BEAM BASED ALIGNMENT OF QUADRUPOLE TRIPLETS BY USE OF MATLAB BASED MODELING

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Abstract

A new beam based method is introduced to measure the transversal shifts of quadrupole magnets in relation to each other within triplet structures. The displacements of the quadrupole magnets can be calculated by quadrupole strength variation in combination with a simulation of the orbit distortions utilizing a MATLAB based model for beam optics. A local smoothing of the quadrupole alignment can be achieved with accuracy better than those of geodetic surveys. Results are presented and compared with data from geodetic surveys.

INTRODUCTION

The storage ring Delta is part of the synchrotron radiation source DELTA located at the technical university of Dortmund. Based on a recent geodetic survey of the entire storage ring it is known that the quadrupole magnets installed in Delta are aligned only with a radial accuracy better than 4.5 mm in reference to the design values. This is because the vacuum chamber rests on the lower pole shoes of the quadrupole magnets. Thermal expansion of the vacuum chamber by synchrotron radiation is shifting the magnets on the girders [1]. For this reasons the orbit has to be corrected by use of dipole correctors.

Within the scope of a current project to realign the quadrupole magnets and therewith reducing the integrated corrector strength primarily geodetic measuring is used. The following problems are occurring by applying this method:

- The measuring is limited by the targeted precision and the inherent refraction error of this technique.
- The centers of the magnetic fields of the quadrupole magnets installed in Delta were not calibrated in reference to the mechanical centers of the magnet iron.
- The alignment is not only based on the mechanical configuration of the magnets but is done with aluminum markers which have to be attached at the magnets by adjusting them to an installation edge.
- The geodetic measurements are normally done in shutdowns when the storage ring is not under the thermal conditions predominating during operation.

With the herein introduced beam based method the deviation of the true magnetic centers of the quadrupole magnets in respect to each other can be measured within triplet structures. The accuracy depends primarily on the calibration error of the beam position monitors (BPMs) and the model for the focusing of the storage ring optics. A recursive appliance of this method allows the beam based realignment of the quadrupole triplets by alternating measurement and adjustment of magnet positions.

MEASUREMENT METHOD

At the beginning of each measurement the orbit has to be placed in the magnetic centers of the outer two quadrupole magnets of a triplet structure. At Delta these magnets are equipped with BPMs. To calibrate the BPMs in reference to the magnetic centers of the quadrupole magnets a beam based calibration (BBC) [2] technique is used. Dipole correctors mounted on the quadrupole magnet in the center of the triplet have to be switched off. The method can only be applied to the plane in which the outer triplet magnets are defocusing and the center one is focusing. Otherwise it is not possible to place the beam in both centers of the outer magnets if the magnet in the center has a non-zero deviation, as can be seen from geometric considerations. In Delta the premises are fulfilled for the horizontal plane, which in fact has the larger alignment errors. In the following a negative strength value k corresponds to a focusing magnet.

The kick angle θ produced by a beam passing a quadrupole magnet with a horizontal position x_{cq} in respect to the center of the quadrupole field k follows from linear optics to

$$\theta = x_{cq} \cdot k \cdot l_{eff}. \tag{1}$$

The strength k of the quadrupole magnet in the center of the triplet is changed by a small value Δk. This can be achieved by separately connecting an additional power supply with each quadrupole magnet via a relay based switching system which has been installed recently [3]. In consequence of the altered quadrupole strength the kick angle θ of the quadrupole magnet changes by $\Delta\theta$. This results in a new closed orbit. At the position of the kick the deviation x_{cq} of the beam from the center of the quadrupole field varies by Δx_{cq} and equation 1 turns to

$$\theta + \Delta\theta = (x_{cq} + \Delta x_{cq})\,(k + \Delta k) \cdot l_{eff}. \tag{2}$$

This equation can be divided into two terms for the kick θ and the kick change $\Delta\theta$:

$$\theta = (x_{cq} + \Delta x_{cq}) \cdot k \cdot l_{eff} \tag{3}$$

and

$$\Delta\theta = (x_{cq} + \Delta x_{cq}) \cdot \Delta k \cdot l_{eff}. \tag{4}$$

The orbit deviation $\vec{\Delta x}$ at all BPMs is recorded. In a simulation of the storage ring optics a virtual dipole corrector

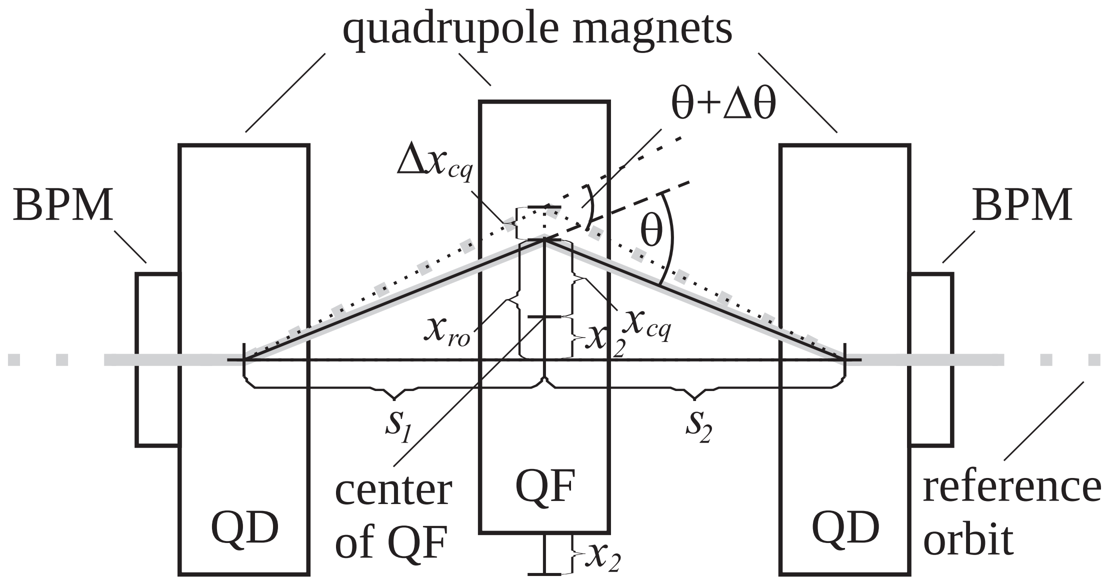

Figure 1: Principle measurement setup for the magnet shift in the horizontal plane.

is placed in the center of the varied quadrupole magnet. By varying the kick angle $\Delta\theta$ of this corrector the quadrupole strength variation Δk is simulated and the measured orbit deviation $\vec{\Delta x}$ is reproduced. Therefor the difference $\left|\vec{\Delta x} - \vec{\Delta y}\right|$ between the measured orbit deviation $\vec{\Delta x}$ and the simulated orbit deviation $\vec{\Delta y}$ is numerical minimized by use of a quadratic minimization algorithm for multivariate functions. For simulating the closed orbit of the storage ring the Accelerator Toolbox (AT) [4] for MATLAB [5] is utilized in the current version included in the Matlab Middle Layer (MML) [6] software for accelerator control. The design model of the storage ring includes the longitudinal positions of the recent geodetic survey.

After convergence the kick angle $\Delta\theta$ and the resulting orbit difference Δx_{cq} at the position of the corrector are obtained. By that the absolute beam position x_{cq} in reference to the center of the quadrupole magnet can be achieved from equation 4:

$$x_{cq} = \frac{\Delta\theta}{\Delta k \cdot l_{eff}} - \Delta x_{cq}. \tag{5}$$

Inserting this into the undisturbed equation 1 the absolute kick angle θ can be calculated which is generated by the whole quadrupole field k acting on the beam. By means of geometric considerations the position x_{ro} of the beam in reference to the connecting line between the outer quadrupole magnets can be calculated from θ and the drift sections s_1 and s_2 as seen in figure 1:

$$x_{ro} = \frac{s_1 + s_2}{2\tan\theta} - \operatorname{sgn}\theta \sqrt{\frac{(s_1 + s_2)^2}{4\tan^2\theta} + s_1 \cdot s_2}. \tag{6}$$

At last the position x_2 of the center of the quadrupole field in reference to the connecting line can be calculated as difference of x_{ro} and x_{cq}:

$$x_2 = x_{ro} - x_{cq}. \tag{7}$$

A positive or negative value of x_2 represents a dislocation to the outside or to the inside, respectively.

Sources of error

The absolute precision of the measured magnet displacements is limited by model errors. Nevertheless, by using this method in an iterative way, that is recursive shifting of the magnets and measuring their position, the absolute precision is not critical. In this case only the accuracy of the BPMs is relevant, which is limited by the resolution of the BPMs, which is $\pm$ 5 μm, and the resolution of the BBC, which is $\leq \pm$ 10 μm. This errors induced by orbit noise are reflected in the statistical error of the measurements.

Possible improvements

As seen in figure 1 the drift sections s_1 and s_2 are defined between the longitudinal centers of the quadrupole magnets. In consequence there is a slight inaccuracy in the geometric calculation because in Delta the BPMs are located in front or behind the quadrupole magnets. Furthermore the magnets are handled in thin lens approximation. By regarding the effective lengths the horizontal progression of the beam inside the quadrupole fields has to be considered, which would yield in another small correction.

RESULTS

With this new method the displacements of the center magnets were measured in two quadrupole triplets. Then one magnet was adjusted in one or more steps to align the triplet. After each step the measurement was repeated. Additionally the positions were surveyed geodetically and the adjustments were observed with mechanical position sensors.

In one case the first magnet of the triplet was dislocated in reference to the entire storage ring. Therefore this one was shifted in place. By means of geometric considerations (see figure 2) the position x_1 of this quadrupole magnet in reference to the connecting line between the second and third one can be calculated from x_2:

$$x_1 = -x_2 \cdot \frac{s_1 + s_2}{s_2}. \tag{8}$$

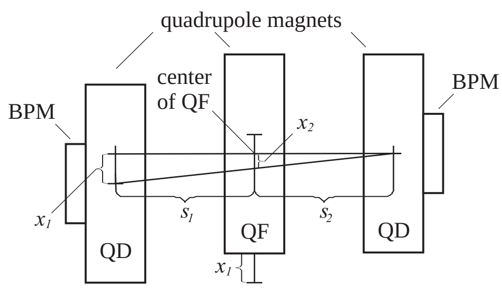

Figure 2: Layout for displacement of first magnet.

The measured values of the beam based method are in agreement with those from geodetic survey and mechanical position sensors but dominated by model deviations. By now an accuracy of ± 50 μm could be achieved.

CONCLUSION

It could be demonstrated that the introduced method provides results in accordance with geodetic measurements. In a next step it will be tried to extend the method to measure the displacements of two or more internal aligned quadrupole triplets beyond the bending magnets. A further goal is to adapt the method to the other plane, which will require more modeling.

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