Report of the Working Group on Instrumentation

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A Concrete Example and Issues Raised in Examination: Instrumentation for a standard arc section of the VLHC

In our working group, we tried to identify the instrumentation required for a typical VLHC arc segment. This was not intended as a comprehensive list, but as a concrete example from which to identify areas for future research. As basic design criteria, we consider that redundancy, fault tolerance, and reduction of time to repair (and diagnose) are issues to be addressed in all equipment design. We have not identified any devices or technologies which appear to be especially challenging. However, we believe several areas will benefit from additional reliability engineering or further study.

Contents of the "electronics coffin" as an example for VLHC

The Instrumentation "Coffin" should house many of the widely replicated electrical systems of the VLHC system, in modular form to make replacement of failed systems fast and easy. All modules should include self-diagnostics to the maximum extent possible to allow secure module diagnostics prior to tunnel entry. In-tunnel debugging is expected to be kept to an absolute minimum by this and related techniques.

Where practical, systems should be sufficiently redundant such that a single failure does not force a beam interruption or a machine shutdown. This is often accomplished at the module level, but may force decisions about the number and placement of beamline components.

The placement of the instrumentation coffin depends on the local radiation dose expected. For the different options of the machine, the radiation profiles in the arcs is required. We envision that the coffin will be located under a dipole magnet or in a small alcove as appropriate. Since the coffin will be manufactured using industrial grade electronics parts and technologies, the radiation exposure must be kept under a reasonable (approximately 10,000 Rad(si)) lifetime dose.

While there may be good reasons to segregate various system groups, the overall "coffin" (perhaps multiple boxes) is expected to have the following as its minimum contents.

Beam-related instrumentation:

It is expected that there will be BPM's at 45--60 degree spacing (in betatron phase). This corresponds roughly to 8 BPM's per betatron period.

There will be some redundancy required for the BPM system. This redundancy comes easily by providing one X and one Y measurement per quadrupole, although it is arguable whether this is overkill. BPM's at each quad also provide an accuracy/consistency check, in addition to redundant coverage in case of failure of any of the channels.

There could be one dipole corrector per beam per quadrupole. In principle, the number of correctors could be reduced, but a large number of correctors provide a high system availability even after a limited number of magnet or power supply failures. Voltage and current monitors are required to ensure function and detect failures. An approximate strength scale is given by a magnetic field of 3 T over a length of 40 cm (1.2 T m)

Some design proposals are considering installation of motor-actuated movers for beam line magnets (quads, in particular). Each mover will require a driver channel and a readback channel, with an appropriate position sensor. In the most optimistic case, this capability might replace some or all of the corrector complement. Each quadrupole will probably require two or more motors, particularly if roll is allowed as a degree of freedom. Three questions for further study are: 1) can the magnet be safely moved in the presence of circulating beam, 2) can a single magnet mover move quadrupoles for both beams and still allow beam steering to sufficient quality, and 3) can a variant of the conventional LVDT be developed to run in the high fringe fields associated with magnets.

The system will also require sextupoles for Chromaticity Correction. These _may_ not need to be instrumented, and will probably have two sense leads per magnet, one sextupole per quad.

Beam loss monitors are required at least near each quadrupole. Additional study is required to determine the optimal number and location of radiation detectors. Understanding of loss rates will allow identification of appropriate detector technologies. The quad system will probably be geared for fast event detection (Coincidence detection using diodes), while the dipole beam loss detection (protection?) system might be done using slow integrated sensing (ion chambers / scintillator w/PMT).

Equipment monitoring instrumentation:

A major portion of the overall equipment instrumentation is expected to be dedicated to magnet protection (in case of quenches). This protection has been generally implemented for each magnet, but it is possible to have it grouped by "N" dipoles, where N>1. The quench protection sensor complement (e.g., LHC) will probably include three (3) detectors per magnet, requiring three isolated lead pairs. Requiring 2 of 3 sensors to register a quench will greatly reduce false quench indications, while still providing redundancy in case of sense lead failure. The quench heater system (again, modeled after LHC) might consist of four separate external heater power supplies, each feeding two heater segments. The LHC model described above would be appropriate for VLHC, but others might be equally appropriate. Additional design and engineering of the magnet and magnet protection systems have been identified as an area which may benefit from additional study with the goal of increasing system reliability and reducing protection system complexity.

For beam-based alignment using quads, as done at several other facilities, it is desirable to modulate the quadrupole current in the range of 10-2 to 10-4 (dI/I). This will require a small power supply (one ampere scale) and two additional leads into the cryostat for magnet current.

Other systems:

For overall system lifetime monitoring, a long-term integrating Radiation Detector would be useful as a "Death Watch detector" for equipment lifetime. With remote readout capability, a database can be developed which will track the exposure for each module. Strong consideration should be given to instrumenting every module with a passive radiation detector (TLD).

Overall system reliability will be enhanced with a remote power cycle capability to reset devices. The concern is that single-bit failures of programming in state machines due to radiation require hard power cycles to reset. Further study of this process associated with beam loss mechanisms in the VLHC is encouraged.

Items which might not be in the "coffin"

The power supplies for the corrector magnets, with two leads per corrector, might not be part of the "coffin" complement.

The cryo instrumentation, which might be at a separate cryo supply/return line, may or may not be part of the "coffin". The cryo instrumentation should be connected to some control system; however, there are reliability and maintainability issues which drive separation of the cryogenic control system from all other control systems to achieve the ability to test and maintain the non-cryo systems without impacting the stability of cryogenic operations. Sensors which serve a monitor-only function and are not integrated in the cryo controls (e.g., insulating vacuum, local cryogen pressure) may be included as part of the coffin electronics is desired to avoid excess wire and reduce equipment costs.

Hardware interlocks:

There are almost certainly hardware interlocks which will be required, which depend on specific implementation of the accelerator systems. These are not included in this description and must be considered.

General recommendations:

Historically, control and instrumentation systems as diverse as discussed here have been designed by engineering teams which communicate insufficiently with each other, and as a result suffer from poor system integration. We encourage that a task force be developed to oversee the development and implementation of integration criteria for these systems. Some of these criteria will address similarity of systems, and some will address imposed differences to prevent inadvertent interconnections among different systems.