

POST-MORTEM ANALYSIS OF BPM-INTERLOCK TRIGGERED BEAM DUMPS AT PETRA-III

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Abstract

PETRA-III is a 3rd generation synchrotron light source dedicated to users at 14 beam lines with 30 instruments. This operates with several filling modes such as 60, 240 and 320 bunches with 100mA or 40 bunches with 80mA at a positron beam energy of 6 GeV. The horizontal beam emittance is 1nmrad while a coupling of 1% amounts to a vertical emittance of 10pmrad. During a user run unscheduled beam dumps triggered by Machine Protection System may occur. In many cases the reason can be identified but in some it remains undetected. Though the beam is lost some signature is left in the ring buffers of the 226 BPM electronics where last 16384 turns just before the dump are available for post-mortem analysis. Scrutinizing turn by turn orbits and the frequency spectrum measured at a BPM can improve understanding of such a beam loss and may help to increase the efficiency of operation by eliminating the sources. Here we discuss in detail the functionality of a Java GUI used to investigate the reasons for unwanted dumps. In particular, the most effective corrector method is applied to identify correctors that might have perturbed the golden orbit leading to violations of the interlock limits.

INTRODUCTION

PETRA-III [1] is a 3rd generation synchrotron light source commissioned with positron beam energy of 6 GeV and 100mA stored current at betatron tune values (36.12, 30.28). The horizontal beam emittance is 1nmrad while a coupling of 1% amounts to a vertical emittance of 10pmrad. The machine is dedicated to users for experiments from 14 beam lines with 30 instruments. This operates with several filling modes, such as 60, 240 and 320 bunches with 100mA or 40 bunches with 80mA. During the normal user operation, there are unscheduled beam dumps triggered by Machine Protection System (MPS) [2, 3]. These triggered dumps may be before or some times after the loss of beam. The loss of beam after the beam dump by MPS is understood as the reason as implied by the protection system. But the loss of beam before the beam dump by MPS or sudden fall of beam current and subsequently filled up by top up are unexpected. In these cases the reason is not identified or some cases it is undetected. But, though the beam is lost, it left some signature on its post-mortem data. From these data proper scrutinization of turn by turn orbits and the frequency spectrum measured at a BPM can improve understanding of such a beam loss and may help to increase the efficiency of operation by eliminating the

sources of disturbance. For these purposes, there are 226 Beam Position Monitors (BPM) distributed in 2303.952m ring to monitor the transverse orbits by Libera System[4]. These BPMs are connected with a Ring Buffer where continuously 16384 latest turns of data for each BPM is stored in Libera. When the Libera server receives a beam dump signal from MPS, it dumps 16384 turns of orbit data for each BPM to an Archive Server with an event time stamp for post-mortem analysis. It is worth to mention that the revolution frequency of PETRA III is 130.121 kHz. Though there are 226 BPMs, all are not activated to trigger a MPS signal. The BPMs in damping wiggler sections in West and North, the BPMs in DBA sections are activated with lower and upper limit of orbit deviations in transverse plane. If the orbit deviations are beyond these limits at any of such special BPM then Libera initiates an interlock event to MPS to fire a beam dump signal. As mentioned above the post-mortem data not only contains orbits but includes these interlock orbit bounds and the Σ -signal of beam intensity. These post-mortem data are huge and contains a lot of information which we want to extract and analyze in this paper using a Java Graphics User Interface (GUI) Web application.

The GUI is developed in Java. It requires JRE 6+ or Java Web Start 1.5+ to run with a memory of 1024MB. It uses FORTRAN subroutine MICADO[5] of CERN library of MADx program for its most effective orbit corrector [MEOC] method. The FORTRAN subroutine is called via a Java Native Interface (JNI) written in C. To run in every computer, where FORTRAN library routines are not available, this code temporarily copies FORTRAN runtime library files (.DLL) into TEMP directory of the user. The post-mortem data are downloaded iteratively from the Archive Server [6-8]. Due to heavy demand on this server, sometimes maybe bit difficult to retrieve data. If occasionally null data is retrieved then one has to read the event once again.

Here we describe the beam dump events for the tripping of corrector magnets, wrong setting of power supplies, failure in RF system temperature regulations, unclosed injection kicker bumps etc. The main features are looking into the frequency spectrum [9] of turn by turn orbits of a particular BPM; the MEOC method is applied to identify correctors that might have perturbed the golden orbit leading to violations of the interlock limits at an active BPM. Due to transient malfunction of a magnet, the orbit will grow and surpass the interlock limits at some special BPM and the beam will be dumped by MPS. In post-mortem analysis this change in orbit can be corrected by a few correctors using MICADO to investigate the cause of beam loss in transverse plane.

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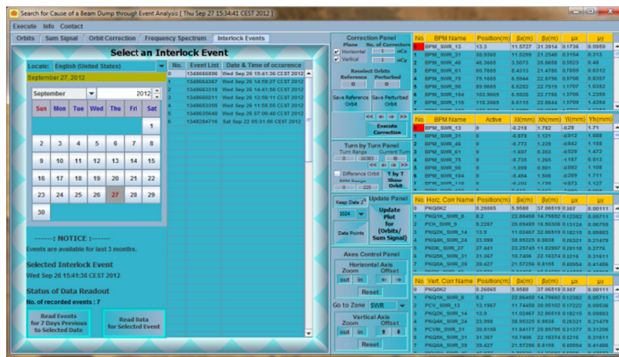


Figure 1: The graphics user interface GUI-MEOC used for Post-Mortem Analysis of BPM-Interlock Triggered Beam Dumps.

GUI-MEOC

The Java GUI-MEOC as shown in Figure-1 has 3 major panels along with the menu bar at the top. They are the Graphics Panels in the left, command Button Panel in the middle and information Table Panel at the right. These are briefly discussed below.

The Table Panel contains information about the 226 BPMs, 687 horizontal correctors, and 608 vertical correctors. These are real or artificial correctors assembled to analyze the cause for beam loss. For this purpose the dipoles, quadrupoles, and sextupoles are split into two parts and an artificial corrector is inserted in between.

In the left there are 5 Tabbed Panes that display the graphics for four different types of observations. These tabbed panes are:

Orbits: This displays the transverse orbits (x , y) for selected BPM and selected range of turns. Once you are in this pane and want to show the orbits for another BPM. Then select the BPM and click 'Update Plot for (Orbits/ Sum Signal)' button.

Sum Signal: This shows the Σ -signal (sum of BPM 4 plate voltages) of the selected BPM in the top and the transverse orbits below. With this you can observe the orbits as a function of sum signal. Once you are in this pane and want to see the orbits for another BPM. Then select the BPM and click 'Update Plot for (Orbits/ Sum Signal)' button.

Orbit Correction: Mostly it is blank as you select it. This pane is automatically selected for most effective orbit corrector method and the corrected and uncorrected orbits are displayed.

Frequency Spectrum: As you observe the orbits in the first pane. In the back ground the frequency spectrum is calculated and plotted in this pane. One can observe the spectrum only after the first pane is clicked.

Archive Interlock Events: This pane is open in the beginning of initialization of the GUI. It displays the recent interlock events occurred for last 7 days including the current day. By default the most recent event is selected in the Event List Table of 'Select an Interlock Event' Panel. Now select the event of your interest by

clicking over the list. Click the button 'Read data for Selected Event' to read post-mortem data from Archive Server.

In the middle, the Button Panel has four subpanels such as Correction Panel, Turn by Turn Panel, Update Panel and Axes Control Panel. They are briefly described here.

Correction Panel: This Panel is mostly used for MEOC. The button 'Save Reference Orbit', once clicked, saves the reference orbit for the turn number as mentioned in the text field of 'Reference'. The button 'Save Perturbed Orbit', once clicked, saves the perturbed orbit for the turn number as mentioned in the text field of 'Perturbed'. nCx and nCy are the number of correctors to be used for MEOC in horizontal and vertical planes respectively. In the left, there are choices for horizontal or vertical plane for orbit correction. By default both are selected. One can select or deselect for particular plane. Once the reference orbit, perturbed orbit, No. of correctors and plane are selected, it is ready for orbit correction. Click the button 'Execute Correction'.

Turn by Turn Panel: This Panel is used for turn by turn data analysis. The current turn number may be entered by typed in or be selected by clicking in the chart. The turn by turn orbit is displayed by clicking the button 'TbT Show Orbit'. If the selection box 'Difference Orbit' is ticked, then the difference orbit between the reference orbit and the current orbit is displayed.

Update Panel: This Panel is used for update of transverse orbits or sum signal display. To navigate to another BPM you may click the button 'Update Plot for (Orbits/Sum Signal)'. As you know the Fast Fourier Transform (FFT) works for 2^N data points. To keep the data points to this order, once the upper limit of turn number is selected, you may use Combo Box to select the lower limit of turns so that it will lie within 16 to 16384.

Axes Control Panel: This last portion of the Panel is used for graphics axes control. In addition, the Menus in the Menu bar extend some additional jobs that necessary for users. 'Show Poincare Map' shows the Phase Space plots at the center of undulator sections for all the DBA cells for 16384 turns or for a selected range of turns.

RESULTS AND DISCUSSIONS

Tripping/Wrong Setting of a Magnet

The orbits are corrected using slow orbit correction [10] with SVD using 191 horizontal correctors and 187 vertical correctors employing 226 BPMs. In normal operation, the golden orbits are maintained with Fast Orbit correction using SVD with 40 fast correctors on either plane. During the process of correction some correctors may set higher currents than desire leading to high orbit oscillations. This can also happen due to improper setting of other magnets such as quadrupoles and sextupoles etc. A small change in set current can be treated as an effect of an artificial corrector incorporated in it. So, in case of unknown beam dumps, the change in orbits in post-mortem data may be corrected choosing a

few numbers of correctors. The MEOC is utilized to investigate the suitable corrector that might have perturbed the orbit beyond the interlock limits. For example, the event (Sun Dec 04 09:18:13 CET 2011) was due to the failure of the vertical corrector magnet PKVSX_SR_82 which was setting wrong values that lead to beam dump. You can see from Figure 2 that the difference vertical orbit was well corrected to zero using the same corrector.

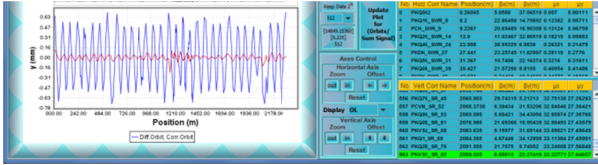


Figure 2: Vertical orbit correction for the Interlock Event on Sun 04 December 2011 at 09:18:13 which indicates PKVSX_SR_82 vertical corrector as the source of disturbance.

Regulation Problem & Tripping of RF System

As per statistics the major beam dump is associated with RF system of PETRA III, though gradually it is delivering more stable operations. We have seen drop in beam current during top up mode as shown in Figure 3(a,c). Sometimes it is refilled with top up and sometimes not, rather leads to self-triggered beam dump. This may be due to not proper regulations in temperature control of cavities. We have seen the frequency in spectrum analysis of orbits during such a failure. As shown in Figure 3(b), we clearly see the dispersion orbit in arc sections looking to the difference orbit in the trailing edge of BPM sum-signal, indicating the failure of RF system when all magnet power supplies are on.

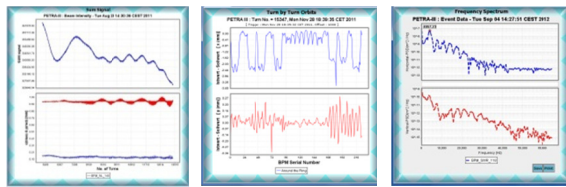


Figure 3: (a) The effect on sum signal and the transverse orbits during the unregulated temperatures of the cavities in the RF system; (b) The dispersion orbit is produced as you look into the difference orbit during the failure of RF system while all magnet power supplies are on; (c) frequency spectrum at a BPM.

Unclosed Injection Kicker Bump

The machine operates in top up mode with 1% current variation. Depending on number of bunches filled, the beam lifetime varies and as a result the beam is injected at different time intervals. It is observed that due to some unforeseen reasons the injection bump is not closed in some rare cases. This led to beam dump due to large oscillations in orbit in the injection plane as shown in Figure 4(a).

Drifting of a Quadrupole Magnet Power Supply

In rare cases the read back current of quadrupoles or other magnets drift from their corresponding set values resulting gradual drift in orbits leading to MPS beam dump. In Figure 4(b,c) one can observe the behavior of quadrupole QA4_OL_61 and the dipole magnets in new DBA sections respectively.

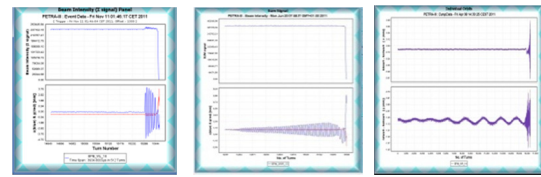


Figure 4:(a) unclosed injection kicker bump; (b) the transient behavior of QA4_OL_61;(c) 600Hz oscillations on power supplies of new DBA octant dipole magnets.

CONCLUSION

This Java GUI Web application is used for post-mortem analysis of MPS beam dumps for PETRA III. It reproduces the source of disturbance accurately for simulated beam dumps by setting higher currents in corrector magnets. This may be intuitively used to apply for other unknown cases, where a corrector set wrong higher value temporarily and come back leading to a beam dump. Same may be applicable for quadrupoles, sextupoles etc. This program is also utilized to trace the orbit perturbation and frequency spectrum left behind by RF system, injection kicker, quadrupoles and corrector magnets which has enabled us to remove the cause of such perturbations for optimal operation of PETRA III

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