COMPUTER CONTROLLED BEAM ALIGNMENT FOR THE GSI THERAPY PROJECT

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Abstract

The GSI therapy project demands exact beam positions in front of the irradiation place for a large number of different beam energies. Beam correction for all required energies are rapidly performed by means of the ion optics program MIRKO, that automatically determines adjustments in steerer settings to correct a mismatch between actual and defined optimal beam positions. Besides the application for the therapy project this program is also used to optimize the beam properities (position and focusing) both in experimental beam lines and ring structures.

1 INTRODUCTION

The GSI heavy ion cancer therpy facility started first patients treatment at the end of 1997[1]. One of the most important features is that none of the various device settings, e.g. currents of magnet power supplies, can be changed during the treatment time for safety reasons. This means in particular that for about 250 different energies the beam has to hit the target using the precalculated set values only.

Most of these values can be obtained by theoretical calculations. If necessary they may be modified experimentally as described earlier[2]. However, there are settings that can neither be calculated exacty an advance nor found by trial and error in a sufficiently easy way.

In these cases smart tools are required which derive corrected set values from measured deviations of beam parameters. Here a method will be presented which was developped to control the beam position in the beam line after the synchrotron and at the irradiation point.

2 THE CORRECTION OF BEAM POSITION

The transverse position of a particle beam is not only determined by the optical elements foreseen for deflecting purposes, i.e. dipole magnets and beam steerers. In practice some additional effects are important, which cannot be calculated or measured precisely enough to determine the beam behaviour in advance. These are the exact beam position and angle at the entrance of the beam line, field errors in dipoles, misalignment of quadrupoles, and even stray fields from other magnets close to the beam line. For completeness also errors in position measurement devices should be included in this list.

On the other hand all these effects are normally linear in good approximation, and therefore, one has a good chance to apply corrections in a relatively simple way. Usually the settings of a pair of steerers per plane have to be determined.

The result of a position measurement of the beam does obviously not include any information about the slope at this point. But this is necessary to describe the beam behaviour completely. Therefore, a second position measurement at a different point is required.

If these two are located on a pure drift space the slope can easily be calculated. In many cases however, there are optical elements between them. Due to the linearity of these elements the knowledge of their transfer matrices is sufficient to calculate the beam position along the beam line. So in practice there will be no restriction due to such optical elements.

Now it is possible to transform the transverse beam position back to the start of the beam line. It would even give the right result if all parameters relevant to this calculation were known. But as mentioned above this is not true in general, and therefore, the result of the backward transformation is not correct.

Fortunately the task is not to calculate the absolute beam positions anywhere in the beam line. Instead of that steerer settings have to be found to shift the beam by a certain amount at the position of the measuring devices. For these steerers the effect on the beam does not depend on the beam position in the steerer. Therefore, any uncertainty in the knowledge of beam position will not affect the calculation of the steerer settings, which reduces then to simple linear mathematics.

So finally we have a model of the beam behaviour that does not describe the beam in detail exacty everywhere, but forms a tool to obtain dedicated corrections for measured deviations of the beam at certain points.

Some remarks: since the observed position error enters in the calculation for its correction, the whole procedure may be repeated if necessary until the result is satisfactory. Usually the beam oscillation due to misalignments of quadrupoles is much smaller than that due to an off-axis beam entering the beam line. Therefore, the result of the tracing back is rather close to reality. A typical back transformation with subsequent correction is shown in Fig. 1.

3 APPLICATION TO THE THERAPY BEAM LINE

The accuracy requirements for the beam line elements with respect to beam position are rather high. One has to keep in mind that the beam has to be on the target within a few millimeters. For a beam emittance of 5 $\pi\ mm \times mrad$ and

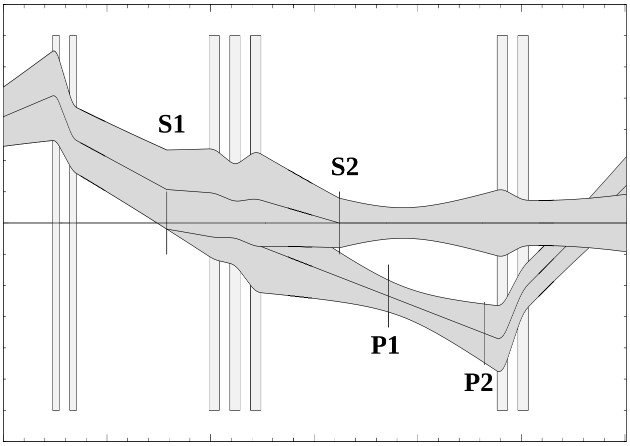

Figure 1: Principle of position correction using MIRKO: position measured at P1 and P2, back transformation to the start, and correction with steerers S1 and S2

a total beam width of about 30 mm the internal divergence is only ± 0.3 $mrad$. Since the magnetic rigidity of the particles may be as low as 15 percent of the maximum design value it is obvious that unavoidable small errors may demand correction.

Our experience showed that the sum of all position perturbing effects is quite well constant from pulse to pulse, but may slowly change over days or weeks. Therefore, it seemed to be necessary to have a tool which establishes a permanent correction, not a feed back system, using steerer magnets but which is easily and fast to handle.

One way would have been to simply include the fittig algorithms described in the previous section into the program that generates all the therapy data. This has however the disadvantage that the ion optical properties of the beam line only enter through parameters that were calculated in advance and put in a file.

So it was decided to use the ion optical program MIRKO[3] directly to do the necessary correction calculations. Since with this program all beam lines and circular accelerators at GSI were designed, it is capable of dealing with all relevant effects, such as space charge, nonlinearities, and misalignments. Its data base contains all geometrical data of the beam line between synchrotron and the therapy target.

In order to decouple the various sources of position errors it is advisable to do the correction of the whole beam line in a number of segments seperately. The first segment ranges from the SIS to the first 7.5 degrees bending magnet. Here mainly the slight variation of the extraction conditions from the ring is compensated. The result will be a well aligned beam entering the first dipole.

Near this point two sources of errors are located: the sensitve dipol itself horizontally, and vertically a systematic misalignment between the two parts of the beam lines due to concrete loads on the floors. In this special case we normally do not correct position and slope but only the position in the very last part of the beam line using the dipole and a vertical steerer at the beginning.

The final correction takes place using the position monitors after last quadrupole doublet. Two pairs of beam steerers upstream are used as correctors. In this particular case the positions on the monitors are not the most important thing to focus on. Because this last doublet is varied to achieve different beam sizes at the irradiation point it is necessary to keep the beam on the magnetic axis here rather than elsewhere in the beam line. The reason that both conditions do not coincide might be an insufficient alignment of quadrupoles and/or position monitors. It should be emphasized here that these kinds of imperfections are the reason to use a smart correction tool.

Each of these correction processes mentioned above consists of the following steps:

- The first of two position monitors (profile grids in our system) is activated.
- A sequence of about twenty machine cycles with different energies covering the whole energy range is executed, and the beam positions are measured and recorded automatically.
- The positions are read by the data generation program and desired horizontal and vertical reference positions may be added manually.
- These three steps are repeated for the second position monitor if required.

Now all the magnet settings and the measured positions for these settings are known. In principle one could now solve the problem by manually entering the appropriate MIRKO commands for setting magnets, perform fittings etc. To facilitate this procedure, a (lengthy) macro file for MIRKO is automatically generated which tells the program that for each energy step the following things have to be done:

- Perform the backward transformation of the measured positions to obtain the beam before the first steerer
- Calculate the steerer settings to fit the desired reference positions
- Write these new settings to a file

While this macro is executed (it takes less than five seconds) the data generation program waits, and on completion it reads the data file with all new settings calculated by MIRKO. It was expected and also observed in practice that the dependence of these settings on energy is very smooth. Therefore, it is not necessary to perform measurements and correction for each of the about 250 energy steps, a number of about twenty is good enough to fit a polynome of 3rd order which can then be used to interpolate the settings for all energies.

These polynomes are calculated and the coefficients appended to the general parameter file for the data generation program from which then the EPROMs are programmed. The correcting procedure for one segment of the beam line takes less than fifteen minutes which is quite acceptable.

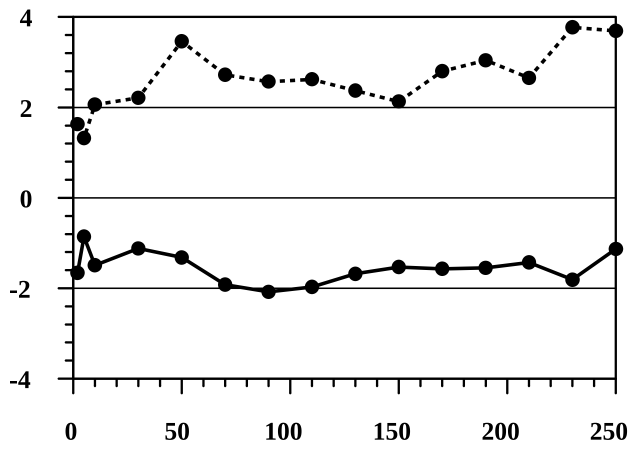

Figure 2: Measured horizontal beam positions [mm] at monitors P1 (solid) and P2 (dotted) as a function of energy step

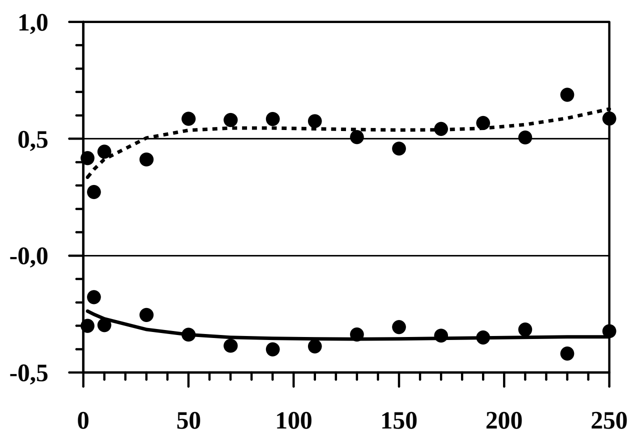

Figure 3: Calculated steerer settings [$mrad$] (dots) and fitted polynomes for S1 (solid line) and S2 (dotted line)

In Fig. 2 the uncorrected beam position at two grids is shown and Fig. 3 shows the result of the calculation including the fitted polynomes.

There are two special features that should be mentioned: if the beam position after correction is independent of energy but has a constant offset, then a new series of measurements is not required. The calculation procedure may simply be repeated with modified reference values for the positions.

In some cases a persistent ripple on the position as a function of energy was observed which was reproducible over a longer time, but could not be fitted with a polynome of reasonably low order. To provide a sulution even of those problems for each of the 250 energy steps the difference between the individually calculated values and the fitted polynomes may be stored separately and added if needed. However this procedure is time comsuming and should only be used if problems at certain energy steps occur that cannot be solved by other means.

4 FUTURE DEVELOPMENTS

At the moment for the position a couple of formal things have to be done: activating of profile grids, choosing and starting the machine cycle sequence, starting and stopping programs in the correct order, and programming the EPROMs. This can in principle also be performed by a coordinating program, since normally between the steps no decisions other then to continue or to repeat a step have to be taken.

An application to standard beam line operation is in its test phase and still mainly used by experts. For this purpose MIRKO is directly connected to the beam line magnets and later will be to the profile grids. The advantage is that any change in focusing or other optical parameters done by hand or program will immediately be included in the position and steerer calculations.

The position monitors do not have to be profile grids or other computer readable devices. Since the values can be entered manually it is possible to use screens or even halo counters to estimate the beam position and use it for the calculation. A calibration of the measuring device is not necessary, because the reaction of the beam on the new settings is calibrated due to the knowledge of magnetic fields and the magnetic rigidity of the beam.

For beam adjustment in target areas it is possible to move the beam parallel up and down or left and right in a controlled way. One can also keep the beam fixed say on an entrance aperture and move it only on a target at a distance behind. All these procedures will be improved in the near future that the operating staff can use them easily.

5 CONCLUSION

For the GSI therapy project most set values for the heavy ion synchrotron SIS and the beam line to the irradiation point can be calculated in advance. Due to unavoidable errors and high accuracy requirements correction of set values for the beam postioning with a smart tool is necessary.

To do this most efficiently the beam dynamics program MIRKO used for the design of ring and beam line is also employed to calculate corrected magnet settings based on measured deviations of beam positions from their required values. The procedure is straight forward and needs little manual work.

For the therapy operation this is absolutely necessary, but also normal target operation of SIS will benfit from this technique.

6 REFERENCES

[1] H. Eickhoff et al., Accelerator Control for the GSI Cancer Therapy Project (this conference)

[2] B. Franczak, Data Generation for SIS and Beam Lines for the GSI Therapy Project, EPAC'96, Sitges, June 1996.

[3] B. Franczak, MIRKO - An Interactive Program for Beam Lines and Synchrotrons, Computing in Accelerator Design and Operation, Proceedings, Berlin 1983.