SLOW ORBIT FEEDBACK AT RHIC*

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Abstract
Slow variations of the RHIC closed orbit have been strongly influenced by diurnal variations. These variations affect the reproducibility of RHIC operation and might have contributed to proton beam polarization degradation during past polarized proton runs. We have developed and commissioned a slow orbit feedback system in RHIC Run-10 to diminish these variations and improve energy ramp commissioning and tuning efficiency. This orbit feedback uses multiple dipole correctors and orbit data from an existing beam position monitor system. The precision of the orbit feedback system has resulted directly from application of an improved algorithm for measurement of the average orbit, from improved survey offsets and numerous measures taken to ensure deterministic delivery of the BPM data. Closed orbit corrections are calculated with an online model-based SVD algorithm, and applied by a control loop operating at up to 1 Hz rate. We report on the feedback design and implementation, and commissioning and operational experience in RHIC Run-10.

INTRODUCTION

The accelerator RHIC [1] at Brookhaven National Laboratory has been operating for eleven years providing collisions of heavy ion as well as polarized proton beams for experiments exploring quark-gluon matter and other specific features of Quantum Chromodynamics. The control of closed orbit of the circulating beam is especially important for the operation with polarized protons. The vertical orbit should be maintained with high precision, below 300 μm of the orbit rms value, in order to ensure the preservation of the proton beam polarization during the acceleration ramps to 250 GeV [2].

The development of the slow orbit feedback was motivated by several reasons. First, the feedback was expected to simplify and speed-up the process of acceleration ramp setup and development. Because of magnet realignments done quite regularly between the RHIC runs as well as because of different machine lattices used from year to year, and even in the course of the same RHIC run, the tuning of RHIC acceleration ramps has been a popular kind of control room work, which often could take more than one day. The orbit feedback, together with other developed feedbacks (tune, coupling, chromaticity) intended to shrink the time scale of the ramp development to less than one control room shifts.

The second reason for the feedback development was to make the closed orbit reproducible from one acceleration ramp to another. And the third reason was related with holding the closed orbit at required precision level during the course of the beam stores. The main problem for the reproducibility of the orbit on the ramps as well as for maintaining a constant orbit at the store was seen to be caused by diurnal slow orbit variations. Although these orbit variations were noted long ago until recently there has been no attempt to develop the feedback in order to tackle the problem. In 2009 RHIC has the first run for physics experiments with the proton beams accelerated to 250 GeV. A considerable polarization loss observed during the acceleration to 250 GeV stimulated the work towards better control of possible depolarization factors, including the control of the beam closed orbit both during the energy ramp and at store.

The additional appeal to address the problem of diurnal orbit variations came from a consideration to move the RHIC working point (betatron tunes) close to an integer value. The move of the working point can be advantageous for the polarization preservation as well as for improving the beam lifetime at the store energy. The closed orbit variation, however, would increase accordingly to the $1/\sin(\pi^*Q)$ law as the betatron tune Q is pushed towards an integer value.

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SLOW ORBIT VARIATIONS IN RHIC

Diurnal variations of the beam closed orbit in RHIC have been noted several years ago. An example of the variations observed during the stores of proton beams in 2005 is shown in Figure 1. Since this region (as well as the IR6 region) contains an experimental detector, the low-beta* optics is applied there, which effectively leads to enhancement orbit excursions in the quadrupole triplets surrounding the interaction point.

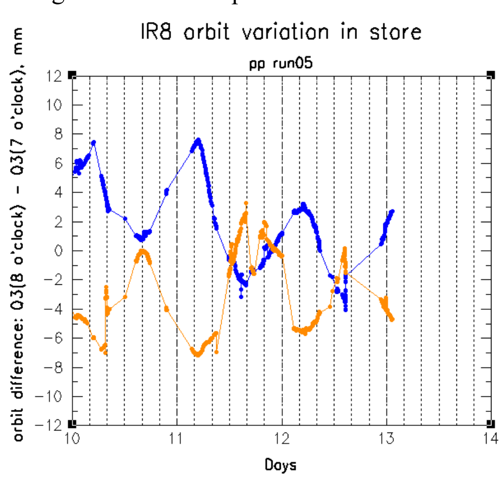

Figure 1: An example of the diurnal orbit variation is shown from RHIC Run-5. The difference of vertical orbit measured on left and right side of IP8 in Blue and Yellow RHIC rings is plotted.

The observed orbit variations are more pronounced in vertical plane. The analysis of waveforms of the orbit variations indicated that sources of the orbit excitation would be located in interaction regions, with the dominating source in IR4 area. As the interaction region magnets are enclosed inside a cryostat, a technique to measure possible movement of the IR quadrupoles inside the cryostat using gamma rays had been suggested [3]. The measurement of quadrupole movement has been never realized though since the decision to develop the slow orbit feedback system was made. Having the orbit feedback we would be able not only to address already identified sources of the closed orbit errors but also to compensate for any other, may be less pronounced, sources. In addition, the orbit feedback was expected to help with development of new acceleration ramps (for instance, ramps to a different store energy or ramps with a different optical lattice).

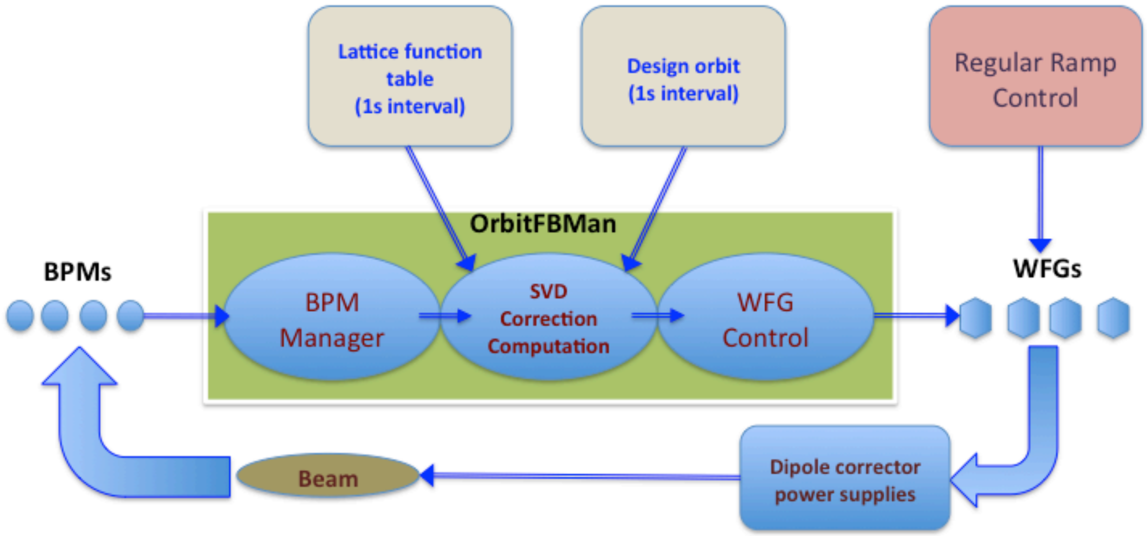

Figure 2: The general scheme of the slow orbit feedback at RHIC.

FEEDBACK IMPLEMENTATION

The slow orbit feedback was implemented using the hardware already present in RHIC. There are 117 dipole corrector magnets and about 150 Beam Position Monitors (BPMs) in each (horizontal and vertical) plane in each of two RHIC rings. These correctors and BPMs have been used during RHIC runs for routine orbit corrections as well as for local orbit control in specific locations. Several orbit correction methods were implemented in the RHIC orbit correction system, including SVD, Sliding Bumps and MICADO algorithms. The correction of the orbit on an acceleration ramp was done by feed-forwarding corrector strength calculated on the basis of orbit measurements from a previous ramp. As the orbit varied with the time such feed-forward correction could not be perfect.

The feedback made use of all existing dipole correctors and BPMs and did not require installing any additional magnets or orbit measuring devices. Yet, the implementation of the feedback during the ramp and for continuous use at the store demanded considerable modifications in corresponding systems in order to accommodate the feedback requirements.

The general scheme of the slow orbit feedback implementation is shown in Figure 2. In the core of the feedback system is the control code OrbitFBMan which encompassed all major parts of the system: the BPM data collection for the orbit input, the orbit correction computation and the application of calculated corrector strength adjustments, with selected gain, to the actual dipole corrector magnets.

The slow orbit feedback is based on steering the measured orbit either to a design orbit or a golden orbit. The design orbit is a combination of several specific local orbit bumps (like bumps in the interaction regions in order to prevent the beam-beam collisions during the acceleration ramp) while the golden orbit is the orbit based on BPM measurements all around the ring, taken at a specific moment. The correction computation is done on the basis of SVD algorithm. During the feedback operation a proper selection of the cut-off parameter for SVD eigenvalues presents an important tool to balance between the quality of the correction and its robustness against possible BPM misbehavior. The correction has to avoid affecting the orbit radial offset (average horizontal shift of the orbit). The control of the radial offset is done by varying RF frequency and by adjusting the bending field of main dipole magnets, and the feedback orbit correction should not interfere with those actions. Therefore, the dispersive component of measured orbit has to be excluded. In order to determine the orbit dispersive component the corresponding momentum offsets is calculated using the orbit data at the arc BPMs and the online model calculation of the horizontal dispersion function. The dispersive component of measured orbit corresponding to the calculated momentum offset is subtracted from the orbit data before the correction computation.

The online model (OptiCalc) is used to calculate the optical functions (beta-functions, betatron phase advances and the dispersion function) required for the correction computation. The OptiCalc model is interwoven with the RHIC magnet control system and provides closest approximation to the machine lattice. During the acceleration ramp the RHIC lattice is continuously changing, since required values of beta-function in the interaction regions are very different at the injection and at the store lattices. In order to accommodate those changes for the orbit feedback a table of optical parameters is created beforehand, using the OptiCalc. The table contains all lattice functions required for the input for the feedback correction with 1s interval.

Like the lattice functions, the design orbit for the correction is also changing along the acceleration ramp. The local orbit bumps presented in the interaction regions as well at several other locations are changed in its amplitude or removed completely during the ramp. Thus, when the feedback is applied on the acceleration ramp the design orbit used as the goal orbit for the correction computation should be constantly updated. At the store the golden orbit taken at the beginning of the store, after the collisions in experimental locations have been perfectly optimized, serves as the goal orbit to be maintained by the feedback.

Several modifications were done in the BPM system to suit the feedback requirements. The algorithm of evaluating the average orbit from collected multi-turn data was refined in order to improve the quality of the measured closed orbit data [4]. Also, the code on BPM front-end computers was reworked to be able to provide deterministic delivery of the BPM data with up to 1 Hz rate. The collection of BPM data from front-end computers, their synchronization as well as exception handling of faulty BPMs was incorporated directly into the OrbitFBMan code. That provided the fastest way of getting the orbit input for the feedback correction. It was found also that the BPM offsets, relative to the center of a nearby quadrupole, had not been correctly accounted inside the system for most of the BPMs. The problem was corrected so that the orbit could be corrected to the center of the quadrupoles with much better accuracy than before.

The OrbitFBMan also incorporated the control of distribution of the computed correction to the actual dipole corrector magnets. The original system of the magnet power supply control in RHIC is based on the use of Wave Form Generators (WFGs). The WFGs are computing modules which calculate and output required magnet power supply currents as a function of time. In order to integrate the orbit feedback into the existing magnet control system, the code controlling WFGs was modified to accept the feedback correction and deliver it to power supplies at 720Hz rate. The computed feedback correction is added up on top of the dipole corrector strength changes provided from the regular ramp control system. The OrbitFBMan checks that computed corrections are within specifications for a maximum requested current I and for a maximum rate of change dI/dt. These specifications are determined on the basis of exception handling by estimates of maximum anticipated, physically realistic change and are significantly tighter than those given by the power supply limits. For instance, the maximum ramping rate of the corrector magnets differs because of different magnet inductances of different magnets.

The integration between the orbit feedback system and regular magnet control system is enhanced by the possibility to feed-forward a feedback correction used on a recent ramp to the magnet settings contained in the regular ramp control system. Another possibility is provided by so-called "replay" of the correction. In this mode the feedback correction used on a previous ramp can be applied again on any of next ramps on top of the magnet settings controlled by the regular ramp system. Both the feed-forward and "replay" techniques provide the way to use the feedback correction on following ramps even if the feedback is kept off. The techniques became essential tool during the work on the acceleration ramp development.

The OrbitFBMan also manages logging of all essential feedback parameters and allow for engaging and disengaging of orbit feedback smoothly. It provides an ability to ramp down the feedback correction so that the current of the dipole correctors become defined only by the regular magnet control system.

The slow orbit feedback is realized on the basis of a simple control loop. The efficiency of the feedback correction efficiency is governed by adjusting the loop gain (the fraction of the calculated corrector strength applied on each step) and the value of SVD eigen-value cut-off parameter.

With all modifications done to BPM and the magnet control system the orbit feedback was expected to operate at 1 Hz rate.

FEEDBACK COMMISSIONING

Commissioning of the slow feedback system was done during this year (2010) RHIC run.

Initial tests were done at the injection energy (10 GeV/n) of Au ions and attempted the correction towards zero goal orbit (without any orbit bumps). The tests explored an optimal operation mode of the feedback, a proper choice of the loop gain and the SVD cut-off parameter. Some initial problems were created by incorrect database information, concerning BPM locations, which led to large local orbit excursions. Also, some of misbehaving BPMs had to be fixed or excluded from the correction.

After that the slow orbit feedback was successfully attempted on RHIC acceleration ramp. The orbit feedback has proved itself as an effective tool of the ramp development. It was used routinely for several energy and lattice changing setups during the machine operation as well as at specific beam experiments. The Figure 3 shows an example of the orbit feedback application on the acceleration ramp. The slow orbit feedback worked successfully trough the transition region of the ramp and interacted well with other control loops and feedbacks used on the ramp (for instance, with the rf radial loop or with the dipole field feedback which regulates main bending field in Yellow ring). Especially we would like to point out to a remarkable achievement when several feedbacks, controlling the orbits, betatron tunes, transverse coupling and chromaticities, were applied simultaneously with great success during a development of the acceleration ramp to 19.5 GeV/n Au ion energy.

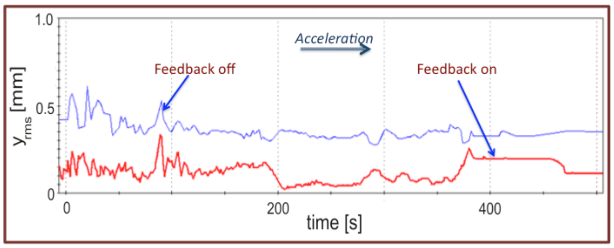

Figure 3: Comparison of vertical orbit rms, measured in Blue ring on two consecutive ramps. The orbit rms on the ramp without feedback affected by the diurnal orbit variations. The ramp with the feedback on produces considerably improved orbit.

Several tests were done with the slow orbit feedback activated at the store. In this case the feedback correction was using a golden orbit, measured at some short time before the feedback activation, as the goal orbit. Encouraging results were obtained demonstrating that the feedback can effectively counteract the slow orbit changes at the store (Figure 4) without deterioration of the experimental backgrounds or beam lifetimes. However the level of the orbit variation from one feedback correction application to another was larger than desired. Possible causes of this problem, like limited resolution of the corrector magnets power supplies, and discrepancies between the optics provided by the online model and the actual machine lattice, are under consideration.

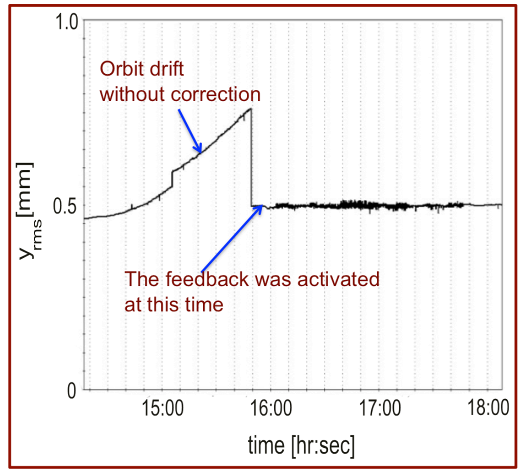

Figure 4: The orbit feedback activated at the store corrects for slow orbit deterioration.

CONCLUSIONS

The closed orbit feedback has been developed and successfully commissioned during RHIC Run-10. In the next RHIC run the slow orbit feedback will be used from the very beginning of the run as a tool of acceleration ramp development and setup. The ultimate goal would be to apply the feedback on every acceleration ramp to counteract diurnal orbit variations.

Also, we will continue to pursue the application of the feedback to maintain a golden orbit during the stores. Related with this development, the concurrent application of the slow orbit feedback together with a fast orbit feedback will be attempted in order to look into possible interactions between the feedbacks. The fast feedback has been under recent development [5] in order to compensate the observed orbit oscillations at frequencies around 10 Hz. Ideally, both slow and fast orbit feedbacks should be run concurrently during the course of RHIC stores.

REFERENCES

[1] T. Roser, “RHIC and its upgrade programs”, EPAC’08, Genoa, FRXAGM01, p. 3723, (2008).

[2] I. Alekseev, et al., “Polarized Proton Collider at RHIC”, Design Manual, (1998).

[3] P. Thieberger, W.W. MacKay, V. Ptitsyn, D. Trbojevic, C-A/AP/225, (2005).

[4] R. Michnoff, et al., “RHIC BPM system average orbit calculations”, PAC’09, Vancouver, TH5RFP013, (2009).

[5] R. Michnoff et al, "10 Hz global orbit feedback" currently under development.