COMMISSIONING RESULTS AND IMPROVEMENTS OF THE MACHINE PROTECTION SYTEM FOR PETRA III

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Abstract

PETRA III is a high brilliant synchrotron light-source operating at 6GeV. The commissioning of the machine had started in April 2009 [1]. In the first months of operation the Machine Protection System (MPS) ran on basic MPS requirements to protect absorbers and vacuum chambers in the damping wiggler section and the undulator section against synchrotron light. Therefore several alarms distributed along the machine are identified and within 100µs a dump command is created. The beam is dumped within 400µs by switching off the RF system [2]. Prior to the first user runs different improvements increasing the reliability and availability were planned and partly implemented in the MPS. This paper presents commissioning results of the system and gives an overview of these new implementations as well as a more detailed discussion of some alarm conditions and the dump procedure. Additionally some key aspects of the Temperature Interlock as one major alarm deliverer are described.

INTRODUCTION

Starting in June 2007 the former preaccelerator PETRA II was rebuilt to a high brilliant 3rd generation synchrotron light source operating at 6 GeV. In seven eights of the 2.3km long accelerator tunnel all installations were removed, modernized and reinstalled. In one eight an experimental hall was built which houses 14 undulator beamlines, experimental hutches and laboratories. In two straight sections of the machine damping wigglers are installed to reduce the horizontal emittance to the designed value of 1 nm rad [1]. A Machine Protection System (MPS) is required to protect absorbers against too high impact of synchrotron light and wigglers and undulators against losses of the electron beam. The MPS needs to dump the beam within several hundreds microseconds in case of unsafe conditions, detected from several alarm deliverers located around the machine [2].

The commissioning of the PETRA III machine as well as the MPS started in March 2009, the first beam was stored in April 2009. In the first months of operation with low beam currents the MPS ran on basic requirements to prevent the machine from damage. Since then diverse functionalities for increasing the availability and reliability of the system were implemented as well as upgrades for diagnostic purposes.

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MPS CONFIGURATION

The MPS is distributed in nine PETRA III halls in 19" crates. A connection to the control system is made via the in-house fieldbus SEDAC. At one position (east hall) the beam current (DC) is measured and digitally distributed by a redundant optical fibre loop which transmits both beam current information and dump information to all crates in the system. 24 alarm modules are shared in 10 crates. Each alarm module features 16 inputs for several alarm deliverers (e.g. beam position monitors (BPM), temperature interlock, etc.).

Every alarm input can be masked by an individual beam current threshold. There are three types of alarms connected to the MPS:

- To protect the machine against damaging by synchrotron radiation or the electron beam about 170 alarms can create a trigger which dumps the beam.
- Further 16 alarms are used to mask other inputs.
- Additionally 50 alarms from magnet power supplies, the RF system and kickers are connected to the MPS which are not triggering a dump but allow a first alarm detection. This can help operators finding the reasons of beam losses and dumps [2].

Figure 1 shows the connections of the MPS; figure 2 shows the topology of the MPS.

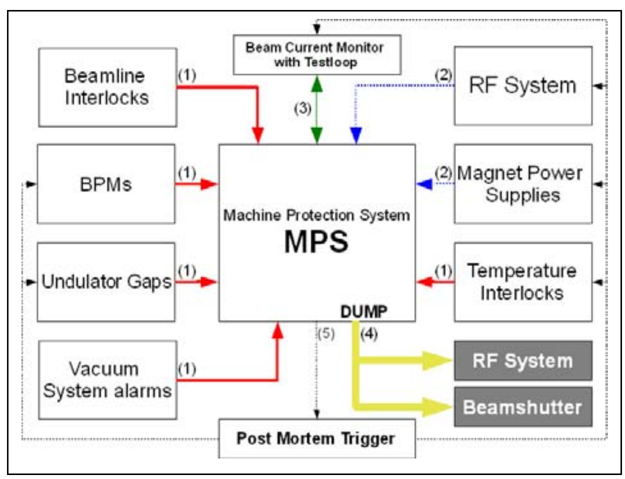

Figure 1: Connections of the MPS. Diverse alarm deliverers are connected to the MPS: red (1) Alarms generate a beam dump; blue (2) alarms are used for the first alarm detection. The MPS compares the measured beam current (green, 3) with an individual beam current threshold for each alarm input. The RF system and beam-stoppers are used for a beam dump (yellow, 4). A post mortem trigger (black, 5) is sent to several systems (e.g. RF system, BPM system).

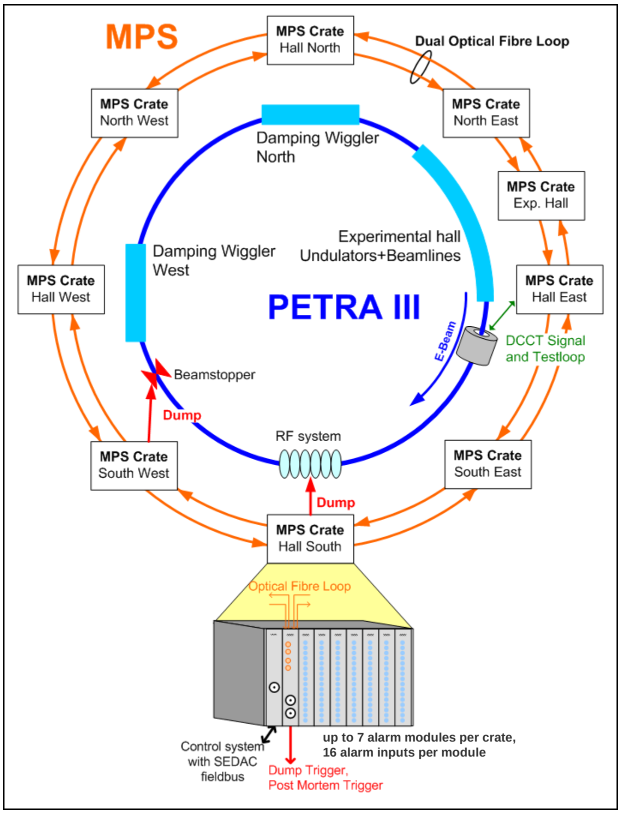

Figure 2: Topology of the Machine Protection System. The inner circle demonstrates the scheme of PETRA III.

Dumping the Beam

If a dump trigger is created due to fulfilled alarm conditions, a 5ms inhibit pulse is send to the RF system. The RF system then stops delivering power to the beam. Within approximately 400µs the beam is lost on a dedicated scraper [8]. As a slow fallback two beam-stoppers are driven into the beam aperture, which inhibits also a new injection of beam into the machine until the operator resets the MPS manually.

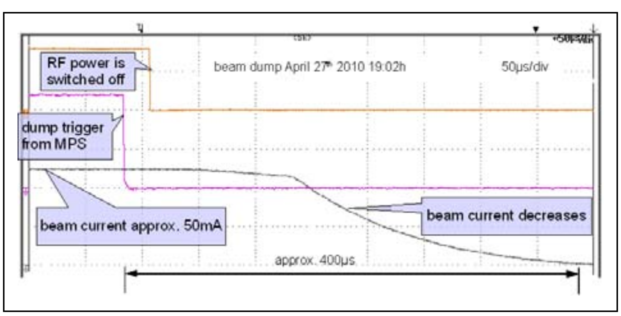

Figure 3: The falling edge of the MPS dump trigger (magenta) switches off the klystron power (orange). The beam (grey) is lost in approx. 400µs after the dump trigger. (courtesy of R.Onken, DESY)

Post Mortem Trigger

The MPS detects a beam loss by a fast drop in the measured beam current. This event is distributed through the optical fibre loop to all MPS crates from where the post mortem trigger is sent to several external systems, such as BPM system, RF system and magnet power supplies. The collected post mortem datasets can be used for time correlated analysis.

ALARM DELIVERERS

A dump can be triggered by the following systems:

Beam Position Monitors

A total number of 227 BPMs are installed in PETRA III for orbit monitoring, feedback and machine protection. The system is based on the Libera Brilliance electronics [3].

95 of these BPMs are connected to the MPS. They are placed mainly in the two damping wiggler sections (12 BPMs each) and in the experimental hall between the undulators. The alarm trigger of the BPMs in the undulator and damping wiggler sections are partly masked (disabled) by the “open” status of undulator or wiggler gaps [2] because then they do not limit the aperture.

Damping Wiggler Section and BPMs

After the first weeks of commissioning all damping wigglers where closed by hand around the beam pipe. Since then the permanent magnets of the wigglers had to be protected against the electron beam, and the absorbers placed between each wiggler had to be protected against synchrotron radiation. The power of several absorbers was limited to 26kW and 100kW respectively 120kW at that time. This corresponded to a beam current of 35 mA [8]. If at least two BPMs send an alarm and the beam current is above the threshold of 35mA the MPS dumps the beam. The BPM itself detects critical states by an orbit deviation of approximately +/-10mm in horizontal or +/-2mm in vertical direction to send an alarm to the MPS [5].

Undulator Section and BPMs

In the undulator section a set of two (single undulator) or three (double undulator) BPM alarms are masked/disabled by the corresponding “open” undulator gap [2]. The power of the synchrotron radiation without correct orbit (BPM) must not exceed 30W. An undulator gap of 12mm with a beam current of 1mA gives a power of approximately 15W in the beamline [6, 7]. Based on this, gaps closer than 35mm and a beam current exceeding 1mA in combination with BPM or other beamline alarms (e.g. fast vacuum shutters in the beamline) cause a dump trigger through the MPS. In the undulator section the BPM alarms are enabled by orbit distortions of approximately +/-0.5mm in horizontal and +/-0.2mm in vertical direction [5].

Temperature Interlock

The temperature interlock modules are an in-house development. Each module concentrates up to 8 PT100 sensors connected in 4-wire technique. Via a fieldbus connection temperatures can be read-out and individual temperature thresholds for each sensor can be configured to enable an alarm signal.

About 1.800 temperature sensors are located at certain locations such as absorbers and the beam chamber in the undulator and damping wiggler sections. Further sensors are placed on magnets and water cooling components for absorbers. 440 of these sensors are placed at sensitive locations and can generate an alarm for the MPS if a sensor exceeds a temperature threshold. 23 sensor groups are composed, each activated if at least one sensor of the group generates an alarm, to reduce the number of necessary MPS alarm inputs by a factor of 20.

The remaining sensors are used for information as shown in the temperature Interlock GUI in figure 4.

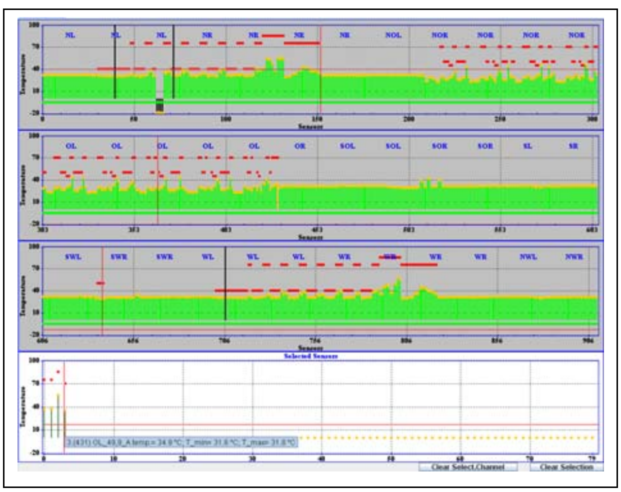

Figure 4: Temperature Interlock Console program. All sensors around the machine are displayed on one screen. Each sensor is represented by a vertical green bar. If the sensor is configured with a threshold, this is displayed by a horizontal red line. A horizontal yellow line at each sensor shows a maximum temperature of the sensor, updated every 60s.

Other Alarms

Beside undulator and wiggler gaps, BPMs and temperatures there are several other alarm sources such as vacuum shutters, getter pumps, a screen monitor, beamline interlock sensors and water flow sensors (absorber cooling) connected to the MPS for generating a beam dump in case of unsafe conditions. Also alarms from the RF system, the magnet power supplies, feedback systems and kickers are connected to the MPS to enable a detailed first alarm detection [2]. An important example are alarms generated by the RF system in case of RF-glitches and -failures which causes a beam loss itself. Together with the timestamps of the alarms, the beam current behaviour and the post mortem trigger one can sample a lot of information for a detailed analysis of the beam loss.

COMMISSIONING OF THE MPS

In the first months of PETRA III operation the MPS ran with basic requirements. During this time the major task was to protect the machine running at low beam currents. Not all functionalities to achieve a high availability were implemented. Observing the MPS hard- and software also led to ideas of suggestive, needful improvements and fine tuning for the system.

Step by step more alarm deliverers where connected to the MPS. With increasing beam current and better understanding of the machine some beam current thresholds in the MPS where also changed to higher values. As well temperature thresholds were increased and new sensors were installed at some new locations.

Due to extensive tests in the laboratory before installation the hardware worked without any problems from the very first beginning.

Since features like first alarm detection and beam loss analysis were not implemented from the beginning, this sometimes had to be done by hand. The first undulator operations took place with beam currents below 1mA. Since high accuracy for such small currents was not foreseen in the MPS requirements some improvements were implemented.

Beside the main goal of protecting the machine from damage, the MPS can serve another important purpose: with its connections to a number of other systems it can support the operators with important information about the chronological order of alarms to derive the reason of a beam loss or beam dump.

FIRMWARE IMPROVEMENTS

The hardware configuration of the MPS mostly remained unchanged since the beginning of the commissioning. Due to the flexibility of FPGAs as the heart of the modules important improvements for several functionalities such as beam loss detection or averaging mechanisms for the measured beam current can be made.

Beam Current Measurement

The MPS measures the beam current with a dedicated beam current monitor (BERGOZ MPCT) [2]. Regarding to the basic requirements the necessary resolution was 1mA. Just at the beginning of the commissioning a more accurate beam current measurement was required to operate with undulators below 1mA. To satisfy this requirement, an averaging of 100ms was implemented in the firmware what still guarantees a safe machine operation. To ensure still a fast tracking of the beam current in the MPS after a beam loss, the averaging mechanism has to be handled dynamically. Therefore the averaging is switched off after detecting a beam loss and is subsequently switched back to the 100ms averaging algorithm. This implementation works very well and provides both a stable beam current measurement with a resolution of 0.1mA and a fast tracking of the beam current in case of a beam loss.

Beam Loss Detection and Post Mortem Data

The new firmware detects beam losses and then triggers an FPGA internal post mortem recorder which stores the 83kS/s beam current values (12 bit) and the dump trigger signal over a total time of 24ms (+/- 12ms relative to the beam loss). This information is displayed in the MPS console GUI and helps the operator to interpret a beam loss by time relation between a beam loss and a dump trigger and the shape of the beam current decrease during the beam loss. Figure 5 shows a detected beam loss without a dump trigger. In figure 6 a dump was generated after a beam loss. Figure 7 shows a dump trigger generated by the MPS with the subsequent beam loss.

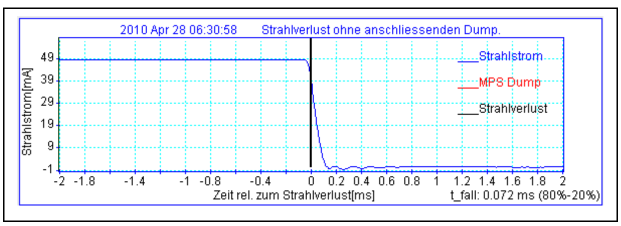

Figure 5: A beam loss occurred (e.g. by RF fail). No dump trigger was generated. The inwards circulating beam causes no dump trigger by BPMs after the beam loss due to the dynamic averaging in the MPS.

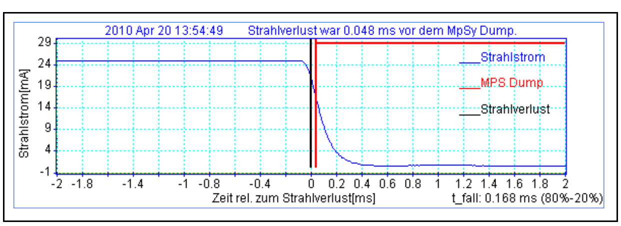

Figure 6: As a result of beam loss a dump is generated just after by the MPS. Due to an inwards circulating beam detected by undulator BPM with small horizontal orbit thresholds the dynamic averaging in the MPS reacts too slow.

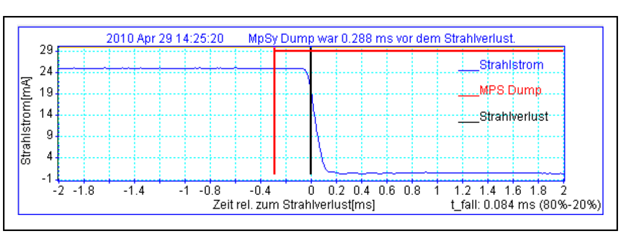

Figure 7: The MPS generates a dump trigger in consequence of fulfilled conditions (e.g. BPM alarms, temperature interlock) resulting in a beam loss.

First Alarm Detection

Preliminary first alarm detection is established in the firmware. This feature points to the alarm input(s) which first fulfilled the dump conditions. The module wide accuracy is approximately 100ns. The system wide accuracy (approximately 30µs) is only given by the delay of the optical loop which is used to send a dump condition among other things to all modules in the MPS.

In a later version more accurate first alarm detection supports timestamps to get a system wide resolution better than one turn (approximately 2µs).

Redundancy of the Optical Fibre Loop

The optical fibre loop is used for transmitting beam current information, dump trigger and synchronisation information in the MPS [2]. For the first time only one of the loops was used. By implementing the second loop the correct operation of the MPS is guaranteed even if one fibre breaks.

SOFTWARE IMPROVEMENTS

In the MPS console program (see figure 8) each alarm input is represented by an icon which shows the state of the input (e.g. alarm/no alarm, dump, disabled input).

One of the first improvements in the software was a simple archiving functionality. With this tool all alarm inputs can be viewed later and support both operators and designers detecting failures and the specific time of events with a resolution of 0.5s. The new implemented first alarm detection in the hardware is displayed by a special icon in the MPS console program so that the operator's attention is directly lead to the correct alarm and therefore to the faulty condition. Post mortem data from the MPS beam current monitor is displayed after beam losses occur (see figure 5 – 7). In figure 8 alarm inputs which are disabled are invisible.

Figure 8: GUI of the MPS console program. Disabled alarm inputs are invisible. The chart on the bottom shows a dump (red bar) following a beam loss (blue curve).

FUTURE EXTENSIONS

In the next steps the firmware will be extended by a function check of the beam current monitor by using a testloop [2]. Therefore a periodic test signal (frequency approximately 120Hz, amplitude 5V, trapezoidal shape) is sent through the test loop. In the measured beam current the test signal is digitally subtracted. By looking for the test loop frequency a defect beam current monitor electronic or toroid can be recognized. This is important since a defect beam current monitor can automatically disable all alarm inputs with a beam current threshold above 0mA (e.g. BPMs, beamline alarms)

The synchronisation of all MPS modules using the redundant optical loop to achieve a synchronous post mortem trigger and timestamps for alarms is going to be implemented. The target time resolution is 2µs.

The software will be extended by a more detailed alarm analysis to give more help to the operator by showing the exact involved alarms as a text string after a beam loss. This includes alarms which do not dump the beam through the MPS such as RF system or magnet power supplies. The concept of this is described in detail in [4]. The archiving function of the MPS will be enhanced by filters since in some cases a large number of entries were generated for a day. Further the post mortem data of the beam current measured by the MPS is going to be archived.

In the next years PETRA III is going to be upgraded by up to 10 undulator beamlines. Therefore MPS extensions are necessary, e.g. a number of new alarm inputs and possibly new functionality. Due to the modularity of the hardware and the flexibility of the FPGA there are many options to match upcoming requirements.

CONCLUSIONS

During the last months improvements to the MPS were implemented in the firmware and the software. Experiences during the commissioning led to new ideas and requirements which were partly installed. During one year of operation – from the starting of commissioning to the first user runs in spring 2010 no faults of the MPS with negative effects to the machine operation were observed, so that the availability of PETRAIII was not limited by the MPS. On the other hand the MPS handles faulty conditions with very high efficiency and provides a secure operation of the machine.

REFERENCES

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