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Functional specification

LHC SLOW TIMING SYSTEM – HIGH LEVEL OPERATIONAL REQUIREMENTS

Abstract

This document describes the high level LHC operations' requirements for the LHC timing system.

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History of Changes

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1. INTRODUCTION

From a timing perspective the LHC is a relatively simple machine with none of the complications associated with multi-cycling. It does, however, have a critical dependency on the timing system for:

- Event distribution;
- Data distribution;
- Control of the Injection process.

The following describes the high level operational requirements for the slow timing system of the LHC with minimal reference to implementation.

An implementation of the system should be available by the end of 2006 to allow adequate time for thorough testing in 2007.

It is taken as given the absolute necessity for near perfect event transmission to all users. Non-receipt of critical events could have catastrophic consequences. The transmission of events to clients must be extremely reliable. Test procedures should be provided.

1.1 INJECTION

Injection into the LHC is a critical process. The potential damage of the high intensity proton beam at 450 GeV is considerable. It must be ensured that the transfer line, injection elements and the LHC are functioning perfectly before any attempt is made to inject potentially damaging intensities. In general this is the responsibility of the machine protection system (MPS). The timing system should, however, avoid unecessarily stressing the MPS.

It is planned to use a low intensity pilot in the LHC as a witness beam with the nominal injection sequence following:

1. Inject pilot
2. Over inject intermediate
3. Dump intermediate
4. Inject pilot
5. Over inject pilot with batch 1 of nominal
6. Continue nominal injection sequence batch 2 through 12

Note that the beam type of the circulating beam can change quasi-instantaneously during an over-injection. The beam type can certainly be different in the two rings.

Considerable flexibility will be require to cover different operational scenarios including: single ring set-up, re-tries, machine development. Interleafed injection into the two rings is a clear possibility. More details of the injection process are provided below.

1.2 MODE

The LHC is not a fast cycling machine (see figure 1). There are periods of tight synchronisation of the loosely coupled hardware and instrumentation systems. However, there are also long periods when the machine is coasting at a fixed energy. These are periods of time when the LHC timing system from an event perspective is quiescent. Data distribution goes on, but the timing system is not necessarily running a table, and no events other than data distribution events need to be going out.

There will be high level control of the machine mode probably driven by an LHC sequencer. The timing system will execute events or tables on request and distribute the machine mode. The LHC is not multiplexing on mode. We will pre-load a table of time/events - we give the table a name, we ask the timing system to play the table. Event tables do not necessarily correspond to modes. We will stay in ramp mode after the end of the ramp and the end of the ramp event table. There may be a need for some equipment to multiplex on beam type.

2. EVENTS

The machine events are generally used to trigger real-time tasks.

2.1 ASSUMPTIONS

- Events will be sent out on a 1 ms boundary. 7 different events on a given 1 ms. boundary is an acceptable maximum.

- The specified latency of the sytem i.e. the time between a request being made by the user and its receipt by the equipment concerned should be of the order 100 ms.

The high level system will attempt to guarantee that the loaded tables will not violate the 7 events per millisecond constraint. (Imagine a table that repeats each 5ms that sends 3 events in one millisecond, and a 17ms table that sends out 5 events in one millisecond, this would imply that when the tables run concurrently there would be a time when both tables would send their events in the same millisecond.) In the case of 7 event condition violation the users are deemed to be aware that the last event to be put on the output FIFO will be delayed by one millisecond.

2.2 EVENTS - REQUIREMENTS

No.	**Requirement**	**Priority**
R1a	Asynchronous timing events: The system shall issue a specified timing event, or events, on request at any time. The required latency between request issued to client receipt is of the order of 100 ms.	Critical
R1b	An API shall be provided to enable the software developer to pass an event request to the timing system. It shall be possible to send more than one event at the same time.	Critical
R2a	Pre-programmed tables of events shall be loadable to cover part of distinct machine modes, for example, the ramp. These event tables will be "played" on request. The request to start the table could be asynchronous or a pre-defined time. See table 2. Read back of table contents shall be possible. Abort of an executing table shall be possible – along with stop, repeat etc. Stop implies continuing a table to end and to cease any repeat. Abort - stop immediately There is not a one-to-one correspondence between mode and a table. The tables are aborted on request. If we lose the beams at the start of the ramp - there is no point in going on with the ramp table. If we switch mode to recover, the first thing we will do is ask the CBCM to abort all executing tables. Tables could cover periods of time from a few seconds to minutes. Tables shall be defined in milliseconds and start at time = 0. Tables are generally, arbitrarily re-locatable in time. However, it should be possible to specify the phase between two concurrent tables i.e. define the "0' of each with respect to some other event (such as the SYNC time, or MILLISECOND MODULO time).	Critical
R2b	The ability to loop over a table of events shall be possible. Typically used in physics to trigger periodic acquisition. Running different tables concurrently should be possible. The ability to request an event to be issued while table(s) are executing is also required.	Critical
R2c	Event table - for example the ramp - preloaded - starting on request within 1-2 seconds should be OK. Going to have to watch having to wait for executing table to finish in certain circumstances.	Critical
R2d	An API shall be provided to enable the software developer to call the timing system to load or modify a table. We should be able to read back the contents of the table. We should be able to modify the table - possibly by reloading the whole thing.	Expected
R3	Events shall have a system identifier or different events shall be defined for different systems. Start ramp RF could be delayed with respect to start ramp Power Converters for example. [See below for discussion.]	Critical
R4	Parallelism – different trims overlapping in time. Power converters typically need to be armed for a given exclusive event, which might not be recognised by all other power converters. See below. Typically maximum number of different groups will be around ten. The grouping of devices is dynamic and may change from correction to correction.	Critical

Events shall include:

- Start ramp – PC, RF, Collimators
- Abort ramp – PC, RF, Collimators
- Power abort
- Injection warning - RF, BPM – ring 1 and ring 2. The incoming beam type will be required.
- RF events during filling, ramp and before physics to synchronise rings. Will trigger functions controling transverse feedback and longitudinal feedback functions during the injection process. Incoming beam type required.
- Synchronised collimator set, synchronised collimator ramp.
- Beam dump – event to BIC (conditioning of BIC, eg, standard beam dump versus emergency beam dump not through timing system)
- Post mortem freeze, note need for different timescales depending on equipment…
- Measurement acquisition - measure orbit, measure beam loss synchronised measurements acquisition
- Kickers – per-injection warning etc.
- BI synchronised acquisition – orbit/beam losses/BCT at pre-defined times in ramp, or on demand. Synchronised kick and measure procedures.
- Wirescanners – fly wire.

Event	**System**	**Time [ms]**
Start Ramp	Power Converters	0
Start Voltage Ramp	Radio Frequency	200
Start Frequency Ramp	Radio Frequency	300
BLM acquisition	BLM	0
BPM 1000 turn acquisition	BPM	0
Start Ramp	Collimators	1000
BPM 1000 turn acquisition	BPM	10000

Table 2: Example LHC timing table – ramp

2.2.1 POWER CONVERTERS

The power converters are one of the main clients of the timing system. The events are received in a gateway and broadcast to all FGCs connected to the gateway. Foreseen events include:

- Start ramp which essentially applies new references. These can be synchronised trims (CTRIM – cubic trim, start and end point supplied by user) or ramps (TABLE – table of time/value loaded by user).
- Start ramp needs to arrive 40 ms or so before intended start point. Could increase the time before our start ramp event is to be acted on to 100ms (from 40ms) which will give us 5 WorldFIP cycles to ensure that the FGCs have received it. There is no hard requirement for this length of time, but the greater the number of WorldFIP cycles that it encompasses the more reliable we should be in theory. In reality, we have never seen transmission errors over the WorldFIP. If there are any unwanted consequences of moving to 100ms, then we can lower this as appropriate.
- R4 is an important requirement – can imagine working on beam 1 and beam 2 in parallel and do not want manipulations to collide. This implies different arming for, and using different “start ramp” events for different sub-sets of power converters.

- The abort ramp event causes every power converter to round off gracefully over pre-assigned time period.
- Post mortem

2.2.2 PARALLEL "START RAMP" ON DIFFERENT GROUPS OF DEVICES

Although strictly an implementation detail, this subject has been discussed at length. Two main options appear possible:

- There is an unsigned short field (16 bits) called "payload" associated with a timing event that can be set by the sender and therefore could potentially be used to implement a solution to R4. There are certain implications of using this field that must be taken into account, however if the events are intended only for consumption by PO then it shouldn't be too much of a problem.
- The use of a limited pool of timing events with reservation possible. Enable, Fire, disable, release. Allocation mananged by middle tier software.

3. DATA DISTRIBUTION

No.	Requirement	Priority
R5	The machine mode shall be distributed as a safe beam parameter [2] at a frequency of 1 Hz or higher.	Very Critical [SIL 2]
R6	The beam energy shall be distributed as a safe beam parameter at a frequency of 1 Hz or higher.	Very Critical [SIL 2]
R7	The LHC squeeze factors shall be distributed as a safe beam parameter at a frequency of 1 Hz or higher.	Critical
R8	Safe Beam Flag shall be distributed as a safe beam parameter at a frequency of 1 Hz or higher.	Very Critical [SIL 2]
R8	The circulating beam type shall be distributed at ~1 Hz at all times. It is possible to have different beam types in ring 1 and ring 2. (Beam type = intensity plus bunch structure. Syntax to be defined.) The timing system shall change the beam type distributed at the moment of injection (for example, in the over injection of a pilot by a nominal batch) with a latency of 100 ms. The timing system shall be informed via a dedicated LHC injection monitoring process. The 16 bit encoding of beam type is to be defined. It is noted that there are potential problem of cross system incompatibility (different beam type transitions for different systems).	Critical
R9	Other parameters shall be distributed. These parameters shall include the RF frequency, the total beam intensity for beam 1 & beam 2, the overall state of the collimator system and the fill number.	Critical
R10	An API is required to input specified data into the timing system. The latency shall be 100 ms.	Expected
R11	Other data items considered useful to LHC operations – as yet unspecified. E.g. bunch pattern, beam position at IPs etc., run number.	Expected
R12	The incoming injected beam type shall be distributed (RF, BI). The RF	Critical

	position (bucket number) of the batch to be injected beam shall be distributed.	
	The failure to transmit the SBPs will result in a beam dump. The fail over strategy in the case of timing generator failure should be clearly established. Stale data must not be sent out.	Critical

3.1 BEAM INSTRUMENTATION

BI clearly need somehow information (expecting to find in the telegram) like the machine mode, injection event (warning, injection, post) context, i.e. beam injected, batch injected, bucket injected (these values could be OR correct and stable during injection +/- 1 second, OR linked to the event with a kind of payload).

BI also need the intensity and energy (planned refresh rate around 10 Hz). This data is required for the BOB/BST master but also locally on FECs without a BOB/BST receiver.

4. INJECTION

4.1 ASSUMPTIONS

- The LHC shall be the master of the LHC injection process. Having evaluated the success, or not, of an injection, it shall decide whether or not to continue with the injection sequence.
- The LHC shall try and do this fast enough to allow use of consectutive SPS cycles, however, this is not, at this stage, guaranteed. The timing system should be prepared for this.
- When the LHC is not explicitly requesting beam, the SPS should be in control of its own destiny. There will be pre-LHC injection training, extraction to the last TEDs of the transfer lines while the LHC is recycling. The SPS shall be capable of making autonomous requests for beam during this period. A well-defined transition of mastership of the beam request process should be implemented. Clearly, the LHC mode should not prevent LHC beam from playing in the SPS.
- All requests for injection into the LHC shall be made explicity by the LHC high level control system.
- The LHC high level control system could issue a pre-injection request to allow injectors time enough to responsd to an injection request.
- Throughout nominal LHC injection, the SPS shall be dedicated to the process. It shall not serve other USERs (e.g. CNGS) during this period.

4.2 SEQUENCE

We will need an injection sequence to be configured before the injection process is started. This sequence shall be set up offline, and will drive the pre-loading of equipment settings and timing, and condition the checks to be performed before injection begins. It will then be used to drive the requested injection sequence.

The timing system shall received one injection request at a time. It will not be loaded with a pre-defined injection sequence. The dangers of damage are high and the LHC must retain explicit control of the injection process. If this means reduced efficiency of the accelerator complex while the LHC is filling, this has to be accepted.

The outline of the injection process is:

0. Preparation

0.1 Pre-warning to injectors that the LHC will be requiring beam – manual/vocal/soft.

0.2 SPS training cycles – request for beam from SPS. Check transfer lines, possibly beam to last TEDs. SPS master.

0.3 LHC to mode Filling. Change injection master to LHC.

1. LHC makes request to CBCM with ring, bucket number, beam type and number of PS batches.
2. Beam injected into SPS, accelerated. Beam quality checks on flat top.
3. SPS - decision to extract or not. The SPS extraction interlock system will have all the information on the state of beam dumps in the TLs, state of the LHC (beam & injection interlocks summary) and status of extraction and line elements to take the appropriate decisions.
4. If all elements are safe and the extraction timings events are distributed when the LHC USER is played, then the extraction kicker will be fired. The timing system will be sending out warning events; the RF system, the pre-pulses. The SPS MTG sends out the extraction forewarning (= injection forewarning) used by the LHC Injection kickers
5. Extraction. Beam down TI2/TI8. [checks on BLMs, trajectory]
6. Injection into LHC [injection kickers having received warning timing events & pre-pulse etc.]
7. The destination (R1 or R2) is sent before the injection forewarning (BI requirements – Lars). Set by LSA

The timing system does not play any role in the injection protection, with the exception of the safe parameter distribution.

8. Beam quality checks in LHC. First turn, beam loss, intensity, emittance.

If the timing system sends out the 'wrong' timing events or plays the wrong user (or destination or whatever we use in the end) such that instead of say pulsing TI8 we pulse TI2, then:

- either all conditions are correct for extraction through TI2 to LHC - the interlock system will then allow extraction. This may not be what OP wants, but this should be perfectly safe (in the sense of no damage).

- if the conditions in TI2 or ring 1 are not correct, then the extraction is automatically blocked.

If the bucket number is wrong then the beam will not arrive in the right place, but there should be no risk of damage. But the LHC may quench depending on the bucket number error.

4.3 RF

LHC RF system [3] expects the bunch number and the destination ring to be delivered to to SR4 by the LHC timing system. This would be delivered every SPS cycle whenever the LHC is in injection mode. Only when the LHC explicitly requests beam will extraction takes place and the LHC injection kickers fire.

- The common frequency is used to set the LHC bucket into which the beam is injected into. The period of this signal is the time for specific bunches circulating in the SPS and the LHC to come back to the same simultaneous positions, every 7 LHC turns or 27 SPS turns.
- Fine positioning of the beam injection phase in the LHC buckets is adjusted with the phase of the LHC RF signal sent to the injectors.

- Signals for RF synchronization must be available in the PS about 450 ms before extracting to the SPS.
- RF systems updates the bucket selector and the phase of the 400 MHz sent to the SPS.
- RF generates injection pulses for the kickers and generates injection pulses for BI.
- Longitudinal feedback, transverse feedback and other settings are preloaded. Batch (or beam type) dependent settings triggered by timing events at the point of injection. Clearly the events have to be set up in advance. The settings are explicitly pre-loaded before every injection.

4.4 REQUIREMENTS

No.	**Requirement**	**Priority**
R13	The timing system shall receive an asynchronous request from the LHC high level control system for beam to be injected into the LHC. The request shall specify: ring, bucket, number of CPS batches and beam type. The beam type shall be a recognised, pre-configured definition specifying bunch intensity, bunch spacing and number of bunches. The request shall be met as soon as is practically possible. It shall be possible to abort a request. The timing system shall not fulfil the request if the LHC mode is not set to a pre-agreed standard (e.g. filling). The ring, bucket number and beam type shall be forwarded with very low latency (< 100 ms) to the LHC RF system. The ring, RF bucket, and Beam Type distributed by the timing system should stay stable ±1s around the LHC injection.	Critical
R14	The timing system shall receive external input from the machine protection system including injection permit and safe beam flag. It shall at all times respect the constraints implied by these inputs. The only links that are needed between timing and beam interlock system concern the safe beam flag and other safe parameters.	Critical
R15	The SPS shall be able to request extraction into the LHC transfer lines if the appropriate dumps are in. The LHC could be in any mode.	Expected
R16	The destination (R1 or R2) is sent before the injection forewarning (Beam Instrumentation – Lars). Set by LSA	Expected

5. TIME OF DAY

For completeness, UTC shall be delivered to the users with 1 microsecond accuracy. Utility routines shall be provided.

6. MULTIPLEXING

The traditional multiplexing criteria of cycle will not apply in the LHC. Multiplexing in the LHC will be on beam type either “Injected” or “circulating”. Both will be sent out. Equipment reacts as required on a system by system basis. Accordingly the multiplexing requirements should be enumerated by the equipment groups concerned.

Implications to be followed up.

7. POST MORTEM CONDITIONING

If a USER permit falls, the BIS will immediately request a beam dump. At the same time it will issue a the timing system will see the beam permit drop and send out a post mortem event on the slow timing and the BST.

In the event of a requested beam dump, which also passes via the BIS, it might be disadvantgeous to perform a ring wide post mortem. Therefore, it should be possible to mask the issuing of the PM event for a short period of time covering the requested beam dump. This is highly critical and must be absolutley reliable.

Use Case	Timing system requirement	Post Mortem required	Rings
Inject & Dump 0 – 1000 turns	Use a timing event at 100 ms to provide redundancy for increased screen protection Start table on pre-pulse receipt	N	1
Circulate & Dump 0.1 – 1000 s	Will use the timing system to trigger the beam dump via the BIS. (If a user permit is pull during this mode the PM event should go out as normal.)	N	2
Filling - intermediate	Will use the timing system to trigger the beam dump via the BIS.	N	1
MD mode Dump one beam	Will use the timing system to trigger the beam dump via the BIS (implies two BD events)	N	1
End of fill	Will use the timing system to trigger the beam dump via the BIS.	Y	2

Note:

- The XPOC events always go out. These are presumably conditioned on beam 1 and/or beam 2. Systems listening for this will include: BPM, Screens, BLM, BCT etc. Their reaction to the XPOC event mustn’t compromise full post-mortem – a system level consideration. See Appendix C.
- Post mortem request includes: Slowing timing event and BST message
- Receipt of PM event in front-ends could compromise normal operation.

8. TESTING

Thorough testing is completely and absolutely vital. Test case failure scenarios should be drawn up to cover as many cases as possible. These should be developed and added to as experience grows.

9. REFERENCES

[1] The CERN Machine Timing System for the LHC era – LHC-C-ES-0004, Gary Beetham on behalf of the Timing Working Group.

[2] R. Schmidt et al, SAFE MACHINE PARAMETERS GENERATION AND TRANSMISSION (SMP), inpreparation.

[3] Philippe Baudrenghein, RF operations through the LHC cycle.

[4] LHC Software Analysis, http://cern.ch/proj-lhc-software-analysis/

10. APPENDIX A – USE CASES

To confirm the above requirements the following scenarios are the subject of Use Case analysis [4].

- Standard trim e.g. orbit correction
- Standard trim in parallel e.g. orbit correction in ring 1, orbit correction in ring 2.
- Pilot injection
- Over injection of pilot by intermediate beam
- Injection onto last TED in TI8 – LHC not ready.
- Ramp

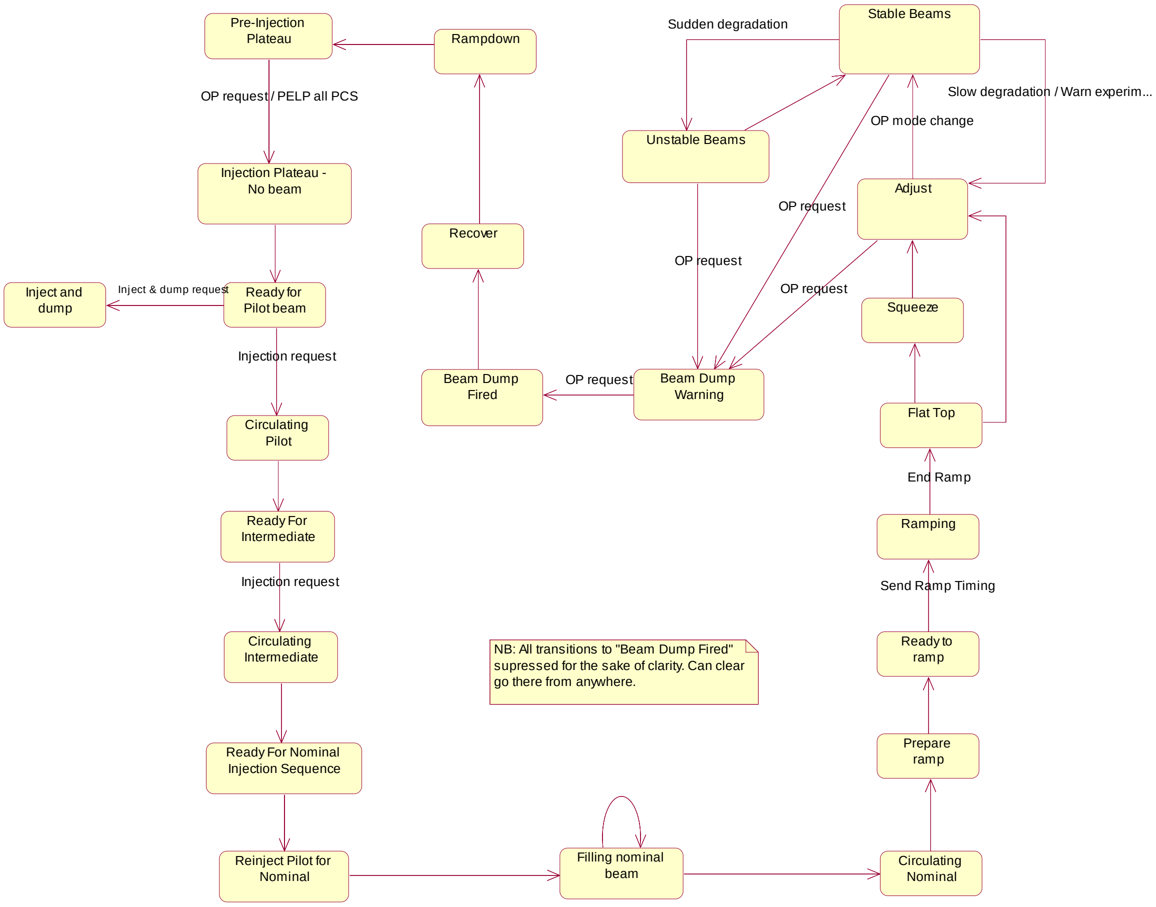

Figure 1: Nominal LHC sequence

11. APPENDIX B – FORESEEN EVENTS

System	Event	Type	Payload	B1/B1?
Power Converters	Start ramp	ms	Y	N
Power Converters	Abort ramp	ms		N
Power converters	Post mortem	ms	N	N
RF	Injection request	ms	Y	Implicit in payload
RF	Start frequency ramp	ms		Y
RF	Start voltage ramp	ms		Y
RF	Start TFB injection			Y
RF	Start LFB injection			Y
RF	Synchronise rings	ms		N
BI and injection kickers	Injection warning T-100msec, T-20msec, 0,			Y

	+10msec			
BPM	Capture trigger	BST		Y
Beam Dump Request		ms Timing pulls user permit		Y
ALL	Mode changes	ms		N
ALL	Post Mortem	ms & BST		N
ALL	XPOC	ms & BST		Y

12. APPENDIX C: XPOC EVENTS

Rather that a single event, this pulls together existing data capture mechanisms and would probably be a table played automatically on the drop of the beam permit. Different tables for ring 1 & ring 2.

	Trigger	Property		Ring1/2
Ring BPMs point 6	BST	Capture		Y
Ring BLMs point 6	BST	Snapshot buffer		Y
Ring BCT	ms			Y
Screens – dump line				Y
BPMs – dump line	BST			Y
BLMs – dump line	BST			Y

BCT – dump line	BST			Y
Septa currents	ms	PM buffer		Implicit
Kicker waveforms				Implicit