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ALIGNMENT OF A MAGNETIC LATTICE BASED ON PARTICLE TRACKING

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Abstract

In calculations based on particle tracking in 3D magnetic field maps alignment of the components of a magnetic lattice is essential to obtain desired properties of beam optics. In this contribution we propose a method to control and correct misalignments during the process of the beam optics design. These misalignments would result from overlapping fringe fields of different field maps. The 3D field maps are obtained from the software for electromagnetic calculations OPERA. The full 3D map is saved in the tracking coordinate system and a ROOT (An Object Oriented Data Analysis Framework) ntuple is then created for analysis. The trajectory of the reference particle is calculated by means of OPAL - open source code developed at the Paul Scherrer Institute (PSI). The transverse magnetic field profiles allow possible misalignments to be precisely determined and the corresponding corrections to be calculated. Moreover, the multipole content in discrete locations along the lattice can be controlled by performing a polynomial fit, which calculates the magnetic field harmonics with respect to the reference track. This method was used at PSI for a design of a model of the magnetic lattice for a superconducting gantry for proton therapy with a large momentum acceptance.

INTRODUCTION

Particle tracking in magnetic field maps is applied in a number of problems in accelerator physics. It is especially useful to verify the desired properties of previously designed beam optics and to apply necessary corrections. One of the challenges in the beam optics design is a proper alignment of of the components of a magnetic lattice. Even a small uncontrolled misalignment can significantly affect the optical properties of the lattice such as dispersion. At the Paul Scherrer Institute (PSI) we designed a superconducting gantry for proton therapy with a large momentum acceptance, as reported in [1]. Our specific beam optics was extremely sensitive to misalignments and to reach the goal of a very large momentum acceptance we performed precise calculations based on particle tracking in 3D magnetic field maps. The magnetic field maps were overlapping so that the magnets were locally affected by fringe fields of their neighbouring magnets and consequently the magnetic "center" was shifted in an individual magnet. In order to check the thus introduced alignment errors by the tracking and to apply necessary corrections, a simple method was developed. This method, on which we report in this paper, can be applied to any problem involving particle tracking in a beam optics system described by different magnetic field maps.

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PARTICLE TRACKING IN A 3D FIELD MAP

There is a variety of software which can be used to track particles in a magnetic field map. In our studies we used OPAL [2] - an open source code developed at PSI which allows particles to be tracked by time integration in field maps. The 3D field maps were generated in the software for electromagnetic calculations OPERA. Due to the overlapping field maps the magnets cannot be aligned based on their individual maps and therefore tracking is needed. In order to verify the alignment of the magnets particle tracks have been recorded by "probes" in OPAL. We introduced probes perpendicular to the reference track at some essential locations of the lattice (Fig. 1). In the presented example, the

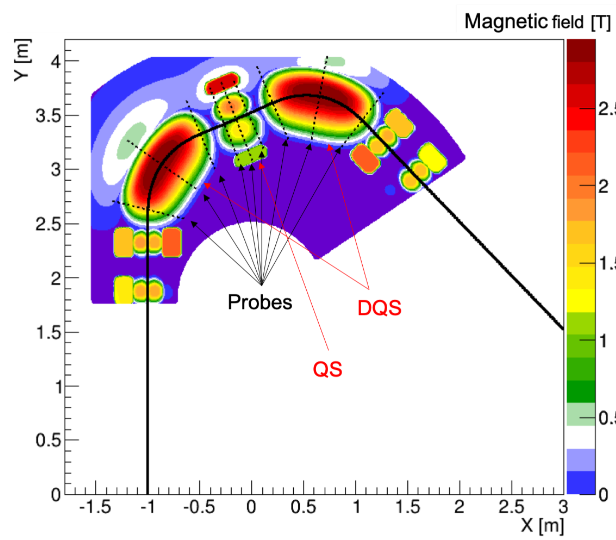

Figure 1: OPAL tracking of the reference particle in a 3D magnetic field map.

alignment of the three superconducting (SC) combined function magnets - two Dipole-Quadrupole-Sextupole (DQS) magnets and one Quadrupole-Sextupole (QS) magnet - is considered. When the reference particle hits the probe, the global coordinates of this point are dumped to an output file. At the end of the tracking the field map is dumped in the same coordinates to another output file. From the precise location and angle of each probe, the transverse magnetic field profile along each probe is well known. The post-processing based on the mentioned output files is described in the next section.

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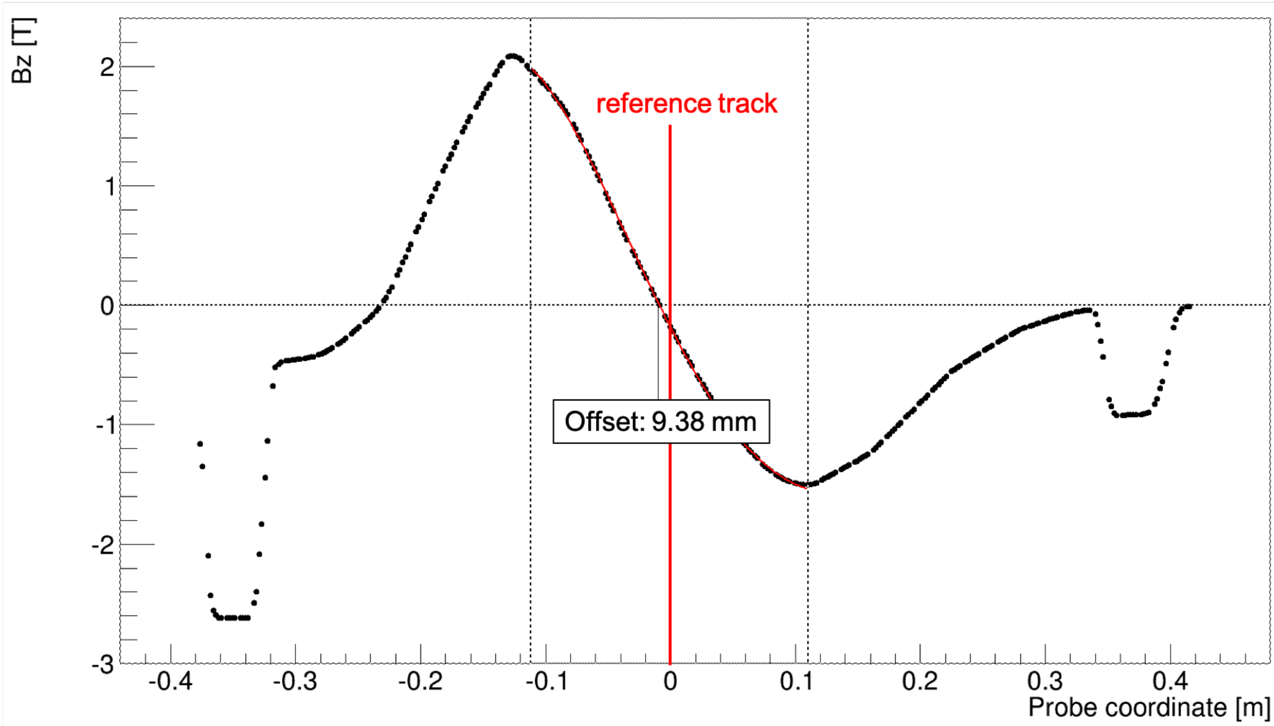

Figure 2: Transverse magnetic field profile of a SC Quadrupole-Sextupole combined function magnet and the location of the reference track.

ANALYSIS OF THE TRANSVERSE MAGNETIC FIELD PROFILES

The whole post-processing of the acquired data and their analysis is performed in ROOT (An Object Oriented Data Analysis Framework) [3]. From the OPAL output file containing the field map an "ntuple" is created. To the same ntuple, new variables - local probe coordinates obtained by the rotation of the axes - are added. Based on such an ntuple, the desired transverse magnetic field profile can be easily plotted by constraining the region of interest to a line corresponding to the selected probe. The output file with the coordinates of the point at which the reference track crossed the probe is already stored in the ROOT ntuple format. After applying the same rotation of the axes as for the field profiles, a line corresponding to the track location can be plotted together with the magnetic profile, as shown in Fig. 2. This figure corresponds to the analysis of a SC Quadrupole-Sextupole combined function magnet (see Fig. 1) and shows the magnetic field profile in the middle of the magnet. The probe coordinate in the X-axis is scaled so that the reference track is always located at the point zero. A polynomial of a sufficient order is fitted to the field profile points for two reasons. First of all, this allows the offset between the reference track and the magnetic field axis to be precisely determined. The resulting offset can be applied in the next iteration of the lattice design performed in OPERA.

The second goal is to control the multipole content seen by the reference track. The corresponding correction factors are easily calculated and used to tune the essential parameters in the next iteration of the magnet design in OPERA. The same method was applied to check the alignment of a SC Dipole-Quadrupole-Sextupole magnet (see Fig. 1), as presented in Fig. 3 showing the magnetic field profile in the middle of the magnet. By fitting the previously mentioned polynomial, the value of the magnetic field at the location of the reference track can be precisely determined. This value can be compared to the desired strength of the dipole component and the corresponding offset can be calculated. Similarly to the previous example, the field harmonics of higher orders, as seen by the reference particle, can also be controlled.

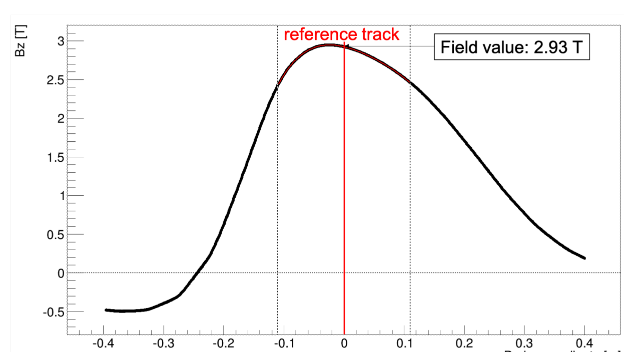

Figure 3: Transverse magnetic field profile of a SC Dipole-Quadrupole-Sextupole combined function magnet and the location of the reference track.

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The method can be summarized in a block diagram, as depicted in Fig. 4.

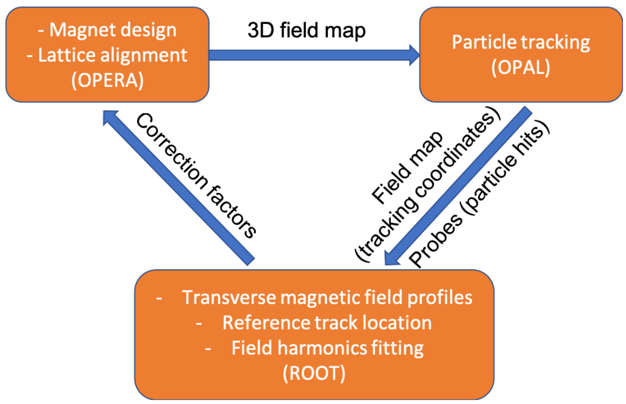

Figure 4: Block diagram of the magnetic lattice alignment based on particle tracking.

CONCLUSION

In this paper we presented a method to control the lattice alignment during the process of the beam optics design. Based on the output of particle tracking in 3D magnetic field maps, possible misalignments can be precisely determined and the corresponding corrections can be calculated to be applied in the next design iteration. At the same time, the magnetic field harmonics are extracted with respect to the reference track. If the values found do not correspond to the desired multipole strengths, the necessary correction factors can be immediately applied to the magnet model for the next iteration of the design. The use of this method can significantly speed up the design process. It has already been applied at PSI to design a superconducting gantry for proton therapy with a large momentum acceptance.

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