THE MACHINE PROTECTION SYSTEM FOR THE ELI-NP GAMMA BEAM SYSTEM

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Abstract

The new Gamma Beam System (GBS) of the ELI-NP project [1], currently under installation in Magurele (RO) by INFN, as part of EuroGammas consortium, can provide gamma rays that open new possibilities for nuclear photonics and nuclear physics.
ELI-NP gamma rays are produced by Compton back-scattering to get monochromaticity (0,1% bandwidth), high flux (10^{13} $\frac{photon}{s}$), tunable direction and energy up to 19.5 MeV. Such gamma beam is obtained when a high-intensity laser collides a high-brightness electron beam with energies up to 740 MeV, a repetition rate of 100 Hz, with trains of 32 bunches within the same RF bucket.
An advanced Machine Protection System (MPS) has been developed, in order to ensure proper operation for this challenging facility. The MPS operates on different layers of the control system and is interfaced with all its sub-systems. For instance, it comprises different kind of beam loss monitors (based on Cherenkov optical fiber), hall probes, fast current transformer together with BPMs, and an embedded system based on FPGA with distributed I/O over EtherCAT, to monitor vacuum and RF systems [2], which require fast response to be interlocked within one RF pulse.

INTRODUCTION

The operative constraints of each sub-system of the ELI-NP-GBS accelerator have been evaluated according to two different criteria: (i) how critical is to monitor the sub-system performance for the overall machine operation; (ii) how fast should be the MPS response to a fault.
In the following, all the controlled sub-systems along with the characteristics for the MPS integration have been listed:

- RF power units – 13 ScandiNova modulators (integrated with Toshiba klystrons) are protected by their own control system. However, they should be interfaced with a fast and reliable system in order to stop the RF pulses and inhibit machine operation, according to personnel safety regulations, in less than 10 ms.
- Low Level RF – 13 LiberaLLRF chassis, as modulators, can handle their own faults but they need fast and reliable interface to get and propagate their interlock to RF Modulator and vice versa, always within 10 ms.
- Vacuum systems – made principally of vacuum gauges and ion-pumps, but also turbo and scroll pumps in some critical modules, such as laser-electrons interaction point and gamma characterization areas. Vacuum activity could be due to different reasons: vacuum leaks, RF breakdown or out-gassing. Depending on the gravity of the issue, the MPS action could range from a RF gun vacuum segmentation (to prevent venting) or a simple intervention on RF systems. In the latter case, RF systems should handle with different severity vacuum activities depending where they occurred: RF structures, RF waveguides, transfer lines, laser interaction points and gamma characterization modules.
- Synchronization – the only task of the MPS on this system it is the control between the front-end and the distributed network of stabilized links, where a laser amplifier could be switched on without the source. This issue need a continuous monitoring.
- Cooling – A series of chillers inside the bunker stabilizes the temperature of RF structures. Faults and consequent temperature drifts will affect accelerating field and then the overall performances of the machine. This does not need a fast response, but a continuous monitoring to stop RF sources if a fault happens.
- Magnets – Malfunctions with optical elements can affect the accelerator with different levels of criticality. Issues with steerers, or quadrupoles, do not cause electron beam dispersion. For this reason, they should only be monitored. Dipoles faults, instead, cause the total dispersion of the beam that could damage other equipment in the bunker. Prompt monitoring of these devices it is then required to stop RF sources as fast as possible.
- Electron beam diagnostics – Beam screens must be protected during the insertion/extraction of moving parts, stopping the beam until the screen is in position. These devices have to be monitored without any velocity constraint.
- Personnel safety – This sub-system monitors gates, emergency buttons and radiation detectors in the whole building. An interlock from personnel safety needs a fast and reliable intervention to stop RF systems and close laser shutters, stopping any kind of radiation in the bunker.

Laser systems and gamma characterization modules have their own dedicated protection system, as far as the MPS is concerned only their vacuum is monitored.

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DESIGN

From this analysis the whole ELI-NP-GBS MPS was designed, as illustrated in Fig. 1, with a:

- Fast-Interlock system for the real-time intervention: to protect RF systems, vacuum equipment, laser shutters and personnel safety.
- Waveform mask: fast-interlock dedicated to analyze in real-time the status of the RF Gun [3] monitoring the input reflected power and electric field inside the cavity.
- Beam Loss Monitors distributed along the facility for different purposes: Cherenkov fiber to detect beam loss due to optical equipment fault; Hall-probes in each dipoles to verify the actual magnetic field; beam position and current monitors to verify the correct transport of the electrons up to the beam dump.
- Distributed system of PLCs: to interlock either magnets power supplies, in case of water flow or thermal issues, or vacuum valves segmenting vacuum regions, when a vacuum leak is detected.
- Fast-valve: standalone, to protect the RF gun from venting.
- Supervisor server integrated with the EPICS control system: to monitor the health of the whole MPS and for the slow monitoring of synchronization, cooling, magnets and beam diagnostics.

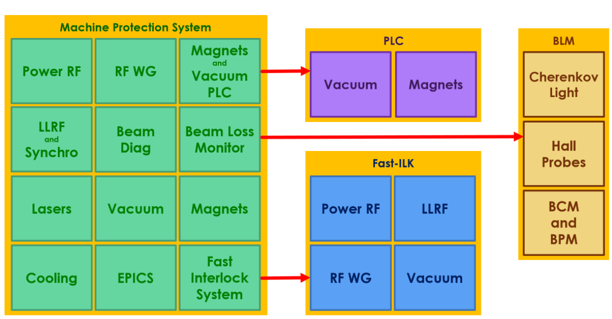

Figure 1: MPS design - Green area is under the EPICS supervisor, purple one is under PLCs, brown one are the Beam Loss Monitors and the blue one is the Fast-Interlock system.

Fast-Interlock System

The Fast-Interlock system based on NI cRIO-9039 with a Xilinx Kintex-7 325T FPGA is hardwired to each monitored equipment. In order to minimize the number of cables in the building and to optimize the effectiveness of the system, only a master unit on the roof and two slave units NI cRIO-9144 distributed in technical rooms have been employed, as shown in Fig. 2. A point-to-point etherCAT network connects master and slave units, in order to improve the performance of the system, ensure the real-time communication and the determinism of the shared data. This system has been duplicated for redundancy, with an identical system running in parallel, and it is wired in parallel to the same monitored equipment. The choice of cRIO framework ensures a very high Mean Time Before Failure (MTBF) of over 100 years. The redundancy not only guarantees the reliability, but allows also to reduce spare parts and to maintain more easily the system, without affecting accelerator operation.

The MPS is currently in final testing phase, almost all the benchmarks have been completed, the preliminary results have been listed in Table 1.

Table 1: MPS Benchmark

System	Results
etherCAT network latency	< 100 μs (jitter < 1 μs)
vacuum issue detection time	20 ms
waveform mask detection time	1 ms
execution time to identify the issue and trip the related device	300 μs

Waveform Mask Interlock

The Waveform mask interlock [4], already tested during the RF Gun conditioning performed at Bonn University (cita altro paper), collects RF reflected power and electric field probe signal envelopes by means of schottky diodes. Such signals will be acquired with a WaveCatcher (3.2 $\frac{GS}{s}$, 500 MHz BW, 12-bit resolution) [5] and analyzed with a DAQ NI PCI-6341 to propagate interlock to Fast-Interlock clients.

Cherenkov Fibers

The Cherenkov Beam Loss Position Monitor is made of optical fiber placed along the whole accelerator. Cherenkov photons produced by escaped electrons (or electrons jet due to primary electrons collision) are detected by a Hamamatsu Multi-Pixel-Photon-Counter [6], and acquired with a WaveCatcher.

Computing the time-of-flight of such photons it is possible to estimate the position where the beam loss occurs. With WaveCatcher sampling frequency of 3.2 $\frac{GS}{s}$ the estimated spatial resolution of the BLPM is about 4 cm.

The main drawback of this kind of BLPM is the transport of dark current together with the beam. In order to minimize this effect, consequently avoiding MPPC saturation, the BPLM has been segmented, as shown in Fig. 3.

Hall Probes

The Hall probe BLM is used to monitor at the same time the dipole and the status of its own power supply. The signal from a Hall probe, inserted in the good-field-region of the magnet, is sampled with a DAQ NI PCI-6341. The voltage

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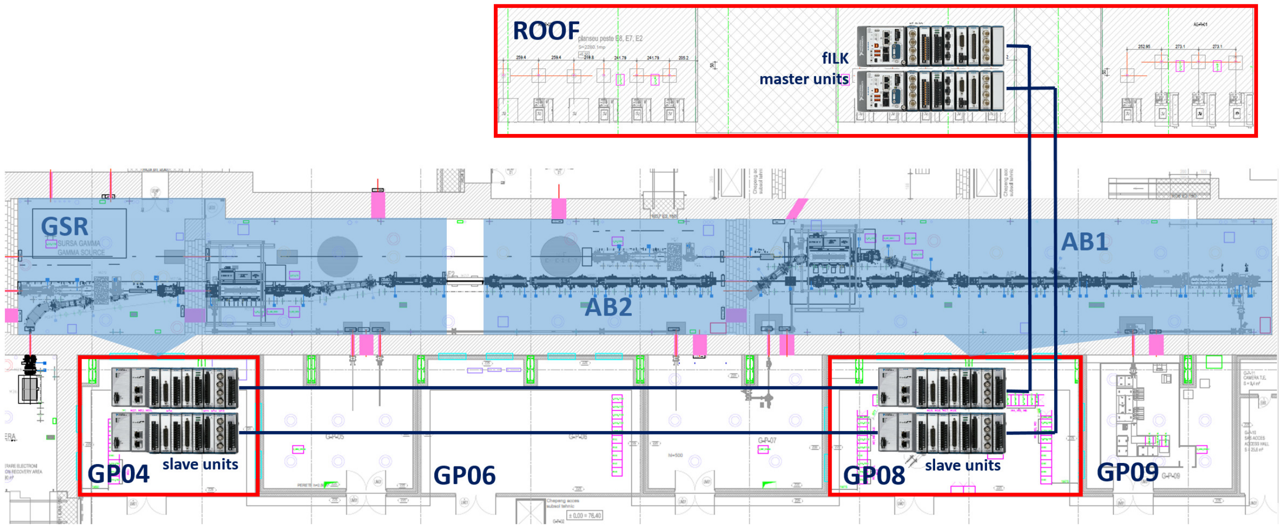

Figure 2: Fast-Interlock system topology.

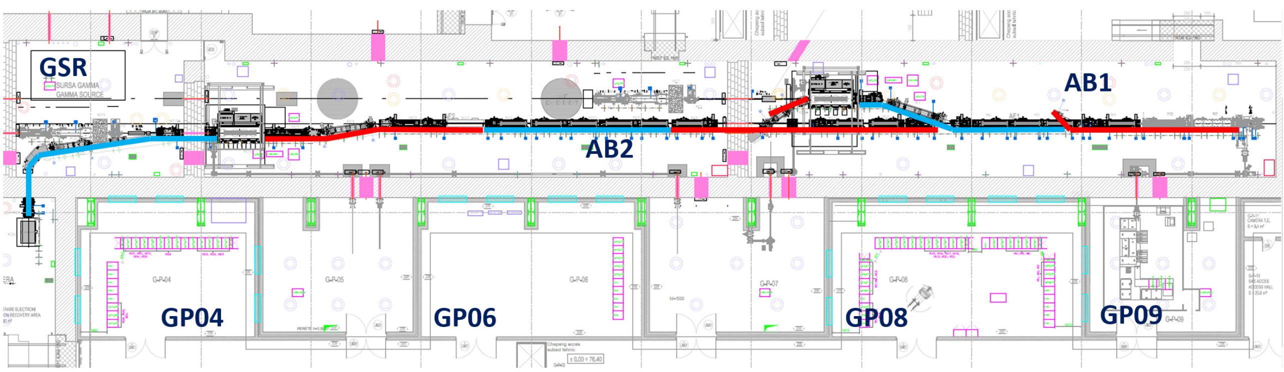

Figure 3: Cherenkov Beam Loss Position Monitors topology.

signal is converted in Tesla according to the probe calibration curve, then using the excitation curve of the dipole it is possible to estimate the current inside coils. If such estimation differs from the power supply read-back, an interlock to the RF Gun modulator is triggered. This BLM not only monitors the performance of the power supply, but is also able to detect other problems such as short-circuits between coils.

CONCLUSION

The ELI-NP-GBS MPS is fully procured and in final testing phase. When installed, it will guarantee safe operation of the machine and it will help operators from remote control to easily run the accelerator, providing diagnostics on beam performance and on the status of each sub-system of the facility.

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