BEAM-BASED ALIGNMENT IN THE RHIC E-COOLING SOLENOIDS*

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Abstract

Accurate alignment of the electron and ion beams in the RHIC electron cooling solenoids is crucial for well-optimized cooling. Because of the greatly differing rigidities of the electron and ion beams, to achieve the specified alignment accuracy it is required that transverse magnetic fields resulting from imperfections in solenoid fabrication be down by five orders of magnitude relative to the pure solenoid fields. Shimming the solenoid field to this accuracy might be accomplished by survey techniques prior to operation with beam, or by methods of beam-based alignment. We report on the details of a method of beam-based alignment, as well as the results of preliminary measurements with the ion beam at RHIC.

INTRODUCTION

We present a simplified description of a proposed beam-based method to accomplish the local alignment of the electron beam to the ion beam along the length of the eCooling [1] solenoid magnets, as well as the accuracy, resolution, and stability requirements imposed on beam position measurement by this method. We also present data taken during RHIC beam experiments to gain experience with the proposed method. The relation between accuracy of local alignment and the efficiency of the cooling process is discussed elsewhere [2], as are the methods of beam position measurement [3] that might be employed to meet the requirements.

In the proposed method of beam-based alignment the ion beam serves as the fiducial, is assumed to be perfectly rigid within the solenoid, and is aligned within solenoid by BPMs at either end. Local dipole correctors and alignment quadrupoles are distributed within the cryostat along the length of the solenoid. The quadrupoles are designed to permit modulation at a few Hertz. The position modulation of the ion beam resulting from the current modulation of a given quadrupole is detected by position monitors located elsewhere in the RHIC ring. The amplitude of this position modulation is dependent upon the location of the ion beam in the quadrupole. Application of a swept four-bump of the ion beam position in the solenoid permits locating the magnetic center of that quadrupole relative to the BPMs at either end of the solenoid. With this information in hand, the quadrupole can be modulated in the presence of the electron beam, the position modulation of the electron beam can be detected in the return path of the Energy Recovery Linac as a local bump is applied to the electron beam position, the position of the electron beam relative to the quadrupole can be determined, and the local dipole correctors can be used to locally align the electron beam relative to the ion beam. The achievable alignment accuracy is dependent upon the accuracy, resolution, and stability of the BPMs at either end of the solenoid and the BPMs that detect the position modulations resulting from current modulations of the quadrupoles.

Determination of the quality of the alignment is problematic. In the RHIC studies the only available means has been measurement repeatability. In the eCooling application the use of a recombination monitor is under consideration.

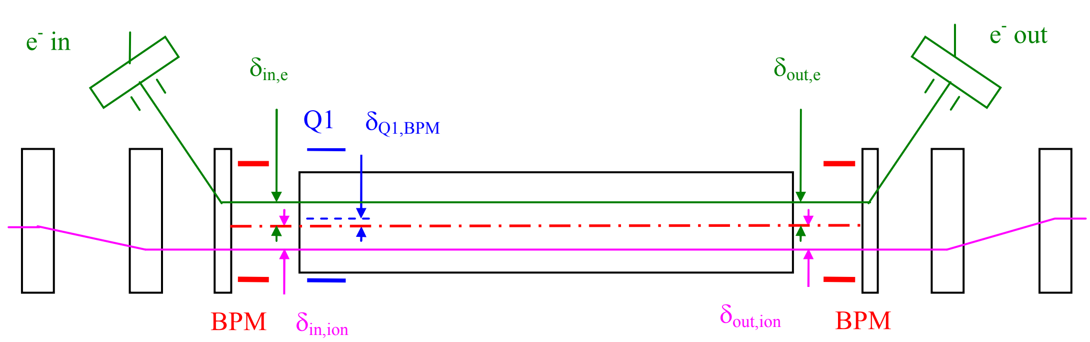

Figure 1: A simplified schematic of the measurement setup, showing only the first alignment quadrupole.

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THE APPARATUS

The essential elements required to accomplish the alignment are:

1. Dipole correctors at both ends of the solenoid, to permit sweeping a 4-bump of the ion beam position.
2. Beam Position Monitors at either end of the solenoid, to measure the relative position of the ion beam.
3. An additional BPM in the electron beam, upstream of the merging dipole. With the BPM immediately upstream of the solenoid, this permits measuring electron beam angle and position entering the solenoid.
4. Correction dipoles within the solenoid cryostat, spaced at intervals along the length of the solenoid. These have two purposes, to accomplish 3-bumps of electron beam position relative to the alignment quadrupoles during alignment, and to provide the corrections needed for electron beam alignment relative to the ion beam.
5. Alignment quadrupoles within the solenoid cryostat, spaced as the correction dipoles. The requirements are to be modulated at 1-10Hz, and that the amplitude of modulation be constant over the duration of a position sweep through the quadrupole. Absolute alignment of the quadrupoles to the solenoid is not required.
6. A high-resolution BPM located in the RHIC ring, external to the solenoid region, to measure the position fluctuation of the ion beam due to beam offset and quadrupole modulation.
7. A high-resolution BPM located in the return path of the ERL, to measure the position fluctuation of the electron beam due to beam offset and quadrupole modulation.

THE PROCEDURE

First, the location of the ion beam relative to the quadrupole is determined:

1. A four-bump through the solenoid is applied to the ion beam. The resulting offsets $\delta_{in,ion}$ and $\delta_{out,ion}$ are measured by the BPMs at the ends of the solenoid.
2. The current in the alignment quadrupole is modulated, and the resulting position modulation $\delta_{mod,ion}$ in the RHIC ring external to the solenoid region is measured.
3. The amplitude of the 4-bump is changed, the three values $\delta_{in,ion}$, $\delta_{out,ion}$, and $\delta_{mod,ion}$ are measured. This data permits locating the offset of this first quadrupole $\delta_{Q1,BPM}$ relative to the BPMs at the end of the solenoid.

The location of the electron beam relative to the solenoid is then determined:

4. The position $\delta_{in,e}$ and angle $\phi_{in,e}$ of the electron beam as it enters the solenoid are measured. The angle measurement can be calibrated by measuring $\delta_{in,e}$ and $\delta_{out,e}$ with the solenoid at zero field.
5. Using the in-cryostat dipole correctors, a local 3-bump is applied to the electron beam position in the alignment quadrupole.
6. The current in the alignment quadrupole is modulated, and the resulting position modulation $\delta_{mod,e}$ at a location in the return path of the ERL is measured.
7. The amplitude of the 3-bump is changed and the value of $\delta_{mod,e}$ is measured. This data permits locating the center of the quadrupole $\delta_{Q1,e}$ relative to the 3-bump strength, for given values of $\delta_{in,e}$ and $\phi_{in,e}$ at the solenoid entrance.

Next, the ion beam is aligned to the electron beam in both position and angle at the entrance of the solenoid:

8. The position $\delta_{in,e}$ and angle $\phi_{in,e}$ of the electron beam entering the solenoid are measured as in step 4 above.
9. The position and angle of the ion beam are determined by measuring $\delta_{in,ion}$ and $\delta_{out,ion}$ and the ion beam is adjusted to be co-incident and co-linear with the electron beam.

Finally, the electron beam is aligned relative to the ion beam in the first quadrupole:

10. The position of the ion beam in the alignment quadrupole is determined by $\delta_{in,ion}$, $\delta_{out,ion}$ and $\delta_{Q1,BPM}$ as established in step 3 above.
11. With the 3-bump offset data $\delta_{Q1,e}$ measured in step 7 above, the relevant dipole corrector is used to position the electron beam to be co-incident with the ion beam.

With the electron and ion beams aligned in the first alignment quadrupole, this procedure can be repeated in the following alignment quadrupoles, with steps 4, 8, and 9 omitted.

MEASUREMENT REQUIREMENTS

Results of an analysis [4] of measurement requirements are shown in Table 1. The analysis assumes that it is necessary to align the electron beam relative to the ion beam with 10μ accuracy, and that the alignment errors are shared equally in quadrature between the electron and ion beams.

Table 1: Measurement Requirements

measurement	accuracy	resolution	stability
$\delta_{Q1,BPM}$	7μ		
$\delta_{mod,ion}$	~125nm	~40nm	~40nm
$\delta_{in,ion}$ and $\delta_{out,ion}$	~3μ	~1μ	~1μ
$\delta_{Q1,e}$	7μ		
$\delta_{mod,e}$	~5μ	~2μ	~2μ
$\delta_{in,e}$	~3μ	~1μ	~1μ
$\delta_{\phi,e}$	~0.3μ	~0.1μ	~0.1μ

The most stringent requirement on accuracy is for measurement of the position modulation of the ion beam. Expected modulation amplitudes of the ion beam are of the order of 0.1mm. It is required to measure these modulations with a resolution of better than 1 part in 100, and that the linearity of the measurement be similarly stable for the time of a position scan across a given alignment quadrupole.

MEASUREMENT RESULTS

Preliminary studies of the alignment method have been completed. A trim quadrupole current was modulated at 1Hz with a depth of 1A. The resulting modulation strength k was about $2.5\times10^{-3}/m^2$. Beam position in the trim quad was scanned, as shown below.

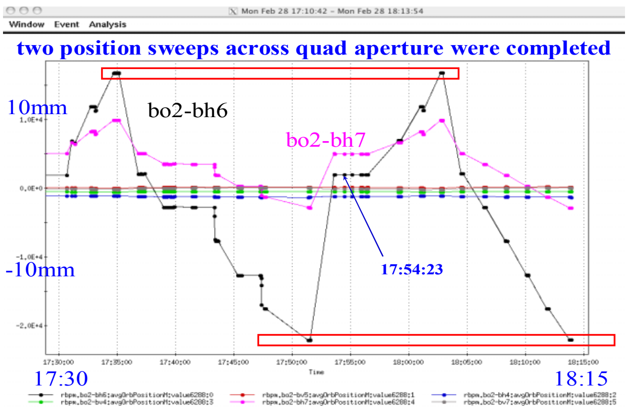

Figure 2: Position scans across the trim quad.

At each position, 10 measurements were taken with the 1000 turn RHIC BPM situated at the trim quad location. RMS variation of these 10 measurements was about 5μ. Similarly, at each position in the trim quad the amplitude of the resulting 1Hz position modulation was measured with a million turn RHIC BPM located at favorable phase advance relative to the trim quad.

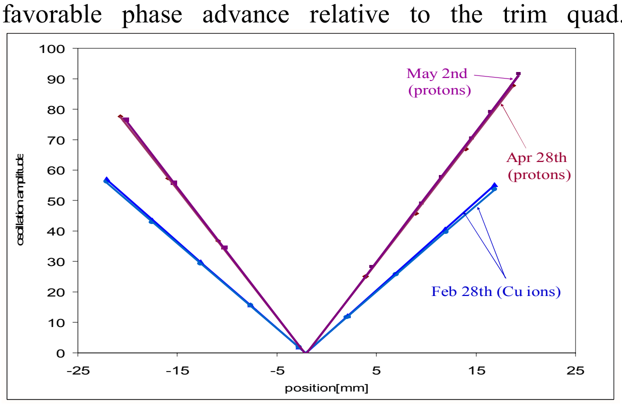

Figure 3: Alignment data.

Figure 3 shows data from 4 sweeps across the aperture of the trim quad, two taken with Cu ions on the same day, and two taken with protons on different days. The difference in slopes results from different optics at injection with Cu and protons. Figure 4 is a zoom showing detail near the origin. The agreement between same-days scans with the Cu beam is ~40μ, agreement between different day scans with the proton beam is ~3μ, and agreement between Cu and proton scans is ~40μ.

Y-intercepts for all data are negative. This was also true for an independent data set taken in the yellow ring. With the exclusion of low-offset data, the intercepts become more negative. One explanation of this would be the presence of an octupole component in the trim quad. The amount of octupole required is considerably greater than

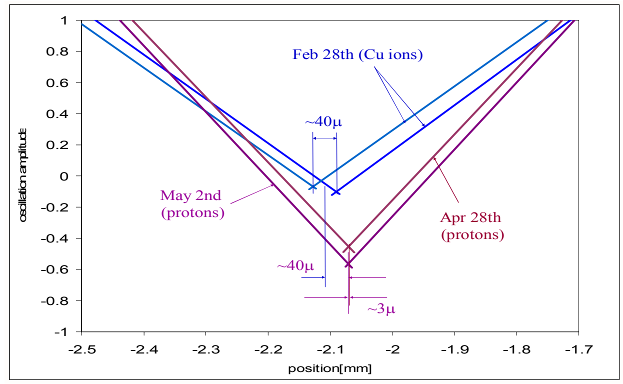

Figure 4: Zoom on alignment data.

the allowable maximum specified for the trim quads. A time-decay of the octupole strength after return to the injection plateau was observed, suggesting that some portion of this may be due to persistent current effects. The presence of octupole complicates the alignment, Asymmetric exclusion of positive and negative-offset data points has a significant effect on the resulting calculated center, resulting in variations of several tens of microns. This requires more study.

DISCUSSION

As mentioned in the Introduction, determination of the quality of the alignment is problematic, and thus far the only available means has been measurement repeatability. Lacking some new insight, to gain confidence will require many repetitions of the measurement. We are investigating a script to automate the measurement and decrease the needed time. The modulation strength for the studies was ~x10 greater than what can reasonably be achieved by the proposed alignment quadrupoles in the solenoid cryostats. The needed improvement in resolution and stability of position measurement might be gained by adapting a recently developed analog front-end [3] to measure at the revolution line. The preliminary conclusion from our analysis and measurements is that it may be possible to meet the measurement requirements for the proposed alignment technique. Further attention is required to address the accuracy, resolution, and stability requirements for both the BPM systems and the associated magnets and their power supplies. It should also be noted that the problem of a 3-bump of the electron beam in the solenoid (an angular kick results in helical motion) requires further attention, as does the assumption of an infinitely rigid ion beam.

REFERENCES

[1] I. Ben-Zvi et al, "Electron Cooling of RHIC," these proceedings.
[2] A. Fedotov et al, in preparation.
[3] M. Gasior and R. Jones, "High Sensitivity Tune Measurement by Direct Diode Detection," DIPAC05.
[4] P. Cameron et al, "Procedure and BPM Measurement Requirements for Beam-based Alignment in the RHIC eCooling Solenoids", C-A/AP/203

