SOFTWARE PACKAGE FOR OPTICS MEASUREMENT AND CORRECTION IN THE LHC

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Abstract

A software package has been developed for the LHC on-line optics measurement and correction. This package includes several different algorithms to measure phase advance, beta functions, dispersion, coupling parameters and even some non-linear terms. A Graphical User Interface provides visualization tools to compare measurements to model predictions, fit analytical formula, localize error sources and compute and send corrections to the hardware.

INTRODUCTION

The primary aim for the development of a software package is to have a tool which is able to perform on-line measurements and calculate corrections which could be implemented on-line. The graphical user interface (GUI) is developed in Java to be compatible in the control system of the LHC and uses the functionalities offered by the LHC software architecture (LSA) [1] and the on-line model [2]. The computational algorithms used for the analysis are mainly written in Python or C. The output of every algorithm used in the software package is stored in TFS tables. This allows easy communication among all the algorithms. The package has already been successfully implemented in other accelerators such as the relativistic high energy collider (RHIC) [3], synchrotron lightsource (SOLEIL) [4] and the super proton-synchrotron (SPS) [5]. This paper will describe the main features of the software package.

HIERARCHY

During operations efficiency is one of the key parameters to make an experiment successfully. The philosophy of the software package is to minimize the user input and expertise needed. A screenshot of the GUI can be seen in Fig. 1.

Figure 2 shows a flow diagram of the analysis steps. During operations the flow diagram in Fig. 2 is followed from the top. The first step in the process is acquiring excited turn-by-turn data, usually 2000 turns. A single kick or an ac-dipole excitations are used to provide the betatron oscillations.

Figure 3 shows an example of the turn-by-turn data from the two different methods: single kick and AC-dipole. The AC-dipole is used to drive betatron oscillations with a predetermined frequency close to the main betatron tune. The first 2000 turns are ramping up of the AC-dipole amplitude followed by flat top for 2000 turns and ramping down for 2000 turns. For the analysis only the 2000 turns at flat top are used. Data acquired using the AC-dipole is not influenced by decoherence. Therefore more turns are used in the analysis.

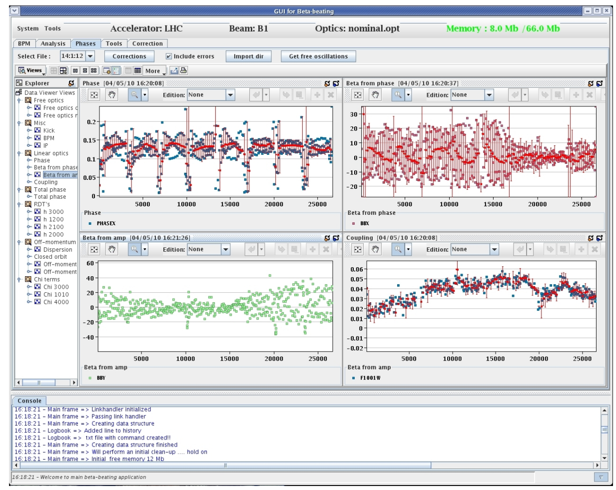

Figure 1: Screenshot of the graphical user interface for the LHC. This tab is showing a typical result of the analysis. Clockwise you have a plot of the horizontal phase advance, horizontal beta-beat from phase, vertical beta-beat from the amplitude and the difference resonance coupling term.

After turn-by-turn data is acquired the code converts the acquired data to the internal data structure used in the software package. A first cut of faulty BPMs and a reduction of the noise of the BPMs is done using using an SVD filter [7].

The second step is a decomposition of the turn-by-turn data into Fourier basis, i.e going from the time domain to the frequency domain. Singular value decomposition [6], or an interpolated FT (SUSSIX) [8], can be used. Both codes calculate the amplitude and phase of the main betatron tune line and coupled line. SUSSIX also calculates the secondary lines generated by non-linearities. A BPM noise statistics is available from SVD. A manual cleaner allows the user to select and remove bpms in the GUI. The automatic cleaner takes the horizontal and vertical tune of all BPMs , assumes a gaussion distribution and removes all BPMs with a tune outside the window of nσ. The last step in the analysis is to compute a large set of optics parameters: $\beta_{x,y}$,$\alpha_{x,y}$,$D_{x,y}$,$D^{'}_{x,y}$,f_{1001},χ_{1010},... both from SUSSIX and SVD. Off-momentum data is taken by changing the radial steering. When the ac-dipole is used to acquire

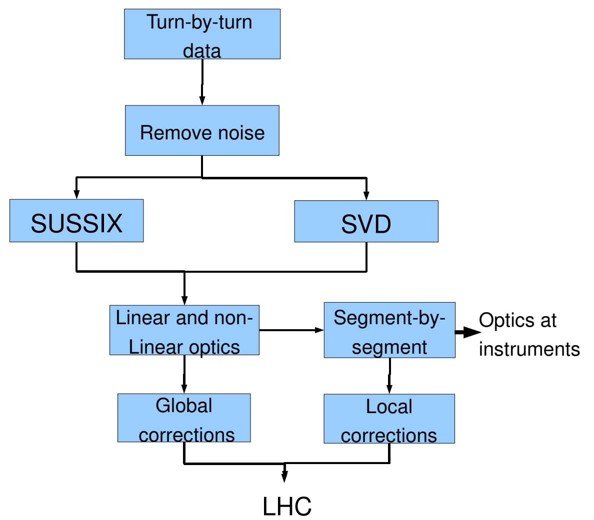

Figure 2: Flow diagram showing the steps done during operation. Turn-by-turn data is acquired using either a single kick or ac-dipole. The turn-by-turn data is then decomposed in Fourier basis. From the output the linear and non-linear optics are calculated. When a large discrepancy is observed segment-by-segment can be used to identify local sources. From this a local correction or when only small distributed errors a global correction can be calculated and send to the machine.

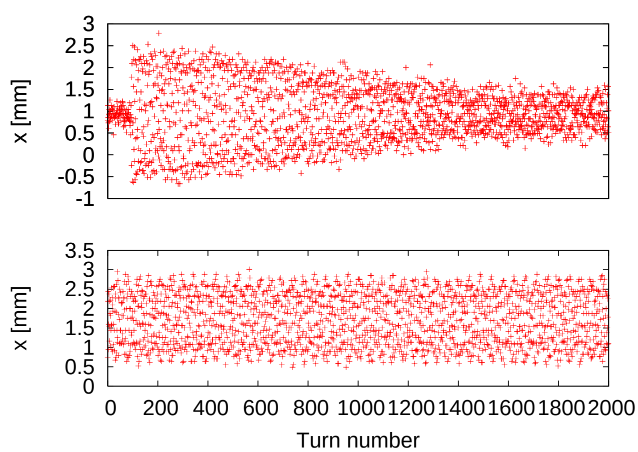

Figure 3: Plot showing the difference between a single kick, tune or aperture kicker and a ac-dipole.

data, the motion is not free. This means that the calculated optics will be actually the driven optics. The free optics can be either recovered by a set of equations [9] or a model where the effect of the ac-dipole is taken into account by introducing a quadrupole at the location of the AC-dipole. Figure 4 shows an example of the difference between free optics and driven optics. The difference in the beta-beat is around 5%. The following optics parameters are calculated:(i) phase advance, (ii) beta from phase and amplitude, (iii) horizontal and vertical dispersion, (iv) off-momentum phase and beta,(v) resonance driving terms and chi terms

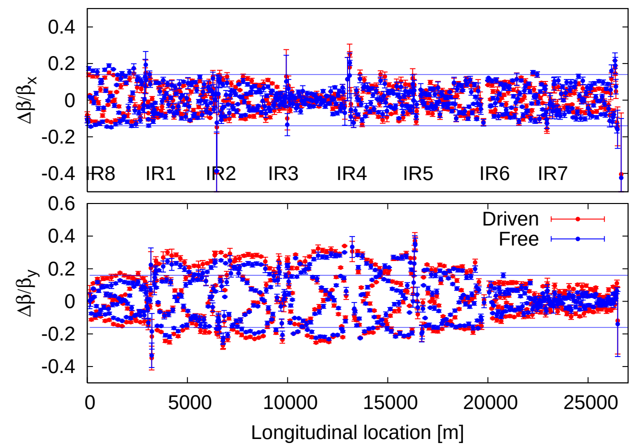

Figure 4: Plot showing the difference between the driven beta-beat from the ac-dipole (blue) and the calculated free beta-beat (red), horizontal plane above and vertical plane below

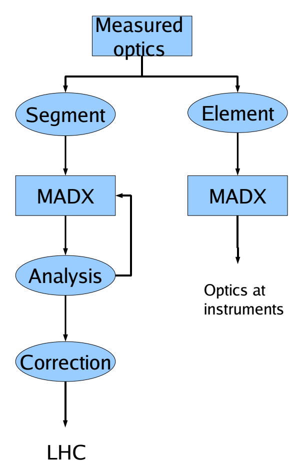

Figure 5: Flow diagram showing the steps done for segment-by-segment. Segment-by-segment uses the measured optics, such as phase,beta,dispersion and coupling to calculate for a segment or a single element.

coupling, sextupolar and octupolar components [10].

SEGMENT-BY-SEGMENT

To ease the process for the identification and localization of local error sources a segment-by-segment approach is developed, Fig. 5 shows a flow diagram for segment-by-segment. The idea is to divide the machine in different segments (IPs and arcs). The segment is treated as a beam line. Measured optics values at beginning and end of the segment are taken. These values are placed in a madx script which forward propagates and back propagates the measured values trough the segment. By taking the measured values as an input all the errors in front of the segment are taken into account, any discrepancy between measured and propagated model indicates a local error in that segment.

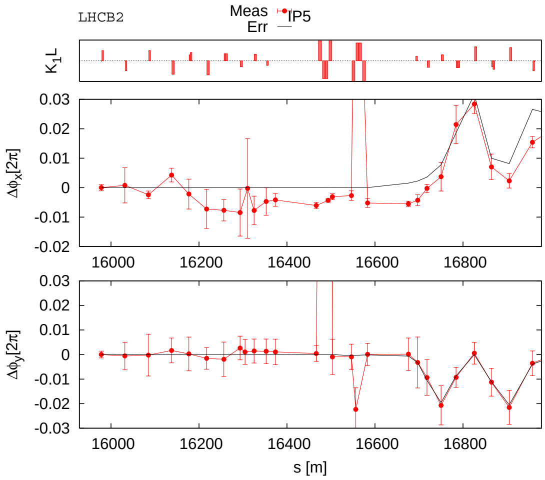

Figure 6: The plot shows the horizontal total phase advance above and the vertical below. The total phase is the difference between propagated phase advance and ideal model phase advance. From the plot below its clear to see that there is an error at around 16700 m.

Table 1: Table showing the calculated betastar for the four experiments using segment-by-segment method. Calculated betastar is within the $\sim 15\%$ of the model.

IP (Model [m])	β_x^* (error$_x$) [m]	β_y^* (error$_y$) [m]
1 (2)	2.28 (0.09)	2.02 (0.35)
2 (2)	2.07 (0.31)	1.85 (0.08)
5 (2)	2.05 (0.67)	2.02 (0.41)
8 (2)	2.07 (0.55)	1.86 (0.89)

The algorithm calculates the segment for different variables such as total phase, beta's, dispersion and coupling. The total phase is the difference between propagated phase advance and ideal model phase advance. Figure 6 shows an example of the output of the segment-by-segment approach. The plot shows the horizontal total phase advance above and the vertical below. From the plot it is clear to see that there is an error at around 16700 m. Another feature of segment-by-segment is calculating the phase, beta and dispersion at instruments, such as wire scanners,interaction points,collimator's... which need to be calibrated with the measured optics to reach optimal performance. This is done by propagating the measured values at the beam position monitor (BPM) close the the instrument. Table 1 shows the calculated β^* for the four experiments. The measured β^* values can be used by the experiments to optimize their measurements.

CORRECTION

The goal of the measurements is to identify and calculate corrections for possible optics mismatch. First local errors are identified and corrected using segment-by-segment. When the optics is corrected to a level where there is no dominant error source left in the machine, a global correction can be applied. Beta-beat and horizontal dispersion is corrected using a quadrupole scheme. Skew quads are used to correct coupling. Vertical orbit bumps are used to correct coupling and/or vertical dispersion. SVD [6] or a Micado is used to calculate the correction. A response matrix or a best corrector approach respectively.

SUMMARY AND OUTLOOK

An on-line graphical user interface has been developed. It has been successfully implemented and used during operations in several accelerators. The GUI handles the whole process from turn-by-turn data to calculating the linear and non-linear optics with a minimum user input. When large discrepancies are found with respect to the model a localized segment-by-segment approach can be used to identify and calculate possible corrections. For smaller distributed errors a global corrections can be applied. Correction schemes are available for beta-beat, horizontal dispersion, coupling and vertical dispersion.

In the future more automated processes should be included to ease operations. Possibilities for non-linear corrections should be investigated.

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REFERENCES

[1] C. Roderick and R. Billen, "The LSA database to drive the accelerator settings", CERN-ATS-2009-100 2009.

[2] S. Redaelli et al, these proceedings.

[3] R. Calaga et al, these proceedings.

[4] G. Vanbavinckhove et al, "Linear and non-linear optics measurements at SOLEIL", Proceedings of PAC09, Vancouver, BC, Canada.

[5] M. Aiba et al, "Beta-Beating Corrections in the SPS as a Testbed for the LHC", CERN-ATS-2009-055 2009.

[6] R. Calaga, "Linear Beam Dynamics and Ampere Class Superconducting RF Cavities @RHIC", Phd thesis, 2006.

[7] R. Calaga and R. Tomás, "Statistical analysis of RHIC beam position monitors performance", 2006, prstab VOLUME 7, 042801 (2004).

[8] R. Bartolini and F. Schmidt, CERN SL/Note 98-017 (1998).

[9] R. Miyamoto, "Diagnostics of the Fermilab Tevatron Using an AC Dipole", Phd thesis, 2008.

[10] R. Tomás,"Direct Measurement of Resonance Driving Terms in the Super proton Synchrotron (SPS) of CERN using Beam Position Monitors", Phd thesis, 2003.