BETA-BEATING CORRECTIONS IN THE SPS AS A TESTBED FOR THE LHC

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Abstract

For several years optics measurement and correction algorithms have been developed for the LHC. During 2008 these algorithms have been tested in the SPS and RHIC. The experimental results proving the readiness of the applications are presented.

INTRODUCTION

Optics correction in the LHC is challenged by the tight aperture constraints requiring a beta-beating correction below the 20%. In the references [1, 2] it was demonstrated through simulation that the correction of the beta-beating and dispersion-beating with measured magnetic field errors [3] in the LHC is achievable. The observables used were the phase advance between BPMs (Beam Position Monitors) and the normalized dispersion as calibration independent observables. The choice of calibration independent observables was due to the fact that BPM resolution and calibration errors [4] for the LHC pilot bunch are not negligible.

PHASE ADVANCE MEASUREMENT

The optics is probed through the phase advance between BPMs as this provides a robust and calibration independent observable. The argument for this is that correcting the phase advance between BPMs is equivalent to correcting the beta function [1]. Although the beta function in the LHC is to be inferred from the measured phase advance between BPMs as done in LEP [5], it is not used for correction since it contains systematic error due to assuming the model transfer matrices. Three different algorithms are implemented to measure the phase advance between BPMs, namely SVD [6], SUSSIX [7] and Harmonic Analysis (or Discrete-Time Fourier Transform). All three yield a consistent phase advance measurement. However it is found that the SVD approach is more accurate when the number of turns is small and there are many BPMs [8].

Before starting optics measurement and correction, closed orbit distortion was corrected as much as possible in order to minimize the optics distortion due to the quadrupolar feed-down component from sextupoles. Chromaticities are also measured and corrected to $Q'_{x,y} \approx 2$ units. The beam is kicked in the horizontal and vertical planes simultaneously and 1000 turn data from all the BPMs are stored for the analysis. The horizontal and vertical phase advances between consecutive BPMs are the observables to be compared to the model. Figure 1 shows one of of phase-beating measurements, in which the difference of phase advance

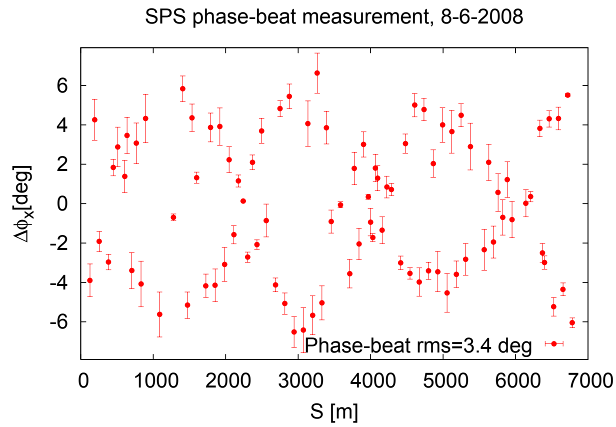

Figure 1: Phase-beating measurement in the SPS.

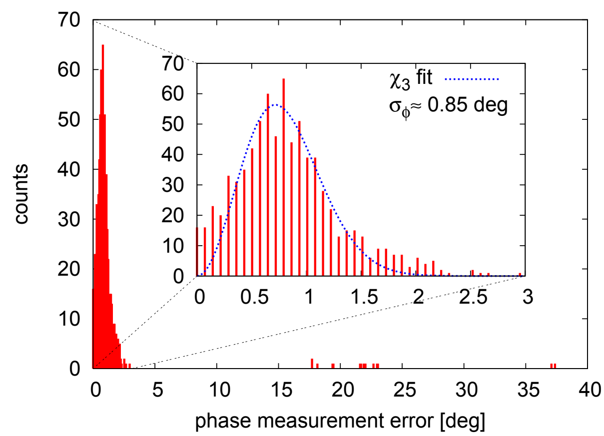

Figure 2: Phase measurement error in the SPS.

between the optics model and the measured values is computed. The phase beating pattern is observed, corresponding to an rms beta-beating of 6%.

The error of the phase measurement is estimated from the discrepancy among several measurements. The phase measurement in the SPS typically features an rms error of less than 1 degree as shown in Fig. 2. It is remarkable that the error distribution agrees to the expected χ^2_3 probability function, since 3 data sets are used and all BPMs are assumed to perform similarly.

Chromaticity deteriorates the phase measurement due to the induced tune spread within the bunch. The impact of chromaticity on the phase measurement was assessed by measuring at two different chromaticities as shown in Fig. 3. A less enhanced effect than in RHIC [9] is observed, where few units of chromaticity would dramatically dete-

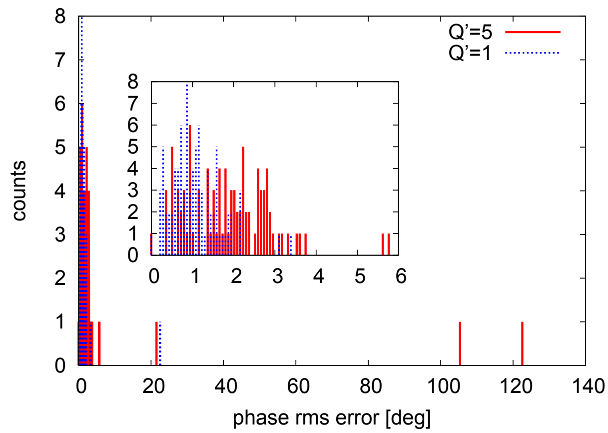

Figure 3: Phase measurement error in the SPS for the chromaticities of 1 and 5.

riorate the measurement for a fraction of the BPMs. The phase measurement error in the SPS doubles by increasing the chromaticity from 1 to 5. This fact has to be taken into account when aiming for precise measurements.

NORMALIZED DISPERSION MEASUREMENT

In order to achieve a BPM calibration independent measurement of the normalized dispersion ($D_x/\sqrt{\beta_x}$) the idea of "Global factor" was introduced in [9]. Basically, the ring average of the normalized dispersion has been verified to be almost independent of optics errors. Therefore it is possible to use the model average to properly normalize the measurement. This has the advantage that all global factors like momentum offset or kick amplitude cancel out. The normalized dispersion is measured from the orbit changes with momentum deviation divided by the square-root of beta function as inferred from the oscillation amplitude of beam centroid. The BPM calibration error is then canceled out since these two observables contain the same error. The quality of measurement between the normalized dispersion measurement and standard dispersion measurement was directly compared using the same data from the SPS, shown in Fig. 4.

The SPS optics would be rather close to the ideal model, and it is obvious from Fig. 4 that the normalized dispersion measurement shows much better agreement with the model. The disagreement in dispersion measurement can be attributed to the measurement error in momentum deviation, which was extracted from the machine setting. Due to a BPM measurement artifact in sector 5 (around s=5 km) the closed orbit measurement in the region was disturbed as we see in Fig. 5. The phase measurement is however not affected by the closed orbit, or DC component of the measurement.

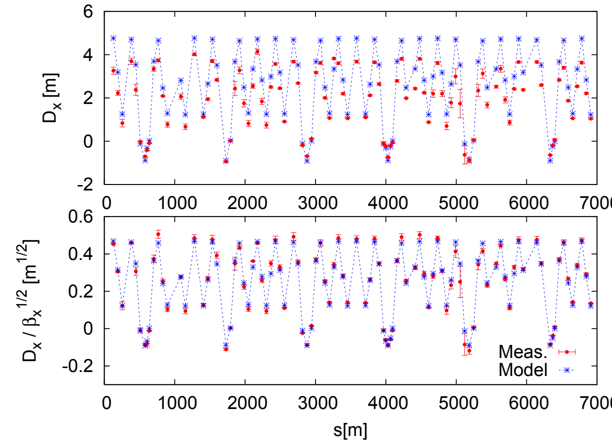

Figure 4: Dispersion and normalized dispersion measurement. The normalized dispersion measurement performs better since does not need the precise momentum offset.

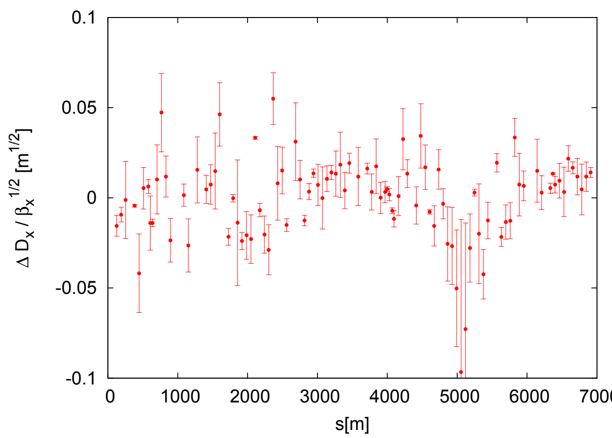

Figure 5: Normalized dispersion beating.

OPTICS CORRECTION

Optics corrections based on the phase advance and normalized dispersion measurements were applied to the SPS. Possible correction knobs were computed using a linear response matrix and applied to the machine.

The knobs for correction here are horizontal orbit bumps at sextupole locations since there are only three quadrupolar families powered in series in the SPS. As shown in Fig. 6, closed orbit bumps of a few mm was applied to the SPS. The sensitivity of response matrix can be adjusted by putting weight on betatron tunes, phase advance and normalized dispersion. The optics measurement and correction procedures were applied twice in the SPS in two different days in order to verify their reproducibility. The results are shown in Figs. 6 and 7, more weight was put on the phase advance than on the normalized dispersion. The phase-beating was effectively corrected by a factor of 2 while the normalized dispersion beating remained unaffected.

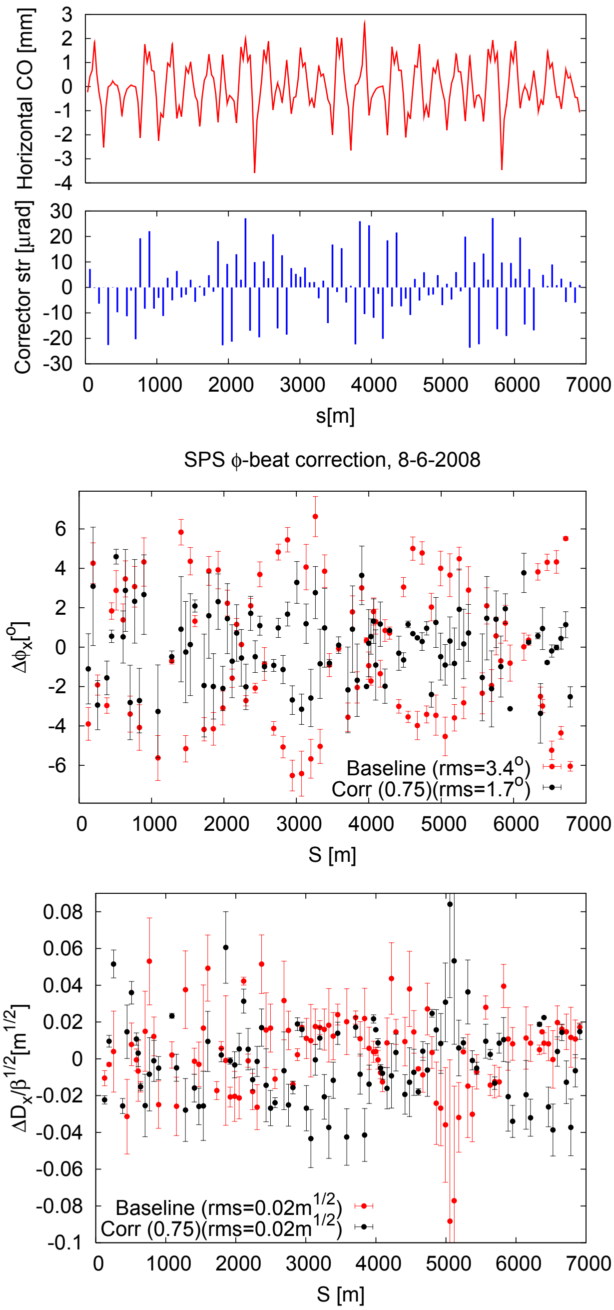

Figure 6: Phase (middle) and normalized dispersion (bottom) beatings before and after correction for the measurements on the 8^{th} of June, 2008. The top 2 plots show the variation of the horizontal orbit and the orbit corrector strengths used for the correction.

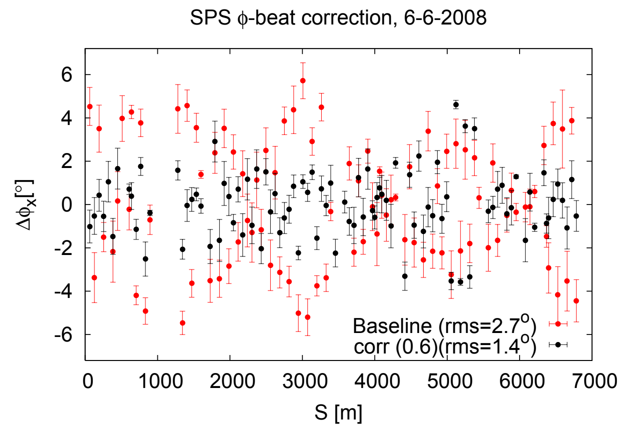

Figure 7: Phase beatings before and after correction for the measurements on the 6^{th} of June, 2008, showing the repeatability of the correction.

SUMMARY AND OUTLOOK

Optics measurement and correction techniques have been developed for the LHC and successfully tested in the SPS. Calibration independent observables such as the phase advance and the normalized dispersion are used for the correction. The impact of chromaticity on the phase measurement has been observed to be less dramatic than in RHIC. The direct comparison of the normalized dispersion measurement and the standard dispersion measurement revealed that the normalized dispersion measurement is indeed more robust. More tests especially on the (normalized) dispersion correction and linear coupling are scheduled for 2009.

ACKNOWLEDGMENTS

We are very thankful to I. Agapov and J. Netzel for help in the implementation of the on-line beta-beating application.

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