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# Modifications to TEAPOT for Studies of Local Decoupling in the RHIC Arcs


L. Scachinger


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Collider Accelerator Department

**Brookhaven National Laboratory**



**U.S. Department of Energy**

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L. Schachinger and R. Talman

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## 1 Introduction

Individual beam position monitors (BPM's) in the arcs of RHIC will be able to measure the beam position in one plane only. Those near a focusing quadrupole (QF) will measure the position of the beam in the horizontal plane while those near a defocusing quadrupole (QD) will measure the vertical position. This configuration gives sufficient information for correcting the orbit in the arcs, but makes local decoupling less straightforward than it might otherwise be[3].

Local decoupling requires a measurement of the beam position in both planes[2] at the same location. With BPM's constructed so that the beam position in only one plane is available, strictly speaking, we cannot directly measure the coupling anywhere. The purpose of this work was to create a TEAPOT environment in which one could explore whether interpolating the beam position between alternate BPM's might yield a position accurate enough to allow the local decoupling of the RHIC arcs.

## 2 Method

We assume that the ability exists (in hardware) to kick the beam in both planes. The procedure we use within TEAPOT[1] is to track a particle with an initial kick in the horizontal plane, and use the measurement of the horizontal beam position at the BPM's which can measure the beam position in that plane (HBPM's) to interpolate the horizontal position at the VBPM's. Since we have a direct measurement of the vertical position at the VBPM's, we can use the interpolated horizontal position and the measured vertical position to calculate the coupling there. We then track a particle with an initial vertical kick, and interpolate to get the vertical position at the HBPM's. By using the in-plane amplitude to interpolate, we minimize the effect of coupling errors on the interpolation.

The interpolation is done using the position of the tracked particle at BPM's that are nearest neighbors to the BPM at which we are computing the interpolated coordinate. For the case in which we are interpolating the horizontal coordinate at a VBPM using the positions at the two adjacent HBPM's the interpolated coordinate is computed as follows:

If we call the horizontal position and angle at the VBPM in question $x_1$ and $x'_1$, and the horizontal positions and angles at the previous and following HBPM's $x_0$, $x'_0$, $x_2$, and $x'_2$, we can write the following expressions for the positions at the BPM's involving transfer matrix elements:

$$x_1 = R_{11}^{(01)} x_0 + R_{12}^{(01)} x'_0$$

$$x'_1 = R_{21}^{(01)} x_0 + R_{22}^{(01)} x'_0$$

$$x_2 = R_{11}^{(12)} x_1 + R_{12}^{(12)} x'_1.$$

When we solve these equations for $x_1$ as a function of $x_0$ and $x_2$, the result is

$$x_1 = \frac{R_{12}^{(01)}}{R_{12}^{(12)} R_{22}^{(01)} + R_{12}^{(01)} R_{12}^{(01)} R_{11}^{(12)}} x_2 + \frac{R_{12}^{(12)} (R_{11}^{(01)} R_{22}^{(01)} - R_{12}^{(01)} R_{12}^{(01)})}{R_{12}^{(12)} R22^{(01)} + R_{12}^{(01)} R_{11}^{(12)}} x_0.$$

The ideal twiss functions (for the machine with no errors) are used to compute the transfer matrix elements. We use the expression above inside TEAPOT to compute the interpolated coordinates $x_1$ and, similarly, $y_1$ (at HBPM's).

## 3 Implementation

In order to use this interpolation the user must invoke the command CPLTRK as described in the TEAPOT manual, which we now quote:

**CPLTRK, KICKX = <value>, KICKY = <value>, THRESHOLD = <value>**

This command computes interpolated coordinates at BPM's which measure beam position in only one plane for use in decoupling. To accomplish this two particles are tracked, one with initial kick px=`kickx` and one with py=`kicky` (in mrad) at the origin. At each detector of type `chcd` or `cvcd`, the coordinates of the tracked particles and the ideal twiss parameters are recorded. At each detector, the missing coordinate (in the plane of the tracked particle for greatest accuracy) is obtained by interpolation, using the ideal twiss parameters and the coordinates of the tracked particle at the adjacent detectors on either side. Output files of the ideal-interpolated and error-present actual coordinates at each `chcd` and `cvcd` are written (see the description of the fort.50, fort.51, fort.60 and fort.61 in Appendix A). These can be used to study the accuracy of the interpolation in detail. The RMS of the difference between the interpolated and actual coordinates is computed as a figure-of-merit for the interpolation in each plane. A warning message is printed whenever the fractional deviation of the interpolated from the actual coordinate is greater than the user-specified `threshold` at a detector.

## 4 Conclusions

We have added to TEAPOT the ability to interpolate coordinates between alternating horizontal and vertical BPM's for the purpose of studying local decoupling. This makes possible investigations of the accuracy of local decoupling schemes (based on these interpolated coordinates) for the RHIC arcs. Since the interpolation is based on ideal twiss parameters, its accuracy will depend on the lattice errors, and a full simulation of the lattice will be needed to test decoupling schemes.

## References


[1] L. Schachinger and R. Talman, "Teapot: A Thin-Element Accelerator Program for Optics and Tracking," Part. Accel. 22, 35 (1987).

[2] L. Schachinger and R. Talman, "Manual for the Program *TEAPOT*: Noninteractive *FORTRAN* Version," Appendix G, March 1995.

[3] F. Pilat, "Correction of the triplet skew quadrupole errors in RHIC," RHIC/AP 58, March 1995.

## Appendix A

FORMAT OF UNITS 50, 51, 60 and 61, CPLTRK OUTPUT FILES

### UNIT 50

| | |
|---|---|
| line 1 | Comment (TitleText: X at Y BPM interpolated from adjacent X BPMs) |
| line 2 | Comment (Markers: 1) |
| line 3 | blank |
| line 4 | Comment ("interp") |
| lines 5 - N | detector #, interp. X at Y BPM for particle with initial XKICK |
| line N+1 | blank |
| line N+2 | Comment ("actual") |
| lines N+3 - 2N+3 | detector #, actual X at Y BPM |

### UNIT 51

| | |
|---|---|
| line 1 | Comment (TitleText: Y at X BPM interpolated from adjacent Y BPMs) |
| line 2 | Comment (Markers: 1) |
| line 3 | blank |
| line 4 | Comment ("interp") |
| lines 5 - N | detector #, interp. Y at X BPM for particle with initial XKICK |
| line N+1 | blank |
| line N+2 | Comment ("actual") |
| lines N+3 - 2N+3 | detector #, actual Y at X BPM |

### UNIT 60

| | |
|---|---|
| line 1 | Comment (TitleText: X at Y BPM interpolated from adjacent X BPMs) |
| line 2 | Comment (Markers: 1) |
| line 3 | blank |
| line 4 | Comment ("interp") |
| lines 5 - N | detector #, interp. X at Y BPM for particle with initial YKICK |
| line N+1 | blank |
| line N+2 | Comment ("actual") |
| lines N+3 - 2N+3 | detector #, actual X at Y BPM |

### UNIT 61

| | |
|---|---|
| line 1 | Comment (TitleText: Y at X BPM interpolated from adjacent Y BPMs) |
| line 2 | Comment (Markers: 1) |
| line 3 | blank |
| line 4 | Comment ("interp") |
| lines 5 - N | detector #, interp. Y at X BPM for particle with initial YKICK |
| line N+1 | blank |
| line N+2 | Comment ("actual") |
| lines N+3 - 2N+3 | detector #, actual Y at X BPM |

## Appendix B

Plan for Local Decoupling in RHIC Arcs with TEAPOT
February 9, 1996

1. Add markers/detectors to the lattice at those single-plane BPMs which are instrumented for other plane interpolation, of type `chcd` at horizontal BPMs and `cvcd` at vertical BPMs.

2. Create a new TEAPOT command,

   ```
   cpltrk, kickx=<value>, kicky=<value>, threshold=<value>
   ```

   which does the following:

   (a) Tracks two particles, one with initial kick px=`kickx` and one with py=`kicky` (in mrad). Note that this is only realistic if the ability to kick the beam in both planes in the accelerator exists.

   (b) At each detector of type `chcd` or `cvcd`, records the coordinates of the tracked particles and the ideal twiss parameters.

   (c) At each detector, interpolates to obtain the missing coordinate (in the plane of the tracked particle for greatest accuracy) using the ideal twiss parameters and the coordinates of the tracked particle at the two adjacent detectors.

   (d) Writes output files of the ideal-interpolated and error-present actual coordinates at each `chcd` and `cvcd`. These are used to study the accuracy of the interpolation in detail.

   (e) Computes the rms of the difference between the interpolated and actual coordinates as a figure-of-merit for the interpolation in each plane.

   (f) Prints a warning message whenever the fractional deviation of the interpolated from the actual coordinate is greater than the user-specified `threshold` at a detector.

3. Update the TEAPOT manual to describe the `cpltrk` command.

4. Write a final report describing this work.

5. At some later date, the interpolated coordinates can be incorporated into the decoupling algorithm in TEAPOT to perform an operational simulation of local decoupling in the arcs of RHIC. It would be natural to include investigation of BPM errors and other operational issues such as signal processing issues for the interpolating hardware.