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Closed Orbit Diffusion and Detection

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Introduction

As time goes by, the closed orbit of RHIC will diffuse from its original state. This will almost entirely be due to slow, random transverse misalignment of arc and triplet quadrupoles, dominated by ground motion. A closed orbit that has diffused "too far" will be corrected, within the detection capabilities of the Beam Position Monitor (BPM) system. The most stringent demands on long term closed orbit stability will probably come at the 6 o'clock and 8 o'clock Interaction Points (IPs), at the centers of the major experiments.

This paper makes simple conservative estimates of the diffusion rate and of the correction accuracy at an IP with $\beta_H^* = \beta_V^* = 1.0$ meter. It is straightforward to scale these results to a general location in RHIC. This paper also cites available references that would be relevant to a more detailed analysis of the problem, should that be attempted.

Diffusion

Although many authors have addressed the problem of the effects of ground motion, the most relevant and complete body of work comes from Roßbach, at HERA - the only operational hadron collider that, like RHIC, has two separate rings of magnets. He reports that, for HERA,

$$< d^2 >^{1/2} \approx 5\sqrt{T} \text{ microns} \tag{1}$$

where $< d^2 >^{1/2}$ is the expectation value of the horizontal or vertical closed orbit error ($\beta = 1$ m), and time, T, is measured in hours [1]. This is quantitatively consistent with the HERA broadband ground motion power spectrum, whose general shape

$$P(f) \sim f^{-1} \tag{2}$$

describes most accelerator sites quite well. Particular sites may also have idiosyncratic narrowband sources - such as large compressors, et cetera.

There are four grounds on which to expect that RHIC will be less diffusive than HERA. In approximate order of importance, they are:

1. The arc cell length and the typical arc beta function in RHIC are less than in HERA. This raises the cut-off frequency, below which RHIC is isolated from the ground motion spectrum.
2. The rural RHIC site is much quieter than the urban HERA site, with its busy neighboring trunk roads, et cetera.
3. RHIC sand is more absorptive than the relatively tight packed HERA dirt.
4. RHIC is approximately half the circumference of HERA.

I am not aware of any contrary grounds, by which RHIC is expected to be *more* vulnerable than HERA. Hence equation 1 should be considered a conservative, worst case estimate for RHIC. For comparison purposes, note that the transverse proton beam size is $\sigma_p^* \simeq 111\,\mu$m, while for gold $\sigma_{Au}^* \simeq 152\,\mu$m when collisions commence, increasing to $\sigma_{Au}^* \simeq 248\,\mu$m at the end of a 10 hour store.

Ground motion data are available for the BNL site, should a more definitive analysis be attempted at a future date [2, 3].

Detection (and Correction)

The BPMs adjacent to every quadrupole in the arcs have an internal diameter of 8 cm, while those close to the IP have an ID of 13 cm. Some are single plane (for example, detecting only the horizontal closed orbit location) and some are dual plane. In all cases, the detection accuracy may be crudely modeled as follows [4].

1. The 1 second "instantaneous" relative accuracy is 1 μm. Measurement accuracy when the same orbit is measured twice, or a difference orbit is measured (for example, before and after orbit correction).
2. The 1 day "random drift" accuracy is 50 μm. Due to thermal effects, et cetera, in the BPM hardware and electronics.
3. The eternal "absolute" accuracy is 100 μm. The ultimate accuracy of a single BPM, after conversion to absolute coordinates in the global RHIC coordinate frame used by the surveyors.

However, it is the closed orbit accuracy at an IP - and at a general arc location - that are of interest here. Information from more than one BPM is available, sometimes with significant statistical advantages.

The dual plane BPMs closest to each IP are ±8.974 and ±25.065 meters away. No (accelerator) magnet lies between the IP and the first BPM. Dipole magnets DX and D0, with horizontal bending angles of 18.86 and -15.18 milliradians, lie between the first and second BPMs.

A pessimistic estimate of the accuracy of d^*, the closed orbit at an IP, comes from assuming that it is linearly interpolated from the inner pair of BPMs.

$$d^* = \frac{1}{2}(d_{-1} + d_{+1}) \tag{3}$$

This leads to an IP accuracy that is $\sqrt{2}$ smaller than the single BPM accuracy: rapid closed orbit motion at the 0.7 μm level can be resolved, and the absolute location is known at the 70 μm level. However, if the average of the *four* innermost BPMs is taken, the IP accuracy is reduced to one half of the single BPM accuracy. It might be objected that the properties of DX and D0 magnets will not be well enough known to reliably use data from the second pair of BPMs, but this is not expected to be a major problem in practice.

An extremely optimistic estimate for closed orbit accuracy at a general location comes from assuming that data from all BPMs (in a particular plane) can be used. In this case the accuracy is

$$\frac{< d^2 >^{1/2}}{\sigma} \approx \frac{1}{\sqrt{N}} \frac{< b^2 >^{1/2}}{\sigma_{arc}} \tag{4}$$

where $< b^2 >^{1/2}$ is the appropriate single BPM accuracy, and $\sigma_{arc} \approx 7.0\ \sigma^*$ is the beam size at one of the $N \approx 150$ arc BPMs. This predicts an IP closed orbit accuracy that is almost two orders of magnitude smaller than the single BPM accuracy. For many reasons, this is not practically achievable.

A couple of things are worth noting in passing. First, the excellent "instantaneous" accuracy of around 1 μm makes possible closed orbit feedback, with a bandwidth of, say, 1 Hz to 10 Hz, as performed at the SLC. It is not anticipated that this will be necessary. Second, diagnostic means other than BPMs may be available for observing and tuning the closed orbit offset between colliding beams [5], although this, too, appears unnecessary.

Conclusions

1. A conservative estimate of the random walk of the closed orbit at an IP with $\beta^* = 1.0$ m has $< d^2 >^{1/2} \approx 5\sqrt{T}\ \mu$m, where T is in hours.
2. Using multiple BPMs, the "store-to-store relative" and "absolute" measurement accuracies of the closed orbit at an IP are expected to lie within a factor of two of each other, at much less than 50 μm.
3. Taking these two parameters at face value, closed orbit correction (in store) will not be performed more than once every 100 hours or so. This is roughly consistent with Tevatron and HERA experience.

References

[1] "Spektrale Analyse der Orbitbewegung bei HERA", J. Roßbach, Proc. of the Bad Lauterberg HERA Seminar '94, DESY-HERA 94-03, March 1994.

[2] "Vibration Survey Report of Building 930, 200 MeV Linac Building, and Associated Areas", Vibration Engineering Consultants, Inc., Topsfield, Massachusetts, August 1985.

[3] "The Analysis of the Ground Vibration Data of the NBTF Site", C.C. Lin, Brookhaven, BNL/NPB-87-54, May 1987.

[4] Tom Shea, private communication, August 1995.

[5] "Coherent bremsstrahlung at relativistic heavy ion colliders", V.G. Serbo, Brookhaven, RHIC/AP/64, to be published.