DATA GENERATION FOR SIS AND BEAM LINES FOR THE GSI THERAPY PROJECT

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Abstract

The GSI cancer therapy project with carbon ions in the energy range from 80 to 430 MeV/u makes it necessary to tune the heavy ion synchrotron SIS and the beam lines to about 250 different energies in this range. Since the beam has to be delivered on demand in various energy sequences, no online tuning or correction of set values of accelerator components can be permitted. To achieve this an additional magnet ramp after extraction is added to the normal SIS acceleration scheme. Thus all dipoles and quadrupoles perform the same magnet cycle independently of the final energy. Certain sensitive machine parameters, e.g. the fast extraction quadrupole, usually need a small energy dependent adjustment. These corrections were determined experimentally for about ten energies and the values for the others are obtained by interpolation. Thus it is possible to set the SIS to any desired energy and deliver the beam on the target using only precalculated set values.

1 THE GSI THERAPY PROJECT

For the precise cancer treatment with carbon ions it is necessary to deliver a well focussed beam (a few mm diameter) at any desired position within the 3-dimensional volume defined by the shape of the cancer [1].

In this paper some special developments in the control of the SIS heavy ion synchtrotron will be described, which are needed to meet the requirements of GSI's therapy project.

To position the beam in the transverse directions, i.e. parallel to the surface of the body, a magnetic deflection system is used to cover an area of about 20 * 20 cm. It consists of a pair of fast scanner magnets at the end of the beam line. To vary the position of the Bragg peak in the depth it is necessary to vary the beam energy, since the use of absorbing matter would reduce the beam quality substantially and make the treatment procedure more complicated.

A total energy variation from 80 to 430 MeV/u is needed to provide the required depth range. According to the longitudinal dimension of the Bragg peak it must be possible to vary the energy in steps of 1 to 2 MeV/u to achieve a contiguous dose deposition in the whole volume. So the accelerator must be prepared to deliver about 250 different energies.

2 ACCELERATOR REQUIREMENTS

The set of beam properties listed in the previous section implies some unusual requirements for the accelerator performance:

There will be no time for manual adjustment of device settings or tunig of the machine when a different energy is demanded from the treatment. As a consequence the settings of all devices must be correct on initialisation for each energy step.

Though it would be possible to make the calculations of these settings online, it is necessary for the sake of safety to calculate all data in advance and store them in the local memory of the devices.

Finally special care must be taken to keep all beam parameters decoupled: first the dependence of beam size (i.e. focussing) on the beam energy must be eliminated by suitable calculations; then the dependence on the magnetic history of the various magnets must be as small as possible because the beam size and position must be reached precisely ever for the first shot with a new energy.

3 MODEL FOR NORMAL OPERATION

The synchrotron SIS is designed to accelerate various ion species in a wide energy range. To control all set values for the devices of such a highly flexible machine, a simple setting of magnet currents is not very convenient if e.g. the energy is to be changed.

Therefore, we use a model of the synchrotron in the control computer, which describes all important properties of the machine and enables us to calculate all device set values in a consistent way. Thus the amount of work to be done for changing of parameters is reduced considerably.

The operator sees on the screen a set of input values, which are more related to the physical properties of the machine rather than currents of power supplies. He may enter e.g. the injection and extraction energy, the betatron tunes, the extraction time, amplitudes of closed orbit bumps, or mass and charge of the particles to be accelerated. He can also switch between fast and slow extraction.

Energy and ion species basically define scaling factors for the current calulations. From the betatron tunes first relative quadrupole strengths using a polynomial approach are calculated. The polynome coefficients are determined offline and allow to change the tune by about ± 0.2 without explicit ion optical calculations. Also the change of the focussing mode between triplet and doublet is done this way.

Several critical machine parameters like the precise third integer tune for the extraction resonance or the flat top field of the main dipoles cannot be set with the required accuracy in one step due to the varying magnetic history and imperfections in the quadrupole model mentioned above. Also the exact settings of the extraction septa and the time function of the fast quadrupole used to drive the beam over the resonance need a final manual adjustment.

For the compensation of dipole field imperfections the beam can be moved radially in the vacuum chamber just by entering the new position in millimeters. To keep the particle energy fixed on the required value both the dipole current and the frequency of the rf system will be changed simultaneously.

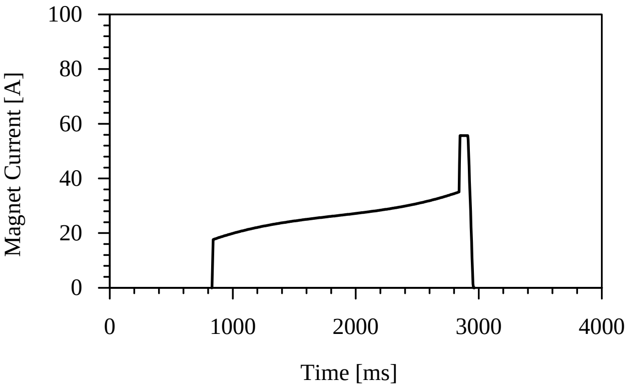

Figure 1: Typical current diagram for the extraction quadrupole including tune correction and spill shaping

The shaping of the extraced beam is done by suitable programming of the fast extaction qaudrupole. Figure 1 shows a typical current diagram: the step close to 800 ms is used to move the tune as fast as possible exactly to the edge of the resonance. The next 2000 ms are specially formed to make the spill nearly rectangular in spite of the non-uniform density distribution in the phase space of the circulating beam. The parameters of this curve (a polynome of third order) are found experimentally. Finally the peak at 2800 ms is used to extract the rest of the beam rapidly and is introduced deliberately to detect incomplete extraction due to incorrect parameter settings. Of course for these procedures the input is made in terms of ΔQ rather than currents.

Inside the model it is first checked which devices or power supplies are involed in performing the requested change of machine parameter. In the case of the extraction energy nearly all devices need new data. For a change of the extraction time only a few power supplies directy related to the extraction process have to be updated. Thus the time needed for data down loading is minimized and the data of all devices are always consistent.

Then the input values are checked with the technical limitations of all involved devices, i.e. minimum and maximum currents and maximum current change rates. If one or more devices would have to be operated outside their working range the input value is reduced to the maximum (or minimum) value which allows all devices to stay within their limits.

In addition to the adjustment of the settings to the common magnetic rigidity all devices must be synchronised in timing. For this pupose the whole accelerating cycle is divided in up to ten time segments each dedicated to a special task, e.g. acceleration to extraction energy or performing the slow extraction. For all devices it is defined in which segment they remain constant and where they have to change their settings. Here they are provided with a series of set values in aequidistant steps of several milliseconds. Thus it can be ensured that all devices act synchronously.

All data are stored in the local memories of the devices and set in real time by the control system. Both the system an the optical model of SIS can handle sixteen completely independent sets of machine settings and switching between these sets is possible from pulse to pulse.

In the program that controls the model an expert level is included which can be used to visualise all time functions of the devices, the deviation of the measured currents or field from the calculated ones, and some physical functions that can be derived from the model, e.g. area and height of the rf buckets during acceleration. In a later state of development it is planned to include graphical input as well.

4 SPECIAL MODIFICATIONS

To produce the beam for the therapy only a subset of the whole spectrum of SIS capability is used. The ion is carbon and instead of free choice of energy about 256 fixed values are predifined. Only slow extraction with duration of about two second is foreseen. Time sharing operation with other experiments is not an issue during the treatment runs.

On the other hand the manual adjustment for some parameters of the SIS model described in the previous chapter is no longer applicable when it has to be done for as many as 256 machine settings. Therefore, it is necessary to find a procedure to calculate the settings of the SIS and all beam line magnets to deliver the beam at the right place with the right quality without any further adjustment.

The solution was to do the manual adjustment procedure in the usual way for only 10 to 15 out of the 256 energy steps. Since we only have to deal with carbon it is possible to consider the experimentally found values for a certain model parameter as a function of the magnetic rigidity alone. This function can be approximated by a suitable polynome. Now the manual input is replaced with a calculated value using this polynome and the particle energy. Figure 2 shows as an example the fine correction of the deflection angle of the electrostatic septum. The bullets are the measured values and the solid line is the plot of the polynome fitted to these values.

Though the set values can be produced with good accuracy with these tools, there is still the problem of repro-

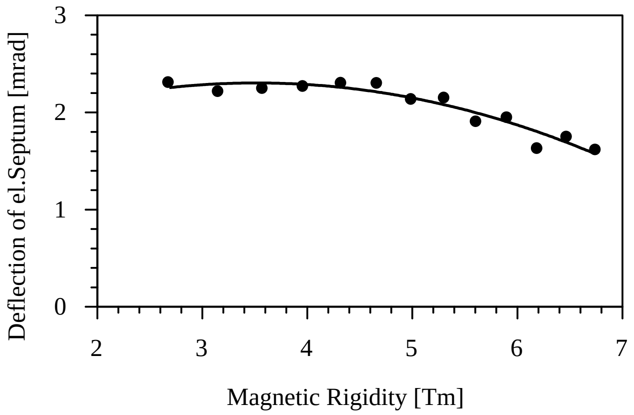

Figure 2: Deflection angle of the electrostatic septum found experimentally for 13 energy steps and the fitted polynome

ducibility left, in particular the dependence on the magnetic history. To solve this we add a special segment to the normal acceleration cycle. Its purpose is to ramp all SIS magnets from their extraction level, which is strongly energy dependent, to a fixed field level corresponding to the maximum used energy. This procedure is time consuming but ensures that each machine cycle has the same minimum and maximum fields inside. Figure 3 shows as an exmaple the main dipole currents for the minimum and maximum energies used for therapy.

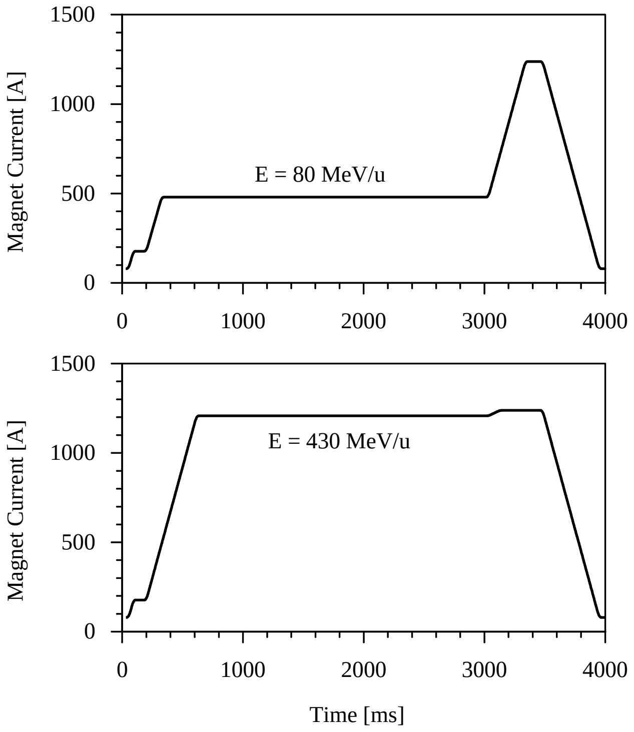

Figure 3: Current of SIS dipole with fixed maximum value for all energies

For the magnet of the beam tranport system between SIS and the target the problem is slightly different. For medical reasons the requested beam energies are always in decending order. Since the magnet are not ramped it is only necessary the start the sequence with the maximum and end it with the minimum energy. So the magnet cycle can also be made reproducible for the beam line magnets.

In addition there is a need to change the beam diameter on the target from 4 to 10 millimeters independently of the beam energy. This problem can also be solved using polynomes for the last two quadrupoles, one polynome for each beam diameter. The coefficients are precalculated and corrected using the measured beam profiles.

During the extraction process the slope of the extracted beam at the electrostatic septum shows a small variation. It causes a migration of several millimeters during extraction which cannot be tolerated. So a dynamic steering system is needed to keep the beam position stable in phase space. The two required elements are a closed orbit bump in the ring and the magnetic extraction septum. With suitable ramping of these two parallel to the extraction quadrupole a constant beam position at the target can be achieved.

To obtain a constant spill we shall add a spill feed back system [2] to correct the currents of the extraction quadrupole. So we do not use any fine tuning of spill shape as shown in figure 1.

All data of all devices are calculated in one program run and stored in EPROMs in the devices. This is to have the therapy data completely independent from any computer system when real cancer treatment is under way. For machine experiments and improvment of the data generation the data of single devices can be calculated and sent to the EPROMs separately. The generation of therapy data will always be made in one run for all devices to be absolutely sure that all data fit together.

5 CONCLUSION

Present status: The settings of all devices of SIS and the beam lines can be calculated in advance without manual interaction for all required energy steps. The beam can be delivered with stable position and shape reproducibly and reliably on the therapy target. Small corrections of the beam size are under way and will be finished during the next few weeks.

Time sharing with other experiments may be possible with some restrictions. It will be permitted as far as no disturbance of therapy operation occurs.

Some special developments for therapy, e.g. the transverse spill stabilisation, will be made available also for normal operation in order to improve the performance of SIS.

6 REFERENCES

[1] H. Eickhoff et al., Accelerator Aspects of the Cancer Therapy at GSI Darmstadt (this conference)

[2] U. Blell, A Feedback System to Improve the Spill Structure (this conference)