OPTICS CORRECTIONS AT RHIC

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Abstract

Excessive beta-beat, deviation of measured beta function from the calculated beta functions based on an model, in high energy colliders can lead to large deviation of beta function at collision point as well as other adverse effects. The segment-by-segment technique was successfully demonstrated in the LHC operation for reducing the beta-beat. It was then applied to RHIC polarized proton operation in 2011. This paper reports the experimental results of optics correction at RHIC. Future plan is also presented.

INTRODUCTION

Optics functions, such as the $\beta-$beat should be corrected to a satisfactory level to avoid limitations during beam operations. Optics measurements were conducted using an AC-dipole kicker. The AC-dipole kicker was used to introduce transverse oscillations. 1024 turn-by-turn data were acquired. From there a fit of the betatron signal [1] or the phase method [2], using SUSSIX [3] is used to calculate the linear optics.

SEGMENT-BY-SEGMENT FOR RHIC

The segment-by-segment technique was introduced in the LHC [4] and has been proven to be very useful during the commissioning. Using the segment-by-segment technique it is possible to locate and correct large local errors. As a first step it was implemented in RHIC to correct the beta-beat. The engine for the segment-by-segment technique is MAD-X [5]. In MAD-X the ring is treated as a beam-line. Initial conditions are the measured optics values. The propagated model is compared with the measurement. If a large deviation is observed a local error source could be present. Few limitations had to be taken into account during the development of the segment-by-segment technique for RHIC. First limitation is that only double plane BPMs are installed around the IPs, elsewhere single plane BPMs are installed. Second limitation is that limited number of independent power converters are available, meaning that the available number of correctors is limited.

OPTICS MEASUREMENT

Optics measurements were conducted at several instances during 2011 polarized proton run. Figure 1 shows a comparison between the two methods, fit and phase method, used to measure the linear optics. The fit method consists of fitting the amplitude of the betatron oscillations. The phase method uses the phase of the main betatron line and the model. The β-beat is shown, being the normalized difference between measurement and model. A good agreement is observed between the two methods. Peak beta-beat of $\sim$ 30%, 40%, respectively in the horizontal and vertical plane. Abrupt jumps in the β-beat indicate strong local errors. Large local jumps are observed in IP_6 and IP_8 and IP_{10}.

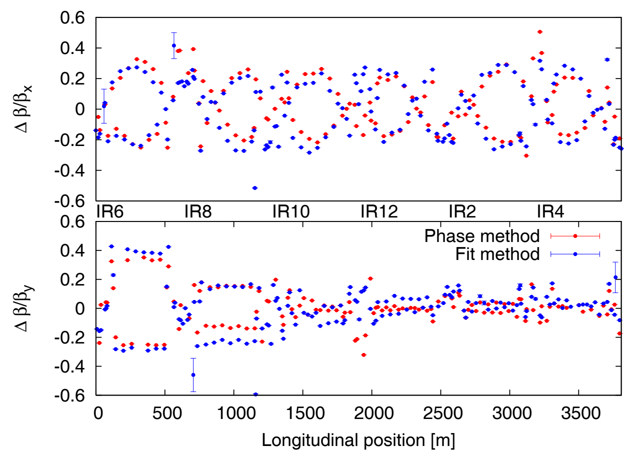

Figure 1: Comparison between the two different methods used to measure the optics at RHIC. Horizontal plane, above and vertical plane, below. Abrupt jumps are observed in the vertical plane for IP_6, IP_8 and IP_{10}

OPTICS CORRECTIONS

In this section the analysis and correction of IP_6 and IP_{12} will be discussed. The observable used is the phase error, being the difference between the measured and model phase advance. Figure 2 shows the phase error observed for IP_6, the largest error is observed in the vertical plane. A suitable correction was found, but because of technical limitations an alternative correction had to be found. The result is shown in the figure, correction (blue), before any corrections (red) and measurement after applying 80% of the correction strength (green). The local error is originating to the right of the IP, indicating that the main source is the triplet. Applying 100% of the correction had a negative impact on the optics. A list of the correctors used for IP_6 is shown in Table 1.

Figure 3 shows the phase error observed for IP_{12}. A suitable correction was found using the correctors listed in Table 2. A large number of correctors were used to achieve the correction shown. The calculated correction (blue) agrees well with the measurement (red). Only a correction of 20% was applied. Measurement after correction (green) indicate a change in the observed phase error.

Table 1: List of Local Correctors used for IP_6 Correction

Corrector	$\Delta K[10^{-4}m^{-2}]$	rel values[%]
Q7I6	0.84	1
Q5IT6	-0.53	2
Q1I6	-0.05	-0.1
Q2O6	0.05	0.1
Q5OT6	1.97	7

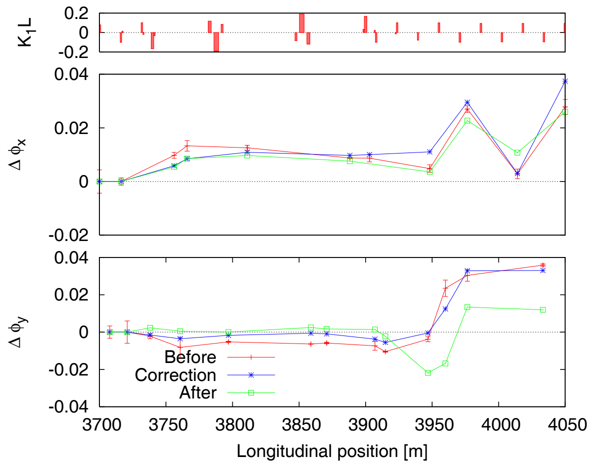

Figure 2: Local correction for IP_6. Small plot is the location and strengths of the quadrupoles around the ring. Top plot is horizontal plane and bottom vertical plane. Measurement before correction (red), fitted model (blue) and measured after correction (green). Largest deviation is observed in the vertical plane.

Table 2: List of Local Correctors used for IP_{12} Correction

Corrector	$\Delta K[10^{-4}m^{-2}]$	rel values[%]
Q6O12	8.9	0.1
Q5O12	-17.9	2
Q2I12	-2.2	0.4
Q3I12	2.7	0.5
Q4I12	18.0	-2.0
Q5I12	26.9	3.0
Q6I12	-44.9	5.0

β-beat for several steps in the correction process is shown in Figure 4. Top plot is the horizontal plane and bottom plot the vertical plane. A peak beta-beat of $\sim 30\%, 40\%$ is observed for the baseline measurement (red). After the correction in IP_6 was applied (green) the peak beta-beat in the horizontal plane remained the same. In the vertical plane the large local jump at IP_6 is corrected. The peak beta-beat is reduced to a 20% level. Applying IP_6 and IP_{12} correction (blue) simultaneously a difference is observed in both planes. The peak beta-beat, in the horizontal plane was reduced to a 20% level. In the vertical plane however, the peak beta-beat was not further reduced.

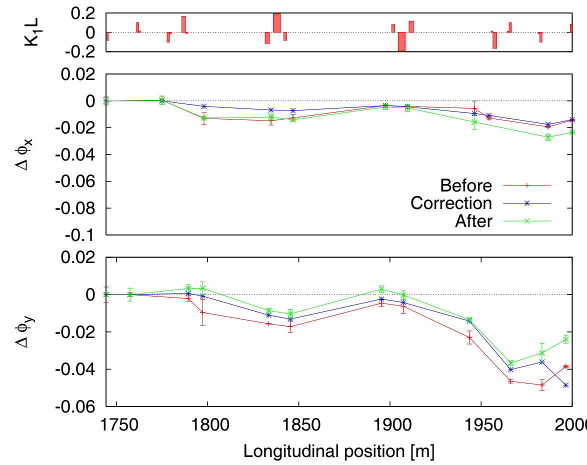

Figure 3: Local correction for IP_{12}. Small plots are the location and strengths of the quadrupoles around the ring. The large top plot is the horizontal plane and bottom vertical plane. Measurement before correction (red), fitted model (blue) and measurement after correction (green). Largest error is observed in vertical plane.

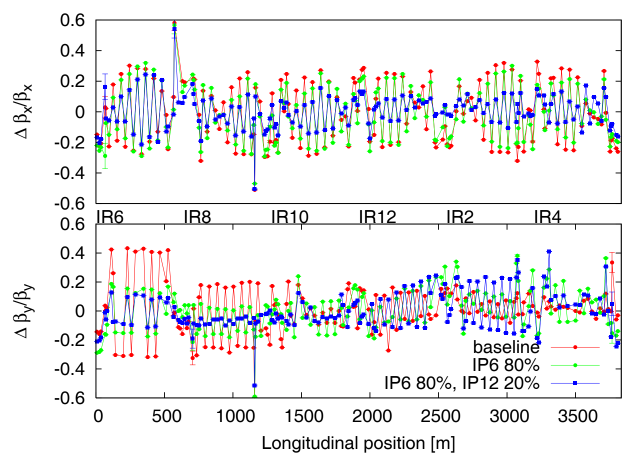

Figure 4: β-beat for several steps in the correction process. After the correction in IP_6 was applied (green) the peak beta-beat in the horizontal plane remained the same. In the vertical plane the large local jump at IP_6 is corrected. The peak beta-beat is reduced to a 20% level. Applying IP_6 and IP_{12} correction simultaneously a difference is observed in both planes (blue). Peak beta-beat, in the horizontal plane was reduced to a 20% level. In the vertical plane however, the peak beta-beat was not further reduced and remained at a 20% level.

OPTICS STABILITY

Optics stability is important for safe operation. Measurements were conducted to investigate the variation of the

β-beat over a period. Baseline measurements were conducted, separated by 1.5 months. In Figure 5 a histogram of the difference in the β-beat is shown. The main difference is below 10%. Figure 6 shows the phase error for the

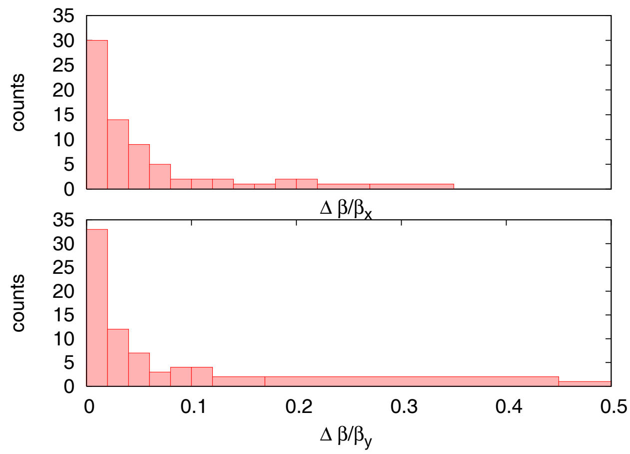

Figure 5: Histogram of the difference in the β-beat. Top horizontal plane and bottom vertical plane. Horizontal label is the difference in the β-beat between two fills separated by 6 weeks.

horizontal plane, top and vertical plane, bottom separated over 6 weeks and using different BPMs. The observed error is very similar for both fills. In the vertical plane there is one missing BPM for fill15329.

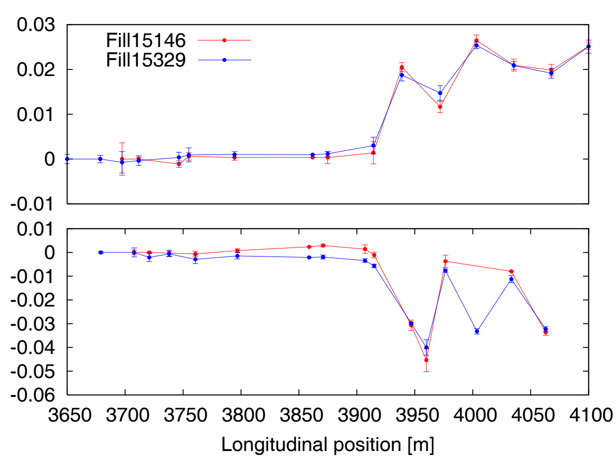

Figure 6: Measurement for the phase error in IP_6 is shown. The horizontal plane, top and vertical plane, bottom. Different starting BPMs were used and measurements were separated by 6 weeks. In the vertical plane there is one missing BPM for fill15329, compared to fill 15220.

CONCLUSIONS AND OUTLOOK

First measurements and corrections using the segment-by-segment technique show promising results. Correction for IP_6 and IP_{12} has been implemented and a reduction in the $\beta-$beat is achieved. The peak $\beta-$beat in both planes was reduced to a $\sim$ 20% level. Corrections were applied in the order of 20%, 80% of the calculated corrections. It will be investigated in the future why full calculated corrections could not be applied. A plausible explanation would be the effect from the AC-dipole. $\beta-$beat has been shown to be stable in the $\sim$ 10% level over a 6 week period. The observed local errors are reproducible from fill to fill and do not dependent on the starting BPM chosen. Scans of IP_4, IP_2 and IP_8 corrections were also performed during the polarized proton run in 2011. Local errors at IP_4 has been identified and a suitable correction was found. A first correction campaign for IP_4 shows promising results. Detailed analysis and comparisons are in working progress.

More detailed measurements and systematic scans of all IPs should be done. The effect of the AC-dipole on the linear optics should be taken into account. When all local errors are corrected to a satisfactory level a global correction should be calculated to correct small distributed errors. Same measurements and corrections should be repeated for yellow. When the $\beta-$beat in both rings is corrected the segment-by-segment should be extended to measure and correct locally the coupling, dispersion and chromatic β.

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