BEAM BASED ALIGNMENT STRATEGY FOR THE GROUP CONTROLLED MAGNETS SYSTEM

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Abstract

The beam based alignment of the beam position monitor (BPM) becomes an important tool to reduce the closed orbit distortion (COD) in the recent accelerator. Usually, it requires the independent control of the quadrupole field. Changing the current of a quadrupole magnet, one would find the unperturbed position. However, the J-PARC Rapid-Cycling Synchrotron (RCS) has seven quadrupole families and only group of each family can be controlled simultaneously. A similar alignment procedure is applicable for the coupled-controlled magnet system, but it becomes very complicated. For the simplest case, three magnets grouped together, four different beam orbits have to be measured at three different BPM locations. The method and some simulation results for J-PARC/RCS case will be presented in this report.

INTRODUCTION

The RCS of the J-PARC (Japan Proton Accelerator Research Complex) provides 1MW proton beam with 25Hz repetition to the target for Spallation Neutron Source. It is also used as an injector of 50GeV Main Ring synchrotron. The circumference of RCS is 348m. The proton is injected at 400MeV (or 181MeV) into two RF buckets and fast extracted at 3GeV [1].

The RCS has 60 quadrupole magnets (QM), and 54 BPMs with every half cell. It has 52 steering dipole magnets (26 each for horizontal and vertical) in order to perform COD correction. There are seven quadrupole families; each family consists of three, six, nine or twelve magnets. There is neither separate power supplies nor auxiliary coil windings on each individual magnet. The quadrupole field can be controlled with each family unit.

It will review the linear orbit theory and discuss a simple case, the individually controllable magnet system at first. Then, it extends to more complicated case and shows some simulation studies. It will also mention about further issues to be accomplished in the future.

FORMULATION FOR INDEPENDENT CONTROLLABLE QUADRUPOLE

With a kick θ at position k, a transverse position x_n of the position $s=s_n$ in a ring is expressed as following.

$$x_n = \sum_k a_{nk}\theta_k \tag{1}$$

where a_{nk} is a matrix,

$$a_{nk} = \frac{\sqrt{\beta_n\beta_k}}{2\sin\pi\nu}\cos\left(\pi\nu - \left|\phi_n - \phi_k\right|\right) \tag{2}$$

where ν is tune, β_n is the beta-function, and ϕ_n is the phase advance at position n. If the kick is due to miss alignment of the k-th quadrupole magnet (QM) Δx_k, it is written as $\theta = gl\Delta x / B_0\rho = Kl\Delta x$. This part of x_n is expressed explicitly,

$$x_n = \sum_k a_{nk}K_k l_k \Delta x_k + \sum_k a_{np}\theta_p \tag{3}$$

where g is the field gradient, $B_0\rho$ is the magnetic rigidity, l is the length of QM, K is $K=g/B_0\rho$. By changing the strength of the field gradient K_n, the orbit change at the same place δx_n becomes as follow [2].

$$\begin{aligned}\delta x_n &= \frac{\partial x_n}{\partial K_n}\delta K_n \\ &= -a_{nn}(x_n - \Delta x_n)\delta K_n l_n\end{aligned} \tag{4}$$

The orbit change is also affected by the distant m-th QM through coefficient a_{nm}.

$$\delta x_n = -a_{nm}(x_m - \Delta x_m)\delta K_m l_m \tag{5}$$

In fact, this formula is used at KEKB, in order to make many displacement measurements by any BPM in the ring [2, 3].

For various initial orbits (i,j), for example $x_1^{(i)}$, $x_2^{(i)}$, .., $x_n^{(i)}$, one can define corresponding equations. At least two equations give a solution of the bellow simultaneous equations.

$$\begin{pmatrix}\delta x_n^{(i)} \\ \delta x_n^{(j)}\end{pmatrix} = \begin{pmatrix} -x_m^{(i)} & 1 \\ -x_m^{(j)} & 1\end{pmatrix}\begin{pmatrix}1 \\ \Delta x_m\end{pmatrix} a_{nm}\delta K_m l_m \tag{6}$$

One can obtain miss alignment of m-th QM Δx_m as the solution.

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FORMULATION FOR COUPLED QUADRUPOLE SYSTEM

In case of a coupled controlled QM system, one can apply a similar method discussed above. The simplest system of the J-PARC RCS is QFM family, which consists of three magnets. In the following discussion, it will take this system as an example. Supposed that these three magnets are located at position *1*, *2* and *3*. Orbit difference δx_n by varying field strength δK is,

$$\begin{aligned}\delta x_n &= [-a_{n1}(x_1-\Delta x_1)-a_{n2}(x_2-\Delta x_2)\\ &\quad -a_{n3}(x_3-\Delta x_3)]\delta Kl\\ &= -[a_{n1}x_1+a_{n2}x_2+a_{n3}x_3+w_n]\delta Kl\end{aligned} \quad (7)$$

where w_n is,

$$w_n = a_{n1}\Delta x_1 + a_{n2}\Delta x_2 + a_{n3}\Delta x_3 \quad (8)$$

Initially, one has to have 4 different orbits (i,j,k,l). The positions x_n at every QFM are measured before and after K modification, and COD difference δx_n are calculated. One obtains THREE simultaneous equations (n=1,2,3), which have 4-unknown, a_{n1}, a_{n2}, a_{n3}, and w_n.

$$\begin{pmatrix}\delta x_n^{(i)}\\ \delta x_n^{(j)}\\ \delta x_n^{(k)}\\ \delta x_n^{(l)}\end{pmatrix} = -\begin{pmatrix} x_1^{(i)} & x_2^{(i)} & x_3^{(i)} & 1\\ x_1^{(j)} & x_2^{(j)} & x_3^{(j)} & 1\\ x_1^{(k)} & x_2^{(k)} & x_3^{(k)} & 1\\ x_1^{(l)} & x_2^{(l)} & x_3^{(l)} & 1\end{pmatrix}\begin{pmatrix}a_{n1}\\ a_{n2}\\ a_{n3}\\ w_n\end{pmatrix}\delta Kl \quad (9)$$

Obtaining 3 sets of 4 solutions, namely 12 variables, one makes another simultaneous equation.

$$\begin{pmatrix}w_1\\ w_2\\ w_3\end{pmatrix} = \begin{pmatrix}a_{11} & a_{12} & a_{13}\\ a_{21} & a_{22} & a_{23}\\ a_{31} & a_{32} & a_{33}\end{pmatrix}\begin{pmatrix}\Delta x_1\\ \Delta x_2\\ \Delta x_3\end{pmatrix} \quad (10)$$

Then, finally, one can extract three unknowns Δx_1, Δx_2 , Δx_3, which are offsets of all QFM magnets.

SIMULATION

In order to confirm above algorism, it is performed simulations by using SAD (Strategic Accelerator Design) [4]. Firstly, it is checked with individual controllable case. Then, it proceeds to check with grouped controlled system, namely QFM family.

Before going to further detail, it should be pointed out that relation among QM miss alignment Δx_n, BPM shift ΔX_n, ideal and measured orbits x_n and X_n, respectively. In fact, there is no way to know the true value of x_n or Δx_n. In the simulation one would usedx_n and Δx_n, however in reality, only measured value X_n and BPM displacement against QM can be determined [2]. Thus, we use (x_n- Δx_n) in the simulation, but only (X_n- ΔX_n) should be used in the actual experiment.

Table 1: Variables in the simulation and measurable

X_n	BPM measured value
x_n	true value; orbit
ΔX_n	BPM miss alignment with respect to QM
Δx_n	QM miss alignment

When the program is developed, the GUI tool (see Fig.1) is constructed together to examine various conditions, monitoring the orbits, or other twiss parameters modification during the virtual measuring process. It is also useful to debug the program and gives hints for the real control GUI.

In typical case, the field gradient of QFM is varying with 5%, and it uses three steering magnets to having four different orbits. The reason is that just one steering would give only linear combination of the other equations.

Figure 2 shows a result of the simulation. Randomised miss alignment of QFM (σ=2.5mm with 2σ cut) are estimated for 100 cases. It indicates that the discussed algorism does work in principle. Figure 3 shows that the difference between initially given shift of QFM and estimated of that.

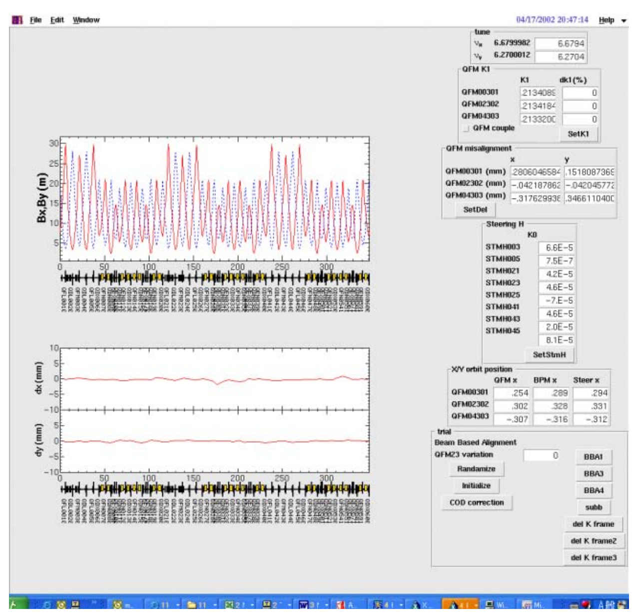

Figure 1: A look of GUI simulator composed by SAD.

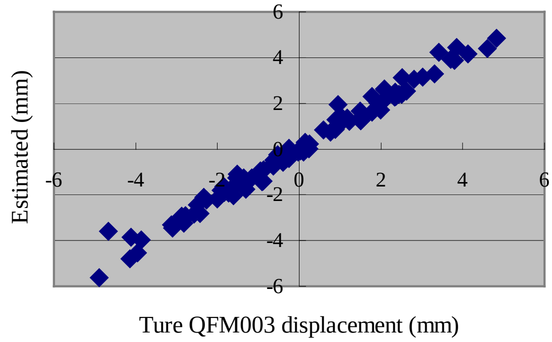

Figure 2: Initial displacement and estimation of the QFM.

A distance between the QFM centre and BPM along the beam axis is about one meter. Hatched area in Fig.3 is given by orbit data at QFM centre. Non-hatched area is used orbit at the location of BPM. If the initial COD is large, the transverse orbit at the QFM and BPM might be significantly shifted and it may introduce an error source.

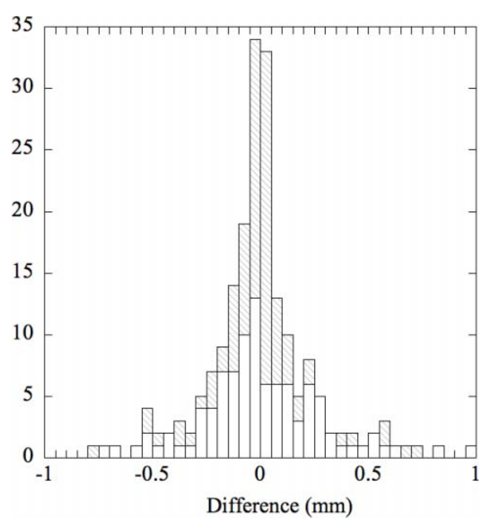

Figure 3: Difference between true and estimated QFM shift. Hatched and non-hatched area explained in the text.

DISCUSSION

The BPM system aims to be ±0.2mm position accuracy, because a beam optics simulation implies that small COD (less than 1mm) requires that accuracy should be better than 0.3mm. The beam based alignment is necessary to achieve this requirement, though it is not so easy. Difficulties could be imaged from the fact that mostly used BPM sensor heads are ϕ257, ϕ297, and ϕ377 of inner diameter [5].

In the case of QFM it is more effective to adjust the horizontal direction. It is not so sensitive to the vertical direction, and this is one of issue to be addressed.

In this report, QFM family is taken as an example, but it is the simplest QM system in the RCS. The most complicated QM system has twelve magnets. Preliminary study for a six-magnet system was done, and it seems to work. But it likes to be more sensitive, whether used orbit data at QM centre or BPM location. While one would continue to study with more realistic conditions, one should look for the possibility to put additional hardware in order to control the QM current individually.

SUMMARY

It is reviewed that the formulation of the beam based alignment method with the single controlled QM system. It is extended for the coupled controlled QM system. Simulation results show the algorism does work. The scheduled beam commissioning of the J-PARC RCS fall 2007. Some issues to be effective BPM beam based alignment plan are discussed.

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