Rasterscan-Method

Fig. 1 shows the principle of the rasterscan-method [2]. 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. Whereas intensity measurements are performed within 13 µs, position control is done about every 150 µs.

When a required dose limit has been reached the beam extraction is 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.

## 5 EXPERIMENTS

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', 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, 5]. 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. 2 shows in the upper trace the SIS-Dipolefield for such a predefined test cycle; the lower trace shows the signal of the SIS beam current transformer.

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

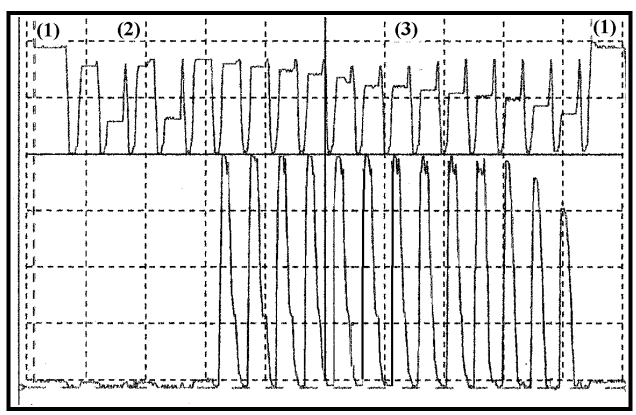


**Fig. 2** SIS-Dipole field (upper trace) and synchrotron beam current (lower trace) for a Therapy test cycle

The preparation pulses with variing 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).
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.
For the accelerator most of the available therapy test beamtimes within the last year were used to optimize the beam parameters in order to achieve the required specifications.

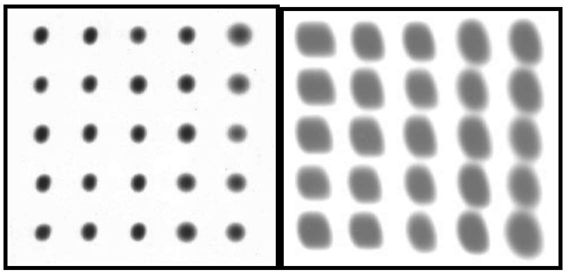

**Fig.3**: Beamspots at the isocenter for 25 energy-steps (strong and weak focusing)

Fig. 3 shows two pictures (a strongly focused beam on the left and a weak focused one on the right) of a polaroid film directly exposed to the beam at the treatment position ('isocenter'). By an appropriate programming of the scanner magnets, 25 spills with different energies were deflected in horizontal and vertical direction to individual positions with a separation of 15 mm (from 430 at the lower left side to 80 MeV/u at the upper right side).

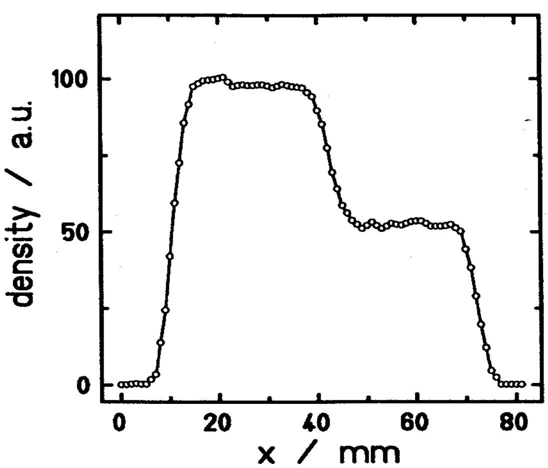


**Fig. 4** Dose profile with a factor of two step at the center

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.

Fig. 4 shows a measured dose profile of a 2-dimensional rasterscan, with a step of a factor of two in the center. The absolute homogeneity of the flat parts is in the range of ± 5 %, that is sufficient for therapy.

## 6 STATUS AND OUTLOOK

- Within the last 2 years 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 treatment and physic experiments, was realized.
- At the treatment place all hardware components are functional
- The reference point for the medical treatment and the central treatment beam are visualized by four laser systems; three movable x-ray systems were installed, which serve for the final inspection and documentation of the patient position with respect to the reference point.
- The Positron emission tomograph (PET) [6] has been installed at the treatment site and successfully tested in various experiments. From these experiments two modes of application of PET-imaging for quality assurance in heavy ion therapy have been deduced: the 'retrospective dose localization' and the 'treatment plan verification'.

Within the next months tests of quality assurance and diagnostic measurements have to be performed for the final approval.
After an adequate period of clinical testing first patient treatments will start.

## REFERENCES

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