INVESTIGATIONS OF SPS ORBIT DRIFTS

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Abstract

The LHC is filled from the last pre-injector, the Super Proton Synchrotron (SPS), via two 3 km long transfer lines, TI 2 and TI 8. Over the LHC injection processes, a drift of the beam trajectories has been observed in TI 2 and TI 8, requiring regular correction of the trajectories, in order to ensure clean injection into the LHC. Investigations of the trajectory variations in the transfer lines showed that the main source of short term trajectory drifts are current variations of the SPS extraction septa (MSE). The stability of the power converters has been improved, but the variations are still present and further improvements are being investigated. The stability over a longer period of time cannot be explained by this source alone. The analysis of trajectory variations shows that there are also slow variations in the SPS closed orbit at extraction. A set of SPS orbit measurements has been saved and analysed. These observations will be used together with simulations and observed field errors to locate the second source of variations.

INTRODUCTION

The trajectories in the SPS to LHC transfer lines are drifting and must be corrected frequently. Each correction campaign costs significant time and buys into the availability for LHC physics. The variations are seen mainly in the horizontal plane. An analysis of the origin of the trajectory variations revealed several sources. The ripple of the 20 kA power supply of the SPS extraction septum (MSE.6 for TI 2 and MSE.4 for TI 8) is one of the main sources for both transfer lines. After the improvement of the ripple between the LHC runs 2011/2012, the shot-by-shot stability was greatly improved, but trajectory drifts prevail. In addition to the MSE, the variation of the SPS orbit is suspected to be a large source [1, 2]. Towards the end of LHC run 1, SPS orbit data during LHC physics beam cycles was collected and analysed to localise the source of the orbit drifts.

OBSERVATIONS OF SPS ORBIT DRIFTS

SPS orbit data was only stored towards the end of LHC run I and therefore limited data is available for analysis. To isolate effects on the circulating orbit from extraction, the orbit data was saved at the flat-top (T=18500 ms), 300 ms before extraction. By taking the difference orbit from a reference, the changes are tracked. The orbits were filtered to take into account only data where the beam was successfully extracted and injected in the LHC.

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In the extraction region, a horizontal orbit bump of more than 35 mm is applied to move the circulating beam as close as possible to the extraction septum and reduce the required strength of the extraction kicker. The data of the larger aperture Beam Position Monitors (BPMs) in the extraction region have large errors and cannot be used directly to define the beam position and angle at the extraction point. A fit based on many BPMs was used to obtain a better estimate. Each orbit is fitted using the function $X(s) = [A\times\sin(\mu(s))+B\times\cos(\mu(s))]\times\sqrt{\beta(s)}+\frac{dp}{p}\times D(s)$, which represents a betatron oscillation plus a dispersion orbit due to momentum offset, dp/p. The fit parameters A, B and dp/p are calculated by a least square fit routine in python.

From the fitted parameters the orbit excursions at two BPMs in the extraction region are calculated. Fig. 1 shows the orbit drifts at BPCE.61805 and BPCE.41801 for extraction from SPS LSS6 to TI 2 and SPS LSS4 to TI 8 respectively. In the horizontal plane the orbit is drifting by 1.4 mm at BPCE.61805 and 1.8 mm at BPCE.41801. In the vertical plane the orbit is stable.

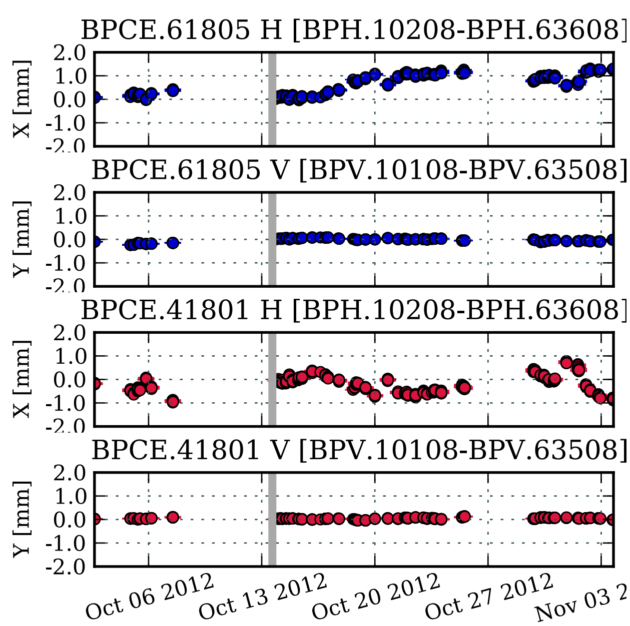

Figure 1: The orbit variation calculated at BPCE.61805 (TI 2) and BPCE.41801 (TI 8) shows a significant drift in the horizontal plane with respect to the reference orbit (grey line).

MATCHING SPS ORBIT DRIFTS TO TRANSFER LINE TRAJECTORY DRIFTS

For the transfer line trajectory drifts previous analysis showed that there are many sources without any clear candidates [2]. Using the fitted SPS orbit data now available, the effect of orbit drifts in the transfer lines were calculated in MAD-X and subtracted from the corresponding measured trajectories. Only the betatron motion was included. For TI 2 the total RMS was reduced from 318 to 158 μm in the horizontal plane and from 126 to 102 μm in the vertical plane. For TI 8 the reduction was 348 to 198 μm in the horizontal plane and from 138 to 106 μm in the vertical plane.The jitter of the extraction septa (MSE6 for TI 2 and MSE4 for TI 8) explain part of the remaining variations. The remainder is a mix of several smaller sources in both planes.

SPS SOURCE INVESTIGATIONS

To investigate the sources of orbit drifts, the orbits have been analysed by Model Independent Analysis (MIA) [3]. Through singular value decomposition MIA separates the temporal and spatial eigenmodes of the orbit data. The spatial eigenmodes with significant eigenvalues can be used to identify the sources of variation. In this case there are two large eigenvalues in the horizontal plane, see Fig. 2. In the vertical plane the eigenvalues are small and will not be considered further.

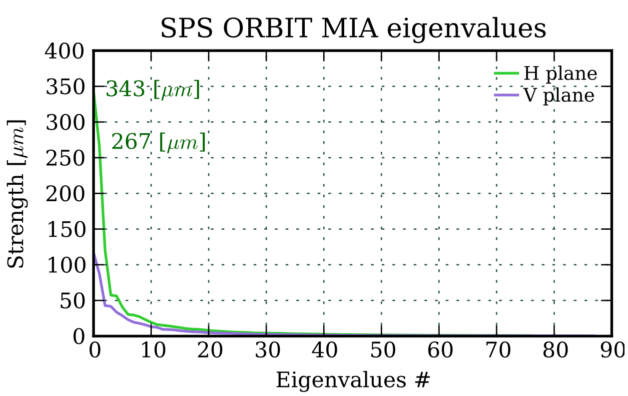

Figure 2: Two strong eigenmodes are found from the MIA analysis, indicating that there are multiple sources.

When there are two strong modes, the actual sources may be a mix of those modes. Therefore the analysis period has been divided into two periods. From Fig. 1 two natural choices appear: 13/10-24/10 and 29/10-4/11. For both periods there are significant variations. There is only one significant eigenmode for each period, see Fig. 3.

Because the SPS has many elements, there could in principle be many sources that match with the same phase advance. To identify the location of the sources, MICADO was used to find the best single corrector among all elements in the machine for all orbits within a given period. Afterwards, a selection of elements, including all extraction elements was compared to the MIA eigenmodes.

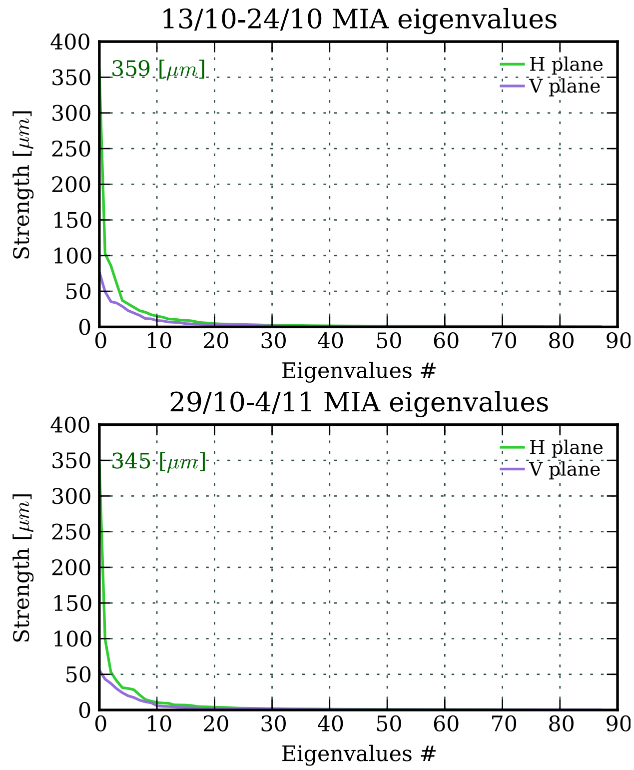

Figure 3: When two shorter analysis periods are used one strong eigenmode appears for each period.

For the first period the best correctors were found to be: MDHB.61804 (orbit corrector) and the MST.617 (thin septum) in LSS6, see Fig. 4. These two elements have a difference in phase advance of 2°. The MSE.618 is only 4° upstream of the MDHB. The MSE.418 in LSS4 also shows up frequently, however only for small orbit differences. The same elements all match the MIA analysis, see Fig. 5.

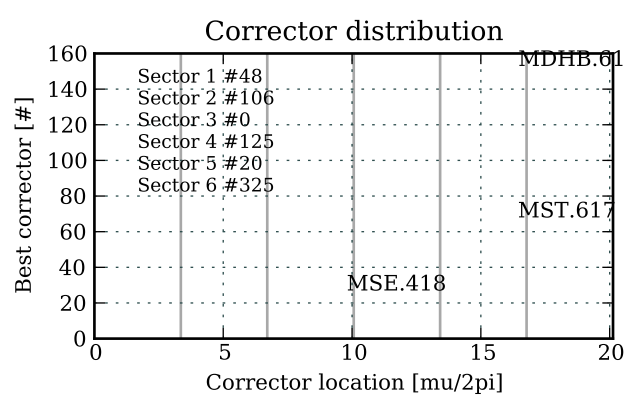

Figure 4: For the first period the MST.617 and MDHB.61804 show up as the main correctors.

The above found sources do not fit for the second period. From the MICADO algorithm, the best corrector was found to be the dipole MBA.606, see Fig. 6. For the MIA eigenmode the best match is the extraction bumper MPSH.62199, followed by MBA.606 and MPLH.61655 (extraction bumper

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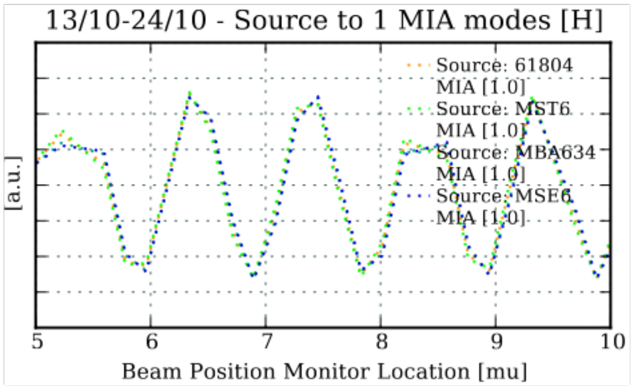

Figure 5: Best matches for the 359 μm spatial mode in the period 13/10-24/10.

magnet). The MSE.418 also fits reasonably well. Sources with the same phase advance $+N \times 180°$ cannot be distinguished and therefore several candidates match as a source. Elements in LSS6 are most frequently proposed as correctors by MICADO for both periods.

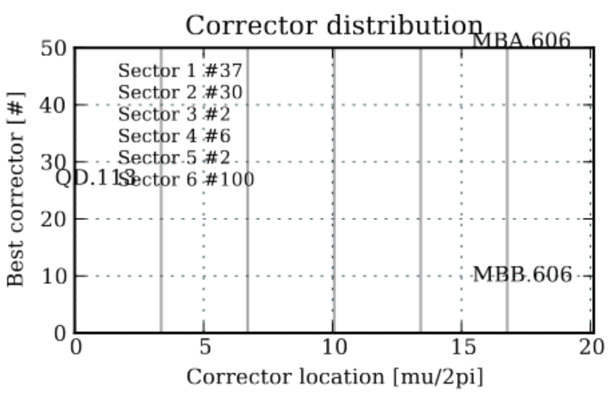

Figure 6: The best corrector for this period is the dipole MBA.606, followed by QD.133 and MBB.606.

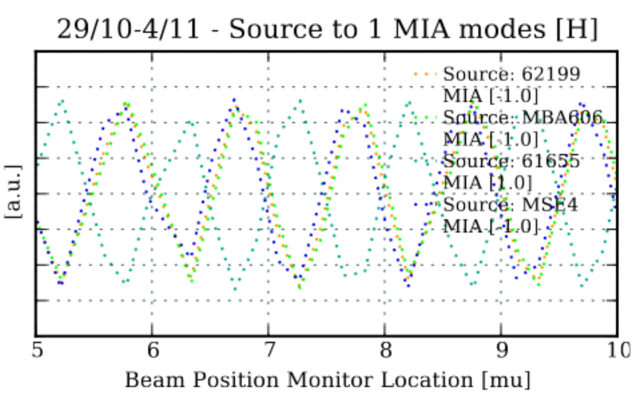

Figure 7: The best matches for the period 29/10 - 4/11.

For the extraction bumpers the logged currents where checked for drifts, but the variations were found to be too small to cause the observed orbit variations. The MBHA.61804 current is not logged, but this orbit corrector should not be active at flat-top. For the MSE and the MST, the circulating beam only sees the stray fields. Lab measurements show that the strength of the stray fields depend on the distance from the septum [4]. Because of the extraction bump the distance to the septa varies strongly over the length of the septum magnet, see Fig. 8. Therefore a model of the bump and septum was made to estimate the effect of the stray field due to a 1 mm change of the orbit. The outcome of the study is however that the stray field of the MSE and MST in LSS6 give additional orbit deviations of only 14 and 7 μm peak-to-peak respectively, which is too small to explain the drifts.

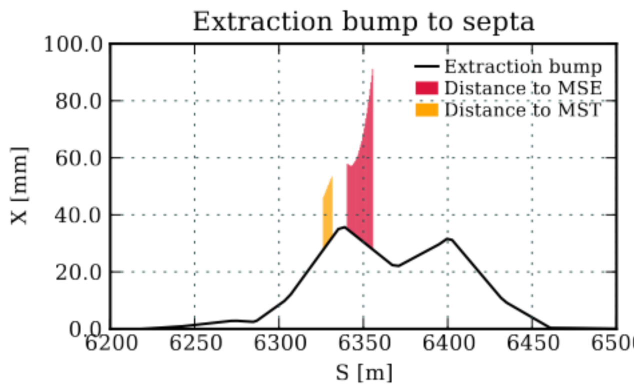

Figure 8: Extraction bump and septa for LSS6 extraction of LHC beam 1. The distance of the bump to the MST varies between 18 and 22 mm and 23 to 63 mm to the MSE.

SUMMARY

SPS orbit data collected over one month have been analysed to find the sources of orbit drifts and consequently transfer line trajectory drifts. Combining the data with transfer line trajectory data showed that the SPS orbit drift is the main contribution to drifts in the transfer lines.

Analysis of orbit data over a month shows that there are two large sources. Several candidates where checked and have the correct phase advance, however no element has been identified with large enough errors to cause the observed variations. In parallel an orbit correction strategy has been investigated [5].

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