LOCAL MAGNETIC ERROR ESTIMATION USING ACTION AND PHASE JUMP ANALYSIS OF ORBIT DATA *

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Abstract

It's been shown in previous conferences that action and phase jump analysis is a promising method to measure normal quadrupole components, skew quadrupole components and even normal sextupole components. In this paper, the action and phase jump analysis is evaluated using new RHIC data.

INTRODUCTION

The action an phase jump method have been explained in previous papers (see for example [1] [2]). The basic idea is to measure the action and phase of the particle trajectory before and after an error located at some longitudinal position s_0 in the accelerator. Those actions and phases allow to calculate the kick $\Delta x'$ experienced by the orbit in s_0 using Eq. 3 of reference [1]. The kick calculated in this way and the orbit values at s_0 allows to estimate magnetic errors with a precision that depends on the experimental data and the kind of analysis done. Until now, successful measurements of skew quadrupole errors [1] [3] and gradient errors [4] have been done in RHIC IRs. Also some studies to evaluate non linear errors with this method can be seen in references [5] and [6].

Analysis of new RHIC data has stimulated two major changes in the method to improve its precision. First, the estimation of the orbit at s_0 (crucial for the action and phase jump method) has been refined which has led to much more precise analysis of simulated orbits as it will be shown below. Second, difference orbits have been carefully constructed from multi-turn orbits leading to a significant noise reduction in the orbit data.

IMPROVEMENT ON ANALYSIS OF SIMULATED ORBITS

The action and phase jump requires at least two BPMs before s_0 an two BPMs after. It will be ideal to have another BPM exactly at s_0 but this is not usually the case. For this reason, horizontal and vertical position of the orbit at s_0 have to be approximated using the closest BPM. For RHIC IRs, the approximation used is

$$z(s_0) = \sqrt{\frac{\beta_z(s_0)}{\beta_z(s_{bpm})}} z(s_{bpm}), \quad (1)$$

where z stands either for x or y and s_{bpm} is the longitudinal position of the closest BPM to s_0. This approximation was good enough since the phase advance between the triplets in the IRs were very small and the orbits used for analysis were chosen such that they have a maximum at s_0.

Simulation experiments with skew and gradient quadrupole errors similar to the ones presented in reference [4] were analyzed using the more precise relation:

$$z(s_0) = \sqrt{\frac{\beta_z(s_0)}{\beta_z(s_{bpm})}} \frac{sin(\psi(s_0) - \varphi)}{sin(\psi(s_{bpm}) - \varphi)} z(s_{bpm}) \quad (2)$$

where φ is the phase of the orbit before s_0 and $\psi(s)$ the lattice phase advance at arbitrary longitudinal position s.

The improvement of action and phase jump analysis of skew error simulation experiment compared to the original one can be seen in Fig 1.It is clear that the skew errors recovered from the simulated orbits using Eq. 2 are a lot closer than skew errors recovered using Eq. 1. The difference between the values used in the simulated orbits and the ones recovered using the action and phase jump analysis with Eq. 1 are as big as 3.5% while the same analysis using Eq. 2 leads to a significantly smaller difference of 0.04%.

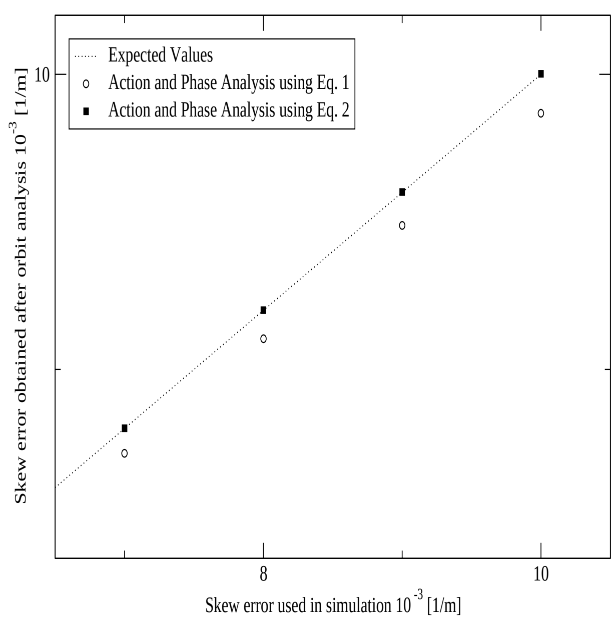

Figure 1: Relation between the skew quadrupole errors used to simulate RHIC orbits and the skew quadrupole errors recovered using action and phase analysis on the simulated orbits. Differences between previous (circles) and current (squares) simulations are shown.

The action and phase analysis of simulation experiments of gradient errors using Eq. 2 shows an even better improvement when compared with analysis of the same experiments using Eq. 2. For the first case, the differences

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between simulated values an recovered values were as big as 1%. For the second case such difference was below 0.004%.

GETTING THE BEST POSSIBLE DIFFERENCE ORBIT

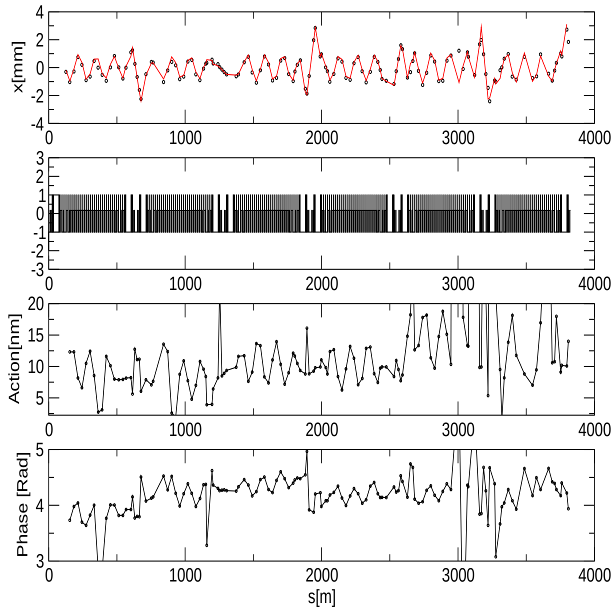

Figure 2: Action and phase jump analysis of a RHIC difference orbit taken during the 2002 proton run. The difference is built out of two separated orbits bi8-qs3.-0.0010.8h.sdds and baseline.1.1.8h.sdds.

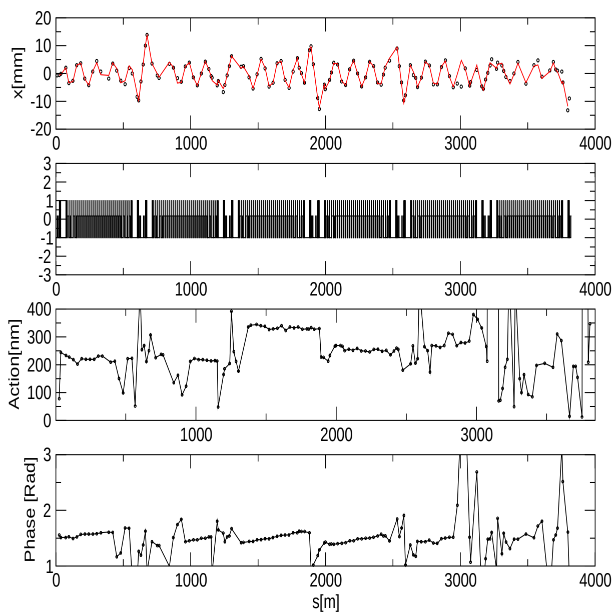

Figure 3: Action and phase jump analysis of a RHIC difference orbit. This time the difference is built from turns 17 and 15 of the same orbit bi8-qs3.-0.0010.8h.sdds.

The action and phase jump analysis uses difference orbits which are built subtracting a baseline from a kicked orbit.

Fig. 2 shows action (third rectangle) and phase analysis (fourth rectangle) of a experimental RHIC difference orbit (first rectangle). This orbit was built subtracting the fifth turn of RHIC baseline (baseline.1.1.8h.sdds) from the fifth turn of a kicked orbit (bi8-qs3.-0.0010.8h.sdds). Even though, jumps of action and phase can be seen in the IRs, the noise is very strong. Previous experiments has shown that the noise reduces as these two orbits are closer time. But, what could be closer in time that the different trajectories of one multi-turn orbit ?. Fig. 3 shows action and phase analysis of the same kicked RHIC orbit (bi8-qs3.-0.0010.8h.sdds) but this time the difference orbit was built out of turn 17 and turn 15 of the same orbit file bi8-qs3.-0.0010.8h.sdds. There is a clear improvement over Fig. 2.

The turns to build the difference orbit should be chosen such that the orbit excursion at s_0 is the biggest possible. A plot of orbit position at s_0 vs the turn number (Fig. 4) is useful for this purpose.

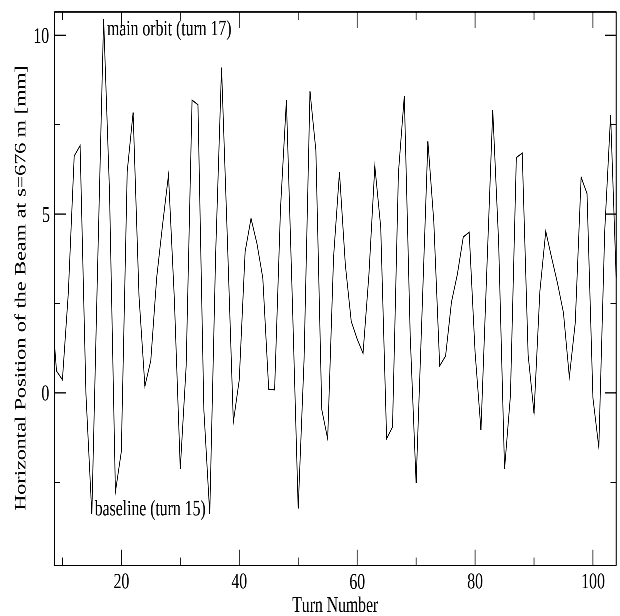

Figure 4: This plot helps to choose appropriate turns to build a difference orbit. For the example of this section, turns 17 and 15 are chosen due to their amplitudes.

APPLYING NEW ANALYSIS TO OLD DATA

During the 2002 RHIC proton run beam experiments were performed to study the optics machine. In such experiments, skew quadrupole errors were intentionally introduced in IR8 with values that range from $-15 * 10^{-3} 1/m$ to $15 * 10^{-3} 1/m$. At least one orbit was taken for every skew quadrupole value and several baselines. Analysis of these orbits were first done in the conventional way (using Eq. 1 and building the difference orbits from separated orbits) and also with the improvements shown above (using

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Eq. 2 and building the difference orbits from different turns of the same orbit). To calculate the skew quadrupole error Eq. 3 was used in every difference orbit and for the two kind of analysis mentioned.

$$a_1 = \frac{\Delta x'(s_0) * y(s_0) + \Delta y'(s_0) * x(s_0)}{y(s_0)^2 + x(s_0)^2} \quad (3)$$

where a_1 represents the skew quadrupole error, $\Delta x'$ and $\Delta y'$ are the kicks in both planes due to the error, and $x(s_0)$ and $y(s_0)$ are the horizontal and vertical position of the beam at $s_0 = 676m$, the location of one of the skew quadrupole magnets in RHIC.

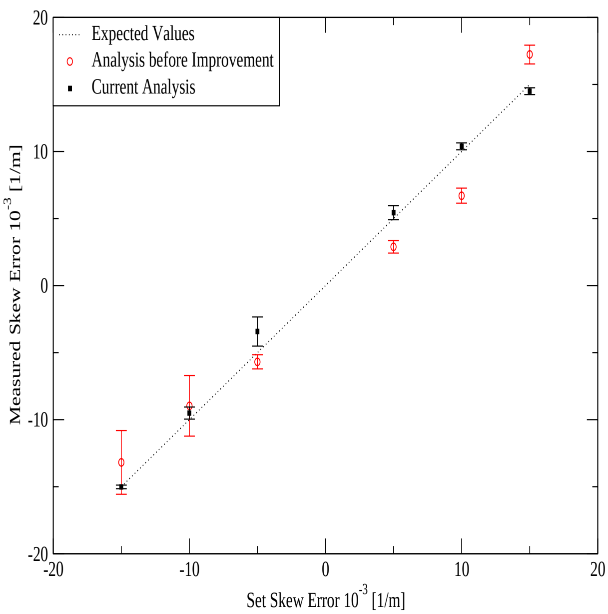

Figure 5: Skew quadrupole errors recovered using the conventional (red circles) and the new (black squares) action and phase analysis on experimental orbits.

The results can be seen in Fig. 5 where the horizontal axis represent the skew quadrupole error set in the ramp editor manager, a software to operate RHIC magnets , and the vertical axis represent the skew quadrupole error values recovered with action and phase jump analysis on the experimental orbits. The circles correspond to skew errors obtained with the conventional analysis while the squares corresponds to the new analysis. The errors bars for each circle were obtained by building 9 different difference orbits with the 9 different baselines available and applying Eq. 3. The errors bars for each squares were obtained by building 6 different difference orbits from 12 turns of the same orbit.

Accuracy is significantly improved with the new analysis since the squares are closer to the expected values than the circles. Precision is improved for large skew quadrupole error values like $15 * 10^{-3} 1/m$ and $10 * 10^{-3} 1/m$ as can be seen by the height of the errors bars and remains constant or get worse for small values like $5 * 10^{-3} 1/m$. This behavior at low values might be due to a contribution from gradient errors already present in the machine.

NEW RHIC DATA

Last beam experiments in RHIC aimed for action and phase analysis were done in 2003. It is shown in reference [6] that data for SVD analysis could also be used for action and phase analysis. Hence, data of several recent experiment in RHIC aimed for SVD analysis were scan in order to apply action and phase analysis. Initially major drawbacks were found in the data. First, the orbits were no kicked at specific places to have a maximum at the IR under analysis. As consequence, Eq. 1 is not a good approximation and this motivates the use of Eq. 2 instead. Second, there were no enough baselines to build the difference orbits. It forces to look somewhere else for baselines and the result was the improvement on the construction of the difference orbits shown in this paper.

In spite of the improvements mentioned, it was not possible to properly analyze new data for several reasons. Most of the RHIC experiments for SVD analysis were kicked in one plane. At least two orbits kicked in different planes are needed to fully decoupled gradient and skew quadrupole errors. The few experiments that kick the orbit in both planes have faulty BPMs at the IRs which are fundamental for action and phase analysis. Also approximations of lattice functions had to be done in the IRS since the optical model only provided lattice functions at the BPMs. Since lattice functions change dramatically at the IRs, this could be an important source of error.

ACKNOWLEDGEMENTS

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REFERENCES

[1] J. Cardona, S. Peggs, T. Satogata, F. Pilat and V. Ptitsyn, “ Determination of Linear and Non Linear Components in RHIC Interaction Regions from difference Orbit Measurements”, EPAC 2002, Paris, 2002, p.311-313.

[2] J. Cardona, “Linear and Non Linear Studies at RHIC Interaction Regions and the Optical Design of the Rapid Cycling Medical Synchrotron”, Stony Brook University, Stony Brook, New York, Ph.D. thesis, 2003.

[3] V. Ptitsyn, J. Cardona, F. Pilat and J. P. Koutchouk, “Measurement and Correction of Linear Effects in the RHIC Interaction Regions”, Proceedings of the 2001 Particle Accelerator Conference, Chicago (2001).

[4] J. Cardona, S. Peggs, F. Pilat, V. Ptitsyn, “ Measuring Local Gradient and Skew Quadrupole Errors in RHIC IRs” ,EPAC’04, Lucerne, Switzerland (2004).

[5] J. Cardona, S. Peggs, T. Satogata, R. Tomas, “ Action and Phase Analysis to Determine Sextupole Errors in RHIC and the SPS”,PAC’03, Portland, Oregon, 2003.

[6] J. Cardona, R. Tomas, “Non Linear Error Analysis from Orbit Measurements in SPS and RHIC”,PAC’05, Knoxville, Tennessee, 2005.

