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Functional specification for LHC Power Converter control

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Summary

Part of the responsibility of the low-level power converter control system is to provide the functionality required by the high-level control system to drive LHC operations. This paper presents a preliminary attempt to define those high-level control requirements for the power converters of the LHC.

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1. Introduction

The LHC aims at injecting, accelerating and then colliding beams with very well controlled beam parameters (e.g. orbit, tune, chromaticity and momentum) in an efficient, reliable and reproducible manner. Analysis of these basic operational objectives has resulted in a list of requirements for the power converters from the standpoint of high-level control. It should be noted that the evaluation of these requirements is necessarily tentative and that the list presented here must therefore be considered as preliminary.

The extensive use of superconducting magnets provides a new set of challenges in dealing with such effects as snap-back, persistent currents and associated multipoles. Many of the more stringent demands come from the need to handle these effects in a reliable manner.

Accuracy, resolution, and stability of the power converters are taken as given by the low-level control. The following figures having been agreed upon [1]:

• Resolution	1 PPM of maximum
• Short-term stability and dynamics	± 3 PPM of maximum
• Reproducibility and tracking between sectors	± 5 PPM of maximum
• Accuracy	± 10 PPM of maximum

Operationally reproducibility is very important and therefore changes or cycling have to be done in a predictable and reproducible way. This applies to any rounding in, rounding off, or curve fitting. Use of these techniques must be robust.

There are about 1702 power converters (PCs) foreseen for the LHC magnets [2]. There are 9 electrical sectors: 8 sectors around the accelerator ring and one sector accommodating the reference magnets in building SM18. Each ring sector contains 1 main bending magnet string (about 150 magnets) and 2 quadrupole magnet strings (about 23 magnets each).

A prototype digital controller for the power converters has been operational for over a year now. This controller has successfully delivered the required PPM precision level required of the current. The next generation of controllers is presently under development. This paper summarises the functionality required of the new digital controllers by the high-level control system.

2. Power converters: high level control requirements

Most of the following requirements arise from consideration of the operational needs with beam, such as setting, ramping, trimming[1] and feedback. The tight constraints imposed by the small aperture of the LHC, both physical and dynamic, also play a key role.

Asynchronous set

The requirement is to set a power converter to a given value asynchronously (i.e. independently of other power converters). On receipt of the command, the power converter moves directly to the new value of the current (I). The possibility to specify a time over which the change is made should be allowed (default : in the shortest possible time while respecting the dI/dt limit). The value of the current should normally be the absolute value of current, but it might be useful for increments (i.e. ΔIs) to be applied. Suitable parameterisation of the given command should allow for this.

Round in and round off might be necessary to avoid high d^2I/dt^2. In fact, so critical is the nature of the magnetic history, it might also be necessary to be able to set the power converters using pre-load tables, in the same fashion as the ramp, which might be loaded to drive the power converters to the requisite level. The tables could contain explicitly the required round in and round out. Alternatively the power converter controllers themselves could, by default, apply round in and round off in a predictable way.

Synchronous set

A major requirement is the ability to allow a group of power converters to be set in a synchronous way (i.e. within a millisecond precision). This is required to apply trims and corrections. It is vital that the power converters concerned move to their new values in a smooth and synchronised way. It is assumed that this synchronisation will be performed via timing events. Synchronisation of command execution is expected to take place to within a millisecond. All equipment should use an identical timing system to drive actions invoked at the high level.

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[1] A trim is usually taken to mean a small change in a parameter or set of parameters. The parameter could be, for example, a beam related variable like tune, or the strengths in a set of corrector magnets.

A synchronous command to the power converter consists of a new value of the current and the time over which the change is to take place. The user must specify a time that respects the limits of all power converters involved. Having checked the command the converter controller should change its internal state (and refuse any conflicting commands), prepare to receive a timing event, and return an OK status to the calling program. (The handshake with the user might not be necessary if a middle layer process, say, can check that all is well: what is vital is that **all** power converters perform the action as required in a synchronous manner.)

The power converters should start the move to the new values on receipt of a pre-assigned timing event. Round in and round off will probably be necessary to avoid high d^2I/dt^2

Ramp or other function

The function to be followed by the power converters could drive the cycle from the high to low energy setting, the set to injection level, or the ramp itself.

The power converters should be able to follow a pre-loaded function on receipt of a pre-assigned timing event. Current functions will be sent down to the power converters. Implicit in this is that the power converters will not have to convert magnet strengths into currents. The calibration curves of the magnets need not be distributed to the power converters.

The current will be expressed as a function of time, or a time-like quantity (for example, vector number in LEP). The spacing of the points need not be regular. The exponential, parabolic, linear nature of the ramp will, probably, be explicit in the functions (a product of settings generation).

During the ramp all equipment should remain synchronised to within 1 ms.

Again round in, round off and the use of splines might be necessary depending on the coarseness of the points sent down.

The low-level controller of the power converter should check all values and rates of change. An error, or acknowledgement, should be returned to the user as appropriate.

The duration of the download of the ramp functions to **all** power converters should be less than 10 seconds.

The ability to read back a loaded ramp table from a power converter should be provided.

Avoidance of high d^2I/dt^2

Splines could be used to avoid high d^2I/d^2t (level to be determined). In the case of the ramp and other functions the modifications should be super-imposed on the given points. The provided function points should not be changed. In the case of asynchronous or synchronous sets, care must be taken that all power converters follow a similar curve to avoid de-synchronised application of a trim i.e. splining should not affect the beam physics parameters such as tune, orbit and chromaticity.

It might be envisaged that a variety of methods exist, these could be invoked as required.

Corrections in the ramp

There is a clear need to allow modification of the current values defined in the ramp functions by feedback controllers such as the tune feedback system. Application of these trims will need to be fast (bandwidth to be determined) and perhaps performed without a handshake with the driving application. They could also be regarded as asynchronous wherein control is left to the driving application.

The perils of sloppy data management in this area are many. How the power converter combines the dynamic trims and the pre-loaded ramp functions and how it deals with the persistency of a given trim remain open questions.

Following LEP one might envisage a virtual trim DAC within the low-level power converter controls. The sum of this and the main DAC provides the total current.

Emergency stop with beam

The power converters should perform an emergency stop on receipt of a pre-defined timing event. This would hopefully enable the ramping process to be stopped while keeping the beam. A synchronised round off of the executing current functions should be performed. Restart functionality should, of course, also be available.

In LEP the quadrupoles and sextupole power converters can perform a fast jump at the start and end of the ramp in an attempt to compensate the quadrupolar and sextupolar multipoles generated by the eddy currents in the main bending magnets. A similar problem exists in the LHC with snapback. Here, however, the slow exponential start to the ramp should allow control via a combination of pre-programmed functions (spool pieces etc.) and feedback on measurements made on the reference magnets. However, how the power converter deals with emergency stops etc. still have to be determined

Surveillance and Alarms

This is touching on a big area, which clearly requires detailed analysis. Surveillance will be performed, either locally or by the central alarm system.

The high-level control system is to monitor, at something like 10 Hz for example, the power converter state, tolerance, demanded setting (database) versus actual. Alarms should be raised if an exception is encountered, if the current goes out of tolerance or if a status fault occurs.

The power converters will need provide a clear definition of how data (such, as DAC values, ADC values etc.) is to be accessed and ensure that this information is available at the frequency required. Any implementation will need to respect the high to middle layer infrastructure deem to be standard (anticipating here the possible use of middle-ware to provide publish and subscribe services etc). Point-to-point enquiry of any given power converter should always be possible.

Interlocks, fault states and diagnostics.

Again a large, complex and critical area requiring detailed analysis. However, the grave risks of power converter malfunction failure are clear. If a failure mode is detected that will lead to, or possibly lead to, beam loss, the beam dump should be fired. The risks are too great to allow reliance on a system based on beam loss monitors.

There will be at least two fluid classes of power converter: critical and non-critical. A sufficiently loaded orbit corrector could, for example, become critical. If a fault state is detected on a critical converter, beam dump should be fired via an interlock system.

It is clear that any problems with low-level power converter control must avoid any potentially dangerous states as far as possible. A DAC accidentally being set to maximum is, for example, intolerable.

High level commands to allow easy analysis of problems should be available.

Post mortem analysis

In the event of beam loss, following a quench for example, a log of the relevant parameters of all power converters for a suitable time period (a minute at a specifiable interval (up to 100 ms), say) should be available for post mortem analysis. Preferably, the frequency at which the logging takes place should be related to the physics time constant of the circuit in question (to, for example, the L/R time of the magnet the PC is connected to).

State transitions

All power converter actions should drive the equipment through a set of clearly defined states. A clear definition of states and the transitions, both static (ON/OFF etc) and dynamic (cycling, ramping, etc.) should be provided.

Command checking

For any of the above commands/user requests, where appropriate, the power converter should verify:

- that the demanded current does not exceed the maximum,
- that any change in current does not exceed the maximum dI/dt, or d^2I/dt^2,
- that the demanded current is not lower than the minimum.

If any limits are violated, an error should be returned to the user and no action taken.

If the action concerns a synchronised change to a group of power converters and only a subset fails, no action should be taken by any power converter.

Security lock

There might be situations in which it could be desirable to freeze a power converter to avoid acceptance of any further commands, for example, just before injection. The power converters should therefore provide a command that allows this. The ability to unlock should also be provided.

Feedback control

At present, the need for feedback control of the following systems has been identified.

- Tune,
- global orbit,
- local orbit in the cleaning sections,

- decapole correction (using measurements of the reference magnets)
- possibly chromaticity (with the strong proviso that this will not be available for the start-up of the LHC) and momentum.

The rates required of the feedback loops for these systems has been the subject of much debate and will be defined in more detail in a forthcoming publication. However, from consideration of measurement times, and magnet response times, it is clear that 1 to 10 Hz will be the likely frequency range at which a system performs a measurement, calculates a correction and applies that correction.

Thus the power converters involved in site-wide feedback control (e.g. those steering the quadrupoles and the correctors) need to be able to respond synchronously to data/commands sent at a rate of 1 to 10 Hz. During feedback, the PC must continue to perform its internal checks (see faulty states and diagnostics), resynchronise its internal clock and communicate its state (see state transitions) to a central computer. The power converters have to provide a response to feedback data within a fixed delay. Any additional delay due to processing at the low level must be minimised.

The power converters involved in analogue feedback of the local orbit may need to deal with correction rates between 10 and 500 Hz. The capability of the power converter digital controller to handle 100 Hz correction rate might allow a control infrastructure, similar to the global orbit feedback control loop.

General Control Issues

Power converter control is just one of many subsystems that will need to be integrated into a high-level control system. It is important that any implementation does not compromise the coherency of the whole. Any solution should avoid at this stage imposing too concrete a solution on the middle and higher level control layers. It should be borne in mind that the power converters will need to interface into an interlock system, an alarm system, and possibly a middle layer providing “publish and subscribe” functionality.

References

[1] P. Proudlock, Summary of the LHC workshop on dynamic effects and their control, LHC project report 99.

[2] The LHC conceptual design report , CERN AC-95-05(LHC).