POWERING INTERLOCKS

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Abstract

Two different powering interlock systems are deployed in the LHC to assure the protection of superconducting and normal conducting magnets, whereas fast magnet current change monitors are installed as additional protection devices against powering failures on magnets having a big impact on the beam trajectory. The presentation summarises the operational state of the Powering Interlock System (PIC), the Warm Magnet Interlock System (WIC) and the Fast Magnet Current Change Monitors (FMCM) after the Hardware commissioning period and initial operation in 2008. The expected modifications during the current shutdown are described in detail along with their consequences on the LHC re-commissioning in 2009. An outlook on future developments for further automation of interlock tests during commissioning, machine checkout and operation will conclude the paper.

FAST MAGNET CURRENT CHANGE MONITORS

According to the current baseline, the LHC will be equipped with a total of 12 FMCM devices (installed on the D1 circuits in IR1 and IR5, the 2 MSD dump septa circuits of IR6, RD34 and RQ4/5 in IR3 and IR7 as well as on two ALICE compensators in IR2). These devices have been procured through a collaboration with DESY and integrated into the CERN environment (as shown in Figure 1). The Fast Magnet Current Change Monitors have been initially developed at DESY and very successful used for the last two years of HERA operation.

Operational Status, Modifications and Re-commissioning in 2009

For the start-up with beam in 2008, only 11 out of the 12 FMCM devices were installed. While the devices installed in the SPS-LHC transfer lines have been fully commissioned and operational for almost 2 years, the LHC devices did not complete their commissioning program in 2008 due to a lack of time and priority [1]. The operational experience with the devices installed in the SPS-LHC transfer lines has however been very satisfactory and confirms the capability of the FMCM devices to reliably detect current changes in the order of 10^{-4} as defined in [2].

Changes to the installations will be limited to the improvement of threshold settings (based on new measurements taken during early operation), the completion of installations and finalisations of the controls interface to allow remote operation and supervision of all LHC and TL devices from the CCC.

Due to these changes, re-commissioning in 2009 is to be done systematically on all devices installed in the LHC. Commissioning can be done remotely from the CCC and without beam as soon as the concerned electrical circuit has completed its hardware commissioning program. Two current cycles, one to injection and one to nominal current, are required to fully validate the threshold settings of a given device. All FMCMs are maskable inputs to the Beam Interlock System, thus are required only once operating with unsafe beam. Due to the criticality of these devices for certain failure cases [3], it is strongly recommended to perform a final validation of the thresholds with dedicated beam tests as explained in detail in [4] before operating with unsafe beam.

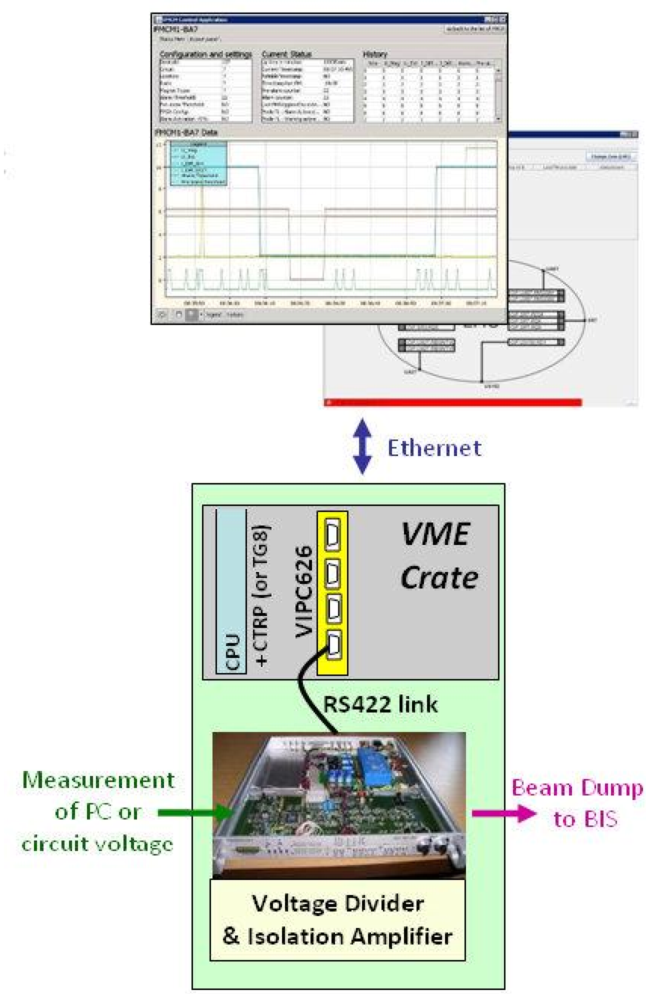

Figure 1: Vertical slice illustrating the integration of a FMCM into the CERN (controls) environment.

WARM MAGNET INTERLOCK SYSTEM

For the protection of LHC normal conducting magnets against overheating, 8 industrial controllers will be installed in the 8 LHC insertion regions, composing the Warm Magnet Interlock System (WIC).

Operational Status, Modifications and Re-commissioning in 2009

All eight systems have been installed and where fully operation as early as in spring 2008. Commissioning of the installations took place well ahead of the Hardware Commissioning period together with the magnet and power converter experts, requiring not more than half a day / installation (insertion region).

Few changes have to be performed to WIC installations during the 2008/09 shutdown. Due to the ongoing civil works in TZ76 for the re-location of equipment from UJ76 (due to the expected radiation levels), the WIC installation in TZ76 had to be temporarily removed and will be re-installed in June 2009.

The major change will be the inclusion of the Fast Boolean Processor FM352-5 into the WIC inputs towards the Beam Interlock System (see Figure 2). While after a magnet overheating the PLC will dump the beam before switching off the converter, the power converter will immediately switch off itself after any internal failure and thus have an immediate impact on the beam trajectory.

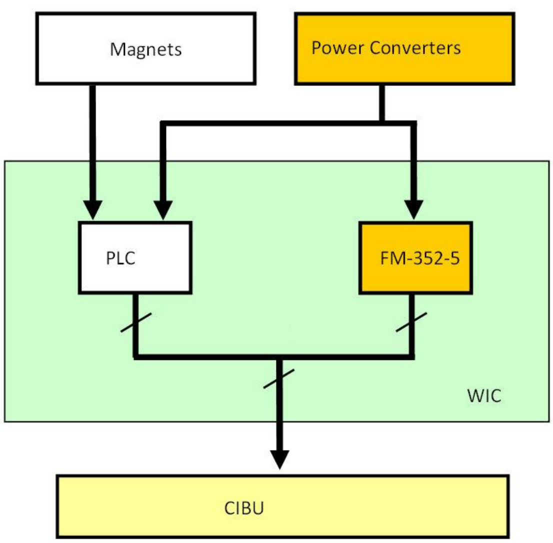

Figure 2: Functional architecture of the WIC interface with the Beam Interlock System, with the PLC and the Fast Boolean Processor 352-5 connected in parallel.

The Boolean Processor will provide a redundant path for the transmission of beam dump requests following such internal power converter failures to eliminate the inherently long cycle time of the safety PLC for such failure cases.

This additional FM 352 module was already installed in all 8 installations in 2008 and will be connected for 2009 operation to the CIBU interface through a special electronic card. For the monitoring and diagnostic of this new module, the PVSS SCADA system has been extended accordingly.

As for any other machine protection system, a systematic re-commissioning of all 8 installations is recommended for 2009 (which due to the modifications and the inclusion of the new module even becomes a necessity for this year). Commissioning will take place ahead of the Hardware Commissioning and will be done locally with the system experts during a half day test period / insertion region. All WIC inputs to the Beam Interlock System are unmaskable inputs, thus flawless operation of the system is required already for early beam operation and possible sector tests. No dedicated beam tests are required to validate the interfaces of the WIC with the Beam Interlock System. It would however be an asset to perform such tests e.g. in parallel with other systems (FMCM, BLM, etc…) to validate the redundancy of beam dump requests after failures in the powering of normal conducting magnets [5].

POWERING INTERLOCK SYSTEM

The powering interlock system assures the protection of equipment in the superconducting electrical circuits of the LHC by interfacing with the LHC Quench Protection System, the LHC Power Converters and external systems such as the Cryogenics, UPS and AUG. The PIC is the largest of the powering interlock systems, composed of 36 individual industrial controllers and protecting more than 820 circuits via hardwired current loops.

Operational Status, Modifications and Re-commissioning in 2009

For the LHC startup in 2008, all 36 installations were fully installed and operational and to a large extent already autonomously driven by the operations crews. The hardware interfaces of 11 electrical circuits were not yet fully commissioned due to non conformities in the electrical circuits or one of its components (e.g. weak magnets, bad splices, QPS issues, etc...). Few real interlock issues were detected and solved during HWC in 2008, mostly due to erroneous database configurations or cabling/connector issues. So far the system has revealed very encouraging figures in terms of its dependability, as the initial reliability estimates of one (safe) failure every 9 months has been by far exceeded (by now the system is installed and operational since around 2 years and no failure of a critical component has been observed).

Several modifications will be applied during the shut-down, namely numerous operational improvements of the PVSS SCADA system, a configuration upgrade to comply with the extension/upgrade of the QPS system as well as a modification of the 'Global Powering Subsector OFF'. The change of the latter aims at avoiding the quench back of numerous 600A correctors, which has been observed to occur during the Fast Power Abort which is anticipatory triggered by the PIC in such corrector circuits after quenches of main magnets (ECR in preparation).

As for the other systems no dedicated tests with beam could be performed to fully validate the functionality of the powering interlock system and its interfaces with the Beam Interlock System [6]. Several emergency dumps having their origin in the magnet powering system allowed however to analyse and validate the correctness and timing of beam dump requests sent by the PIC. The sequences of two such events are shown in Figure 3 and 4. The first one being the consequence of a water fault in the DC cable of the defocusing quadrupole circuit of sector 81, occurring on 11th of September 2008 at 22:45:08 when operating with beam 2 only. The second one shows the incident of 19th of September on the main dipole circuit of sector 34 (without beam). For both cases the reconstruction of the event sequence from history buffers of Powering and Beam Interlock System confirmed the completion of the beam dump only 2-3 ms after the occurrence of the initial fault.

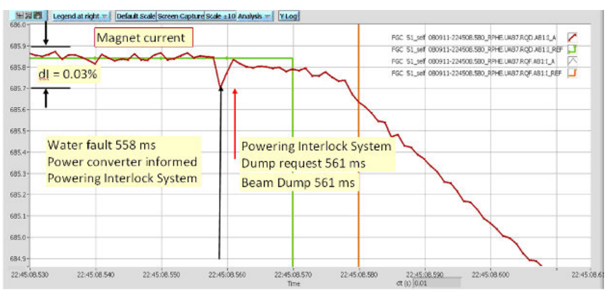

Figure 3: Event sequence of interlock signals, following a water fault in the DC cable of the defocusing quadrupole magnet chain of sector 81.

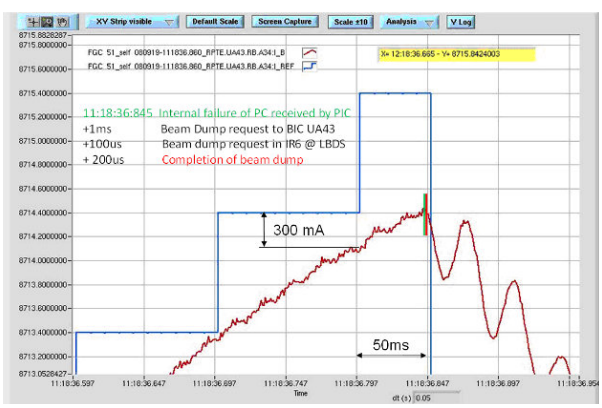

Figure 4: Event sequence of interlock signals, following the incident in the main dipole circuit of sector 34.

The change of current in the magnets is in both cases in the order of only 30ppm with respect to the reference current at the time of the fault (compared to a nominal performance of 1-3 ppm of the main power converters in terms of resolution, stability and reproducibility). This current change would correspond to an approximated displacement of the beam of less than 0.1mm before the completion of the beam dump. This confirms that failures within the powering system of the LHC are transmitted in due time to the Beam Interlock System to avoid any substantial movement of the beams and consequent beam losses.

AUTOMATED TOOLS FOR INTERLOCK COMMISSIONING

The powering interlock systems (PIC, WIC and FMCM) account for around 1/4 of all user inputs towards the Beam Interlock System (32 inputs from the PIC, 8 from the WIC and 12 from FMCMs installed in the LHC). The amount of connections, combined with a considerable amount of beam dump requests expected from the powering system especially during early operation emphasises the need for a systematic (re-) validation of these interfaces. Automating these tests will allow to retest the connections and configurations (for the PIC a configuration file within each controller defines whether a failing circuit will request a beam dump through the maskable and/or unmaskable) on a regular basis, even during operation.

A first version of such automated MPS commissioning tools have been developed for the powering interlock system and have been validated during 2008, requiring around 1 hour/sector for the validation of the necessary 1500 logical tests. Results of all such tests are stored in the LSA database. These tools will be further refined and extended to WIC and FMCM and other main clients of the beam interlock system in the course of the year.

CONCLUSIONS

With the exception of some of the FMCM devices, the powering interlock systems of the LHC have been fully operational for commissioning and first beam operation in 2008 and revealed a very satisfactory performance in terms of functionality and dependability. A number of operational improvements will be applied during this shut-down, but will only have a minor impact on the re-commissioning work in 2009. The main focus for this year will be to refine and finalise the developments for automated commissioning tools to further speed up and facilitate future re-commissioning work and systematic checks of the interfaces with the beam interlock system.

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