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FURTHER IMPROVEMENTS IN POWER SUPPLY CONTROLLER TRANSIENT RECORDERS FOR POST-MORTEM ANALYSIS OF BPM ORBIT DUMPS AT PETRA-III

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Abstract

PETRA-III is a 3rd generation synchrotron light source dedicated to users with 14 beamlines beginning operations in 2010. The storage ring was modified in 2014 for an additional 12 beamlines in two extensions. It is operated with several filling modes with a total current of 100 mA at electron beam energy of 6 GeV. The horizontal beam emittance is 1.30 nmrad with 1% coupling. During a user run the Machine Protection System (MPS) may trigger an unscheduled beam dump due to high deviations in orbits if transients in the magnet power supply (PS) currents are detected which are above permissible limits. PS controllers provide transient recorder data, showing differences between current set-point and readout values in a time span of several seconds around the moment of a beam loss. We describe automatic management system handling a large number of PSs, performing automatic transient recorder data readout, storing and is available for offline analysis. We discuss hardware implementation of transient recorders and its configuration software, a Java GUI application used to investigate the transient behavior of different PSs, which might have been responsible for emittance growth, orbit fluctuations, or the beam dumps seen in a post-mortem analysis.

INTRODUCTION

PETRA-III [1] is a 3rd generation synchrotron light source commissioned with an electron beam energy of 6 GeV and 100 mA stored current at betatron tune values of 37.12 and 30.28. The horizontal beam emittance is 1.30 nmrad while a coupling of 1% amounts to a vertical emittance of 13 pmrad. The machine was commissioned for experiments at 14 beam lines with 30 end-stations in 2010. The storage ring was further modified at extensions in East and North to incorporate 12 new beam lines including a super luminescence beam line from dipole radiation in 2014. PETRA operates with several filling modes, such as 40, 60, 80, 240, 480 or 960 bunches with a beam current of 100 mA. During the normal user operation, there are unscheduled beam dumps triggered by the Machine Protection System (MPS) [2]. These triggered dumps may occur before or sometimes after the loss of beam. The reasons for beam loss due to the MPS are of course understood. But the loss of beam prior to the beam dump by the MPS or a sudden drop in beam current, are both unexpected events. In these cases the cause remains unidentified or in some cases undetected. However, although the beam is lost, it leaves its signature in its post-mortem data. These post-mortem data are huge and contain a lot of information which can be extracted and analysed in a special Java Web Application Most Effective Orbit Correction (MEOC) [3, 4]. Here we discuss how the Power Supply Controller (PSC) Transient Recorders are used in the post-mortem analysis to pin point the source of disturbance in magnet power supplies, which will help us to avoid or rectify the source of orbit perturbation in machine operation in the future.

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MAGNET CONTROL SYSTEM STRUCTURE OVERVIEW

Petra III ring contains 1158 magnets, supplied by 669 power supplies. Each power supply (PS) is digitally controlled by a corresponding intelligent power supply controller (PSC), responsible for switching the PS on/off, setting the output current value in various ramping modes, monitoring the output current values and performing other PS-specific control as well as PS diagnostics functionality as shown in Fig. 1.

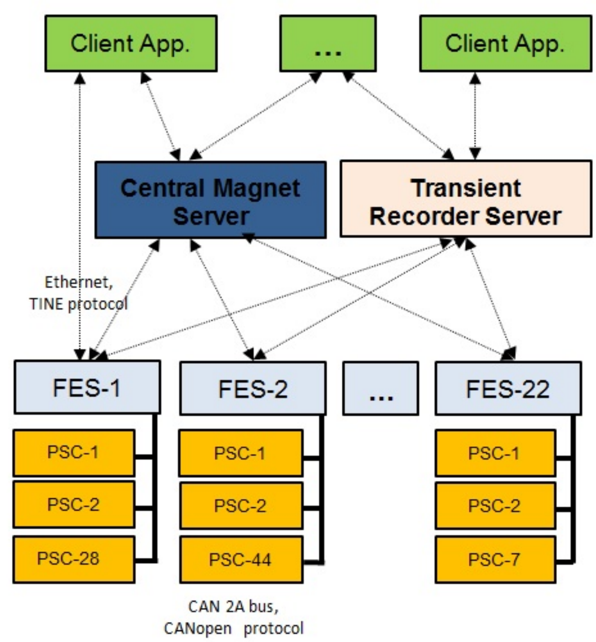

Figure 1: Magnet Control System structure overview.

All PSCs are managed by 22 front-end servers (FES) over 40 CAN buses [5] using CANopen [6-8] protocol. The Central Magnet Server communicates with front-end servers over Ethernet, using TINE [9] protocol and plays a role of the system integration unit and managing PSC group operations. It offers client applications a hardware and bus topology independent view, by hiding device hardware, addressing and fieldbus details.

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PSC TRANSIENT RECORDER IMPLEMENTATION

Firmware of the PSCs, besides other diagnostic functionality, implements also a transient recorder (TR) unit consisting of:

- Circular buffer for storing samples of a difference of output current set value (Sv) and a read back value (Rv).
- Configuration parameter set: maximum allowed output current deviation, trigger position, number of samples used for averaging, delay after ramping finish.
- Triggering system which analyses the absolute value of Sv-Rv and compares it to user-defined maximum deviation parameter.

Every 500 microseconds a sample, being a difference of set and read back value is calculated and stored for averaging. Depending on the user-defined settings the averaging can use from 2 to 255 samples. The averaged value is stored in a circular buffer of capacity of 20160 16-bit values. After receiving a start command, if the TR detects an event (that absolute value of the Sv-Rv difference is greater than programmed maximum current deviation), a trigger flag is raised in the PSC status word, the position in the circular buffer of the triggering sample is marked, and the data collection runs until the trigger position matches the requested position in the buffer. The trigger position, similarly to a trigger position in digital oscilloscopes, can be set from 0% (buffer contains only samples after the triggering event) up to 100% (the buffer contains all samples before the triggering event). Due to the impedance of the magnet circuit, the absolute value of Sv-Rv difference can temporally grow both during and just after the ramping process. Therefore the triggering mechanism is disabled during the ramp. A delay-after-ramp-finished parameter let to disable the triggering also for a specified period after the ramp is done. The details are shown in Fig. 2.

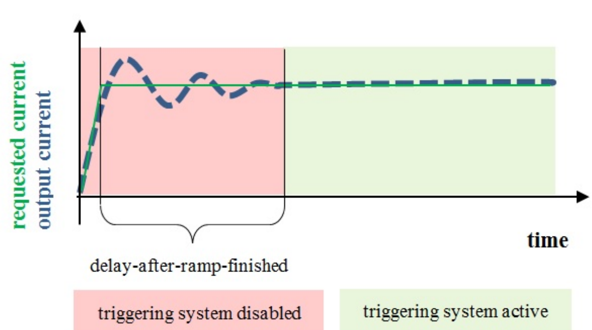

Figure 2: Triggering system disabling conditions.

In addition each sample stored in the circular buffer has a single-bit label showing, whether the sample was collected during the ramp, which helps to interpret the sample value during further analysis.

Completion of the data collection is indicated in the PSC status word and the circular buffer becomes ready for next trigger event readout.

FRONT-END SERVER MANAGEMENT OF TRANSIENT RECORDERS

The FES continuously monitors status of each PSC. For all PSCs whose transient recorders have received the trigger and which have finished collecting samples, a readout procedure is initiated. The entire circular buffer content (20160 samples, 40320 bytes) along with a header containing a PSC status 'snapshot' at that moment is transferred, when the trigger is detected. The snapshot consists of the requested value of the output current, the read back value of the output current, the PSC status word, the number of samples used for averaging and a triggering sample position within the data buffer.

The readout of transient recorder samples buffer is performed as a CANopen segmented SDO [8] transfer. In order to minimize impact of elevated CAN bus load during the transfer on a normal control operation, an additional, dedicated, low priority SDO channel is used. After the transfer of transient recorder data is completed the triggering system becomes reactivated again. The transferred buffer and the header form a record of the transition event, which can be accessed by client applications as well as by the Transient Recorder Server over the TINE interface.

The front-end servers are also responsible also for keeping the PSC transient recorders configuration up-to-date. If the PSC status shows the PSC has been power-cycled or reset, then the FES sends over the CAN bus the recently used TR parameter set.

TRANSIENT RECORDER SERVER

The Transient Recorder Server integrates a huge number of transient recorders and front-end servers into one system, by providing users with methods to access each PSC and thus its transient recorder by its name and hiding all Front-End Servers and CAN buses addressing details.

The most effective TR configuration strongly depends on the corresponding power supply output current range and on electrical properties of the related magnet. The Transient Recorder Server maintains a PSC configuration data base, where configuration of each TR is stored. It also provides users with a possibility of creating PSC configuration groups (e.g. "quadrupoles, 400A") and assigning the same configuration to all group members. One can also issue commands such as "start", "stop", or "test trigger" to all transient recorders belonging to a selected group. It greatly simplifies testing and maintenance of such a complex system.

The Transient Recorder Server collects transient recorder event records from the front-end servers and stores them on the disk. The stored records can be obtained by client applications over the TINE interface for further analysis. There is also an automatic mechanism to delete older records, in order to keep the archive size reasonably small.

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TRANSIENT RECORDER SYSTEM MAINTENANCE CLIENT APPLICATION

Users can manage the transient recorder system by using a dedicated Magnet PSC Transient Recorder Management Client application (as shown in Fig. 3). The application communicates with the Transient Recorder Server over Ethernet using TINE protocol and reflects the entire functionality of the server. It offers users a comfortable interface to configure and examine a single transient recorder. It also makes it possible to define configuration groups, assign power supply controllers to them, and next to propagate a configuration of a single, selected Transient Recorder to all group members.

There is a feature also to display of status information (such as triggering system active/not active, TR triggered, buffer data transmission in progress) of each of all the transient recorders. The displayer can the present status of transient recorders organized in configuration groups, or also in other, user-definable ‘operational’ groups, which might serve better, more machine operation specific, views.

The client application obtains a list of the most recently triggered recorders, and the user can examine a transient recorder event for each of them. The time based plot of the transient recorder event, as well as FFT plots are helpful for a rapid data analysis or the case documenting of the specific event.

The possibility of exporting the event in the form of an ASCII file may be used for some further studies.

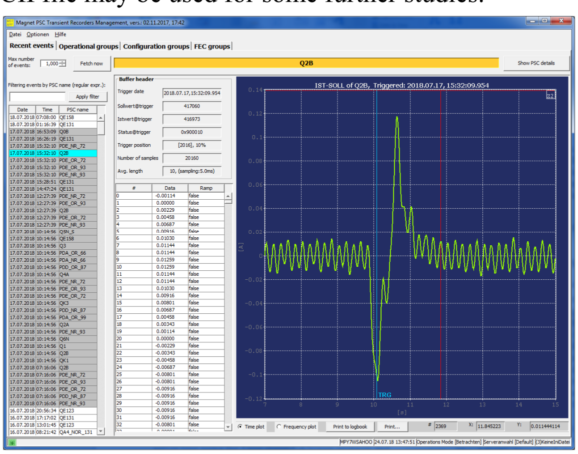

Figure 3: The graphics user interface of Magnet PSC Transient Recorder Management Client application.

RESULTS AND DISCUSSIONS

Using post-mortem beam transverse orbit dump data a proper scrutinization of turn by turn orbits and the frequency spectrum measured at a BPM may improve the understanding of a beam loss and may help to increase the availability of machine operation by eliminating the sources of disturbances. For these purposes, there are 246 by Libera [10] Beam Position Monitors (BPM) distributed in 2303.952m ring to monitor the transverse orbits.

These BPMs are connected with a Ring Buffer where the 16384 latest turns of data for each BPM are continuously stored in each Libera. When the Libera server receives a beam dump signal from the MPS, it dumps its 16384 turns of orbit data for each BPM to an Archive Server with an event time stamp for post-mortem analysis. 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 a transient malfunction of a magnet, the orbit will grow and surpass the interlock limits at some special BPMs and the beam will be dumped by the MPS. In a post-mortem analysis this change in orbit can be corrected by a few correctors using MICADO [11] algorithm to investigate the cause of beam loss in transverse plane.

The MEOC is utilized to investigate the suitable corrector that might have perturbed the orbit beyond the interlock limits. For example, the event (Mon Apr 16 15:14:41 CEST 2018) was due to the transients of the vertical corrector magnet PKVSX_WR_140 which was receiving wrong set values due to spikes leading finally to a beam dump via orbit interlocks. You can see from Fig. 4 that the difference orbit was well corrected to zero using the same corrector.

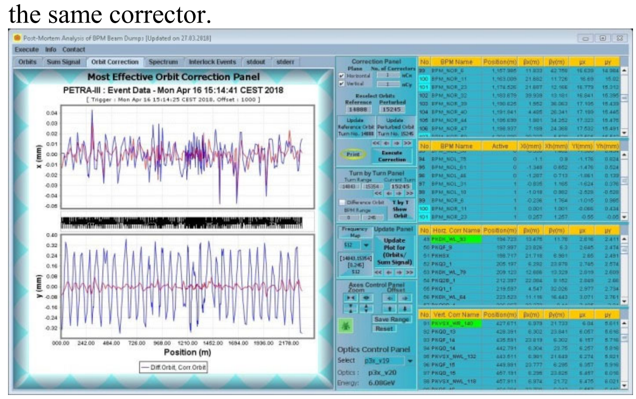

Figure 4: Vertical orbit correction for the Interlock Event on Monday 16 April 2018 at 15:14:41 which indicates that PKVSX_WR_140 vertical corrector as the source of orbit perturbation.

CONCLUSION

The present PSC Transient Recorder is utilized to monitor the transients in 669 PSs of the PETRA III electron storage ring. All the PSs are manually put in active mode which are triggered when the difference in read and set values are larger than the thresholds of respective PSCs. This is used with a post-mortem analysis of BPM beam dumps to find the responsible PS that disturbs stability or causes a loss of beam. We are currently developing better, more user friendly utilities of PSC transient analysis in order to improve stability and reliability of PETRA III operation.

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