LHC COMMISSIONING: REQUIRED APPLICATION SOFTWARE

M.Lamont, CERN, Geneva, Switzerland.

Abstract

Effective commissioning of the LHC with beam demands a well-designed, coherent suite of high level software. The challenges include a large amount of heterogeneous equipment, large distributed beam instrumentation systems, the dynamic effects of superconducting magnets and tight constraints on the key beam parameters. All of which have to be dealt with while respecting the destructive power of the beams. The required software is briefly elucidated.

INTRODUCTION

The LHC will pose some major operating challenges. These include the need to deal with large amount of heterogeneous equipment; drive the accelerator through a complex cycle in the presence of dynamic effects and very tight beam constraints. This must be done while respecting the destructive power of the LHC beams.

The overall requirements for the LHC high level controls system include:

- Monitoring, recording and logging of accelerator status and process parameters;
- Display of operator information regarding the accelerator status and beam parameters;
- Provision of operator controls to affect changes to the accelerator;
- Automatic process control and sequence control during all beam related modes of operation and covering all operational scenarios i.e. control within normal operating limits; Commissioning, Physics (proton-proton, ion-ion, TOTEM..), Machine studies etc..;
- Fault diagnostic and recovery;
- Prevention of automatic or manual control actions which might initiate a hazard;
- Detection of onset of hazard and automatic hazard termination (i.e. dump the beam), or mitigation (i.e. control within safe operating limits).

Herein the focus is on the requirements for beam based commissioning. The high level controls requirements for technical services; vacuum; cryogenics; machine protection; and quench protection and energy extraction are taken as given.

A large proportion of the final software will be required for effective commissioning. An attempt is made, however, to prioritise the demands of the first two years' operation with beam.

The breakdown of the requirements is as follows:

- Core Functionality
- Equipment
- Instrumentation
- Measurements/Optimisation
- Exploitation
- Standard facilities
- Interfaces to other systems
- Other issues

Space and time limit this paper to a quick run through of the key requirements. More details of the LHC high level software requirements may be found at [1].

CORE FUNCTIONALITY

Experience has shown [2,3] that the provision of common functionality for use by all applications addressing all equipment and instrumentation classes can greatly facilitate: the production of the required code; maintenance; and the effective exploitation of the accelerator.

This core functionality should include:

Settings Management

LHC operational settings will span a complex parameter space which will include: settings for the machine cycle (injection, decay, snapback, ramp, squeeze etc) in terms of high level physics parameters (for example, momentum; tune; chromaticity; orbit including various bump and angle adjustments). Magnet properties will have to be dealt with in terms of strengths, multipole errors, transfer functions etc. Equipment settings will need to cover: Power Converters, RF, Kickers, Collimators, TDI. Feed forward & feedback settings management tools will also be required.

A coherent settings management system covering all relevant equipment and beam related settings is required. Closely related, of course, is the facility to generate all requisite settings, a process generally known as settings generation.

Along with the settings one needs archive, reload, rollback and copy facilities. Tools for database configuration of the parameter space and associated data are also required.

Trim

Adjustment of all settings must be possible where required. This should be done with an appropriate high level view of beam & accelerator parameters.

All trims must be recorded with undo, rollback functionality as standard.

Equipment Expert Settings Management

Management of the settings of the specialised equipment settings usually only visible and adjustable by the equipment expert should ideally use the same operational settings management system outline above.

Equipment State Control

The core layer should provide ability to manage the state of state aware equipment. Traversal of the associated state transition diagram should be possible automatically. One should be able to control the state of multiple equipment thorough a simple, standard interface.

Equipment Monitoring

All critical equipment states and settings should be monitored. Alarms, and possibly interlocks, should be raised if state or setting is not that demanded.

Standard Equipment/Instrumentation Access

A standard API should be provided to allow equipment and instrumentation access. This mechanism should provide the expected functionality of a modern middleware (get - set, publish - subscribe, synchronous - asynchronous, security etc.).

Optics

A standard interface should provide access to the on-line Twiss parameters and other optics related parameters.

Machine Mode & Run configuration

Machine mode and run configuration data (beam characteristics, crossing angle configuration etc.) should be managed centrally and published to any subsystem needing this data.

EQUIPMENT SUBSYSTEMS

Although all equipment has eventually to lock into the machine cycle, there is a clear need to treat the systems independently when looking at performance, monitoring, and fault recovery.

One would expect standard tools for the core functionality described above. These tools will allow:

- Operation Settings management
- Expert Settings Management
- Equipment State Management
- Equipment Monitoring

In addition the following functionality will be required by some systems:

- XPOC. Post operational checks to confirm proper equipment functioning. Critical for the beam dump for example, where the post operation checks would include beam line trajectories, screen images, beam losses etc.,
- Post Mortem,
- Management of Critical Settings,
- Timing: time of day, event and data distribution.

Running briefly through the various subsystems and highlighting particular issues:

Collimators

The collimators will require:

- A dedicated application allowing adjustment of settings, optimisation with respect to closed orbit, beam size,
- Automated set-up process via interface with beam loss system. Probably implemented at the gateway level,
- Generation and editing of ramp & squeeze settings.

Fixed displays, logging, post-mortem and alarms as standard plus safe settings management will be required.

Injection Kickers

The injection kickers will require:

- A high level application allowing traversal of system state transition diagram, settings management (including usual trim/archive functionality),
- Definition of operational state diagram taking into account external conditions – interface to sequencer,
- Verification of proper receipt of pre-pulses & slow timing,
- Visualization of kicker waveform (shall be recorded every cycle),
- XPOC: Post Operation Checks: Typical signals acquired are the magnet current pulse shape, the currents of the injected and circulating beams, and the beam permit and beam abort gap signals
- Safe settings management,
- Post Mortem - Logging – Alarms – Visual confirmation of states.

Beam dump system

The beam dump system will require:

- Application for basic control and diagnostics.
- Kicker: safe settings management with no trim possibilities for operators. Status. Synchronisation. All manipulations to be recorded.
- Septa: FGC plus all associated functionality but current tracked. Current reference dealt with by operations. No trimming outside tolerances.
- Operational state management: On, reset, check, validation dump, inject and dump mode.
- Access into zone: re-close, check, validation dump sequencing. Test sequences.
- XPOC.
- Analogue acquisition: check kicker pulse against extracted beam etc.
- Extraction channel instrumentation monitoring.

Power Converters

A large system intimately involved in most accelerator operations. Requirements will include:

- Full integration into settings and trim management.
- Generation and editing of injection plateau ramp & squeeze settings.

- Real-time channel - use as orbit, tune and chromaticity feedback actuators.
- State control.
- Monitoring.
- Post Mortem – Alarms – Logging – Fixed Display.

Magnets

Putting aside the magnet model requirements for a moment, it is clear that monitoring the state of the cryo-magnets will be important:

- Monitoring – display, summary, alarms etc,
- Logging,
- Interlock status.

RF

The RF system's requirements will include:

- All equipment shall be controllable from main operational software.
- The system shall use the standard high level settings management facilities: control of phase, frequency, voltage etc. Traversal of state transition diagram, RF line and module control.
- Function generation via FGCs.
- Interface to Schneider PLCs for control & surveillance of power equipment (klystrons, power supplies etc.)
- High bandwidth remote acquisition: mountain ranges, analog signals, time waveforms, phase loop, injection transient signals. Monitoring of APW wideband longitudinal pickups, plus signals of first N turns at injection.
- Fast synchronization signals – diagnostics required.
- Low level control & Beam control – synchro, phase, radial loops. Diagnostics and alarms.
- Cavity control – STD – settings – fast feedback & tuning.
- Longitudinal feedback: feedback response, monitoring and control – STD & functions
- Alarms, Logging & Post-mortem
- Unit control, state, status
- Bunch length via Wall Current Monitor.
- Timing signals, injection requests

Transverse Feedback

The transverse feedback system will require:

- Stand alone application providing state management, parameter control, and settings management. The system shall be fully integrated into high level system.
- XPOC plus diagnostics.
- Analogue acquisition – a large amount of data plus appropriate analysis tools.

MQA & MKA

MQA and MKA will require an application providing mode aware state and settings management. Actions will have to be synchronized with measurement acquisitions.

BEAM INSTRUMENTATION

General

As above, interfaces are required to allow invocation of standard facilities:

- Operational Settings management
- Expert Settings Management
- Equipment State Management
- Equipment Monitoring

Besides these, functionality is required to allow:

- Acquisition (On demand, subscription, event driven),
- Synchronisation with equipment actions,
- Concentration of data from the large distributed systems: BPMs, BLMs,
- Management of critical settings,
- Logging,
- Post Mortem,
- Alarms,
- Fixed Display.

Given the standard facilities, the particular demands of the individual beam instrumentation systems are shown in table 1.

System	Special requirements	Pty.	App.
BPM	**Concentration, Post Mortem, various acquisition modes, real-time**	**1**	**xxx**
BLM	**Concentration, Post Mortem, Critical Settings, real-time**	**1**	**x**
BCT		**1**	
BTV	**Settings, state, interlocks, analysis**	**1**	**x**
Rest Gas	**Settings, state, interlocks**	**2**	**x**
Sync. Rad.	**Settings, state, interlocks**	**1**	**x**
Wire Scanners	**Settings, state, interlocks**	**2**	**x**
Luminosity		**1**	**x**
Tune plus derivatives	**FFT, PLL, settings, state, timing, analysis**	**1**	**xx**
Abort Gap		**2**	
Schottky		**3**	**x**
Wall Current		**1**	**x**
BST	**Diagnostics**	**1**	

Table 1: Prioritized overview of BI requirements. App indicates the needs for dedicated application software.

Measurements

All measurements are to be recorded together with associated measurement parameters. Standard facilities are to be provided for display; browsing; analysis; archiving; and the use of reference measurements for comparison etc.

An API to allow access to the data for post-mortem, post-run analysis, from the web should be provided. A standard data format should be used with appropriate interface to analysis tools (MAD, Mathematica, etc.).

Key Applications

There are a small number of vitally important enabling applications utilizing the results of common beam measurements. The essential list is: Tune FFT utilizing the QKA and the damper; Tune PLL utilizing the damper and ticklers and the BPM system in various modes (described below).

The importance of these applications is their ability to get a handle on, for example: chromaticity; central frequency; non-linear Chromaticity; and coupling via the closest tune approach.

MEASURE AND ADJUST

Full integration of trim/measure functionality will be required. This will allow dynamic configuration of complex measure/trim procedures. These need not necessarily be realized as separate applications. Some examples are shown in table 2.

Measurement	Method	Priority
Dynamic Aperture	Kick	2
Aperture	Bumps, lifetime, BLMs	1
Matching - screens	BTVs, quads	1
Tune scans	Lifetime, beam size	2
Field error feed down	Local orbit bumps	1
Emittance	WS or SR	1

Table 2: Potential measurement procedures

Scans

Dedicated applications will be required for routine optimisation. These will include: collimator positioning with respect to the orbit and BLMs; luminosity scans.

Orbit

The BPMs, in their, various acquisition modes, provide data that can be harnessed in numerous ways. Potential uses include:

Trajectory
- Threading
- Linear optics, polarities checks
- Injection point steering
- Momentum
- Momentum offset [sector to sector]
- First N turns - closure
- Sum signal

Orbit
- Closed Orbit Correction
- Dispersion
- Sliding Bumps
- Crossing, separation, spectrometers

1000+ turns
- Phase advance, Beta Beating
- Tune
- Beam response after kick
- Off momentum beating

Dedicated applications should be in place to provide this wide functionality. Prioritization is possible.

SEQUENCER

A powerful sequencer will be required to safely drive the accelerator through the designated operational cycle. The requirements on the sequencer include the following.

- Perform tasks in parallel
- Handle multithreading/distributed processing logic
- Multipole sequence definitions.
- Re-use of sub-sequences
- Easily configurable
- Catch return code of executed tasks and react appropriately
- Display progress, handle break points
- Abort executing task(s).
- Manually drive sequence
- Manually drive sequence for given subsystem
- Manually abort sequence
- Security
- Logging and error reporting
- Condition actions based on external input from monitoring/machine protection

Injection Sequencer

Also required, possibly as a separate application from the machine sequencer, will be an injection sequencer. This will be responsible for driving and monitoring the injection process. It will have to interface to the timing system and make appropriate request for beam nominally qualified by the ring number, beam intensity, number of batches and position in the LHC ring (RF bucket number). After each injection, input from beam quality monitoring processes must be accepted and the decision on whether to carry on the injection process evaluated. The sequencer should provide manual and automatic modes.

STANDARD HIGH LEVEL FACILITES

A number of important facilities must be standardized across all systems. This is includes the interface to the equipment level, transport mechanism, analysis and retrieval tools etc. The main reason for standardized solutions, besides economy of effort, is the need to be able to cross- correlate easily signals from the numerous sub- systems. Standard high level facilities shall include:

- Logging
- Alarms - a universal system with 24/365 availability.
- Post Mortem
- Fixed Displays. Numerous demands, the display should be easily configurable, mode dependent.
- Analogue Acquisition

- Shot Data Analysis allowing easy fill-to-fill analysis.

MACHINE MODEL

On-line model

There is a need to establish easy transport of data between the machine settings, beam measurements, the results of beam based analysis, and MAD-X. Conversely we should be able to run MAD on-line and check results of proposed adjustments to the machine against a realistic machine model. Parameter adjustments calculated by MAD should be easily introducible into the control system. We would not expect a direct interface between MAD and the machine.

Magnet Model

As elucidated elsewhere in these proceedings [4] there is a clear need to incorporate an on-line, and the results from offline invocation of the, magnet model. These will provide transfer functions, DC harmonics, and predictions of decay and snapback harmonics which will have to be fully integrated in the settings management system.

INTERFACES TO OTHER SYSTEMS

The LHC will be critically dependent on the proper functioning of the technical and essential machine infrastructure. Beam based operations will need reliable exchange of data relating to the mode of operation and key process parameters of the following systems:

- Vacuum
- Cryogenics
- Cryostat Instrumentation
- Quench protection & energy extraction systems
- Technical services

Other key systems include:

- Access
- Radiation monitors (RAMSES)

All data coming from these systems should feed into the standard logging, alarm, fixed display systems.

Clearly a well defined data exchange mechanism with the experiments is also required. Again data from this channel must be logged and displayed as appropriate.

Machine Protection

The integration of the machine protection system with beam based operations needs to be carefully considered and all interfaces must be clearly defined. MPS considerations should be fully integrated in the machine mode model.

Feedback/real time

The real time controllers and associated acquisitions and actuation will run independently of the application layer. However, it is clear that the real-time architecture has to be carefully integrated into the overall system.

Data and control flow between the two systems will include:

- Optics changes during squeeze
- Twiss/matrices
- Magnet transfer functions
- Energy
- Pre-programmed I(t) in corrector circuits
- Circuit configuration
- Knob definitions
- Correction limits
- Reference orbits
- References in general.
- High level control of the controllers
- Control loop parameters
- RT corrections for use in run-to-run feed forward.

OTHER ISSUES

Security

There are a number of issues here but basically unauthorized write access to process parameters during beam operation must be prevented.

Remote Access

While respecting the above constraint, access from outside the technical network to piquets and, perhaps, LHC@FNAL should be possible: firstly in read mode, secondly in write mode for a configurable set of devices and parameters.

Scripting Environment

A scripting environment providing the means of rapid application development will be requied. Care must be taken over the reliability of any code thus developed and its possible detrimental effect on machine functioning.

Software Interlocks

State and settings of equipment, and key beam measurables should be monitored. Interlocks should be thrown if states and/or settings are out of tolerances.

STANDARD OPERATIONAL FACILITIES

Standard operational facilities should include:

- Console manager - standard operating system
- Standard error handling facilities
- Alarm system interface
- Electronic Logbook
- Web based documentation
- Database utilities
- Screen capture & print utilities
- Standard components for data visualisation
- Standard support applications such as phonebook etc.
- Page 1 or equivalent

Control system

Facilities for monitoring and troubleshooting the controls infrastructure should include, for example: timing system diagnostics and tests, CBCM monitoring and BST/TTC diagnostics.

The status of and diagnostics for front-ends/field buses, gateways, network, servers and databases should also be readily available. A remote reboot utility will be useful.

CONCLUSIONS

A summary of the application requirements for the beam based commissioning of the LHC has been presented. Some prioritisation has been performed. Only a brief evaluation has been performed here, more details are available at [1].

The software provided should, of course, be developed in a coherent framework, and be implemented using appropriate, maintainable technologies. The code itself should be maintainable and extensible and be reliable and well tested.

REFERENCES

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3. M. Albert et al, “LHC Software Architecture: TI8 Commissioning”, LHC Project Note 368.
4. M. Lamont, Field Model deliverables for sector test and commissioning, these proceedings.