WHAT DATA IS NEEDED TO UNDERSTAND FAILURES DURING LHC OPERATION?

R. J. Lauckner. CERN, Geneva, Switzerland

Abstract

The LHC will require a post-mortem data recording system for faults in the commissioning and preparations without beam, as well as for operation with beam. What data should be recorded in order to understand faults? What are the requirements for synchronization? How should Post Mortem and Logging Data be used in the Control Room?

1 INTRODUCTION AND MOTIVATION

The stored energies in the LHC beams and magnet systems will inevitably lead to a reduction of operational efficiency because of the need to protect components by dumping beams or extracting the magnetic stored energy from the cryostat. Diagnosis of these incidents, their causes and consequences will improve the availability of production beams by:

- providing a rapid explanation of the best procedure to initiate appropriate action and restore beams,
- building a longer term knowledge of accelerator operation which will lead to better operational procedures, and
- enhancing the performance of the machine protection system which will allow operators to increase the beam intensity.

Moreover, it is essential to monitor the correct functioning of the various protection elements which include quench detection, machine protection and the beam dumping systems. In the unlikely event of damage to components an explanation of the incident will be of prime importance.

A facility for the collection, analysis and management of relevant information must be complete and coherent across all systems to achieve these aims. Such a system may be referred to as a ‘Post Mortem Facility’.

As well as diagnostics for Beam Abort and Power Abort incidents, the Post Mortem Facilities should also be prepared for more general usage. Applications will include diagnosis of significant beam losses, collection of data during machine development and investigation of ‘mysterious’ problems.

2 ALARM, LOGGING AND TRANSIENT DATA

There has been an increase in the data that is regularly logged from SL accelerators. Starting from machine settings, and data to report and to improve overall operational efficiency, logging has been extended to applications such as energy calibration and equipment management. The CERN Alarm System also archives all fault states; the information provides diagnostics for severe events such as the fire in the SPS BA3 building. Modern industrial supervisors invariably include logging and trending capabilities. Future developments will also be generated by INB regulations.

From these observations it is clear that:

- the Post Mortem Facility must be designed with close attention to the complementary logging and alarm systems;
- Post Mortem analysis will be performed at the accelerator level and the equipment level. In this paper the emphasis is given to data required for accelerator level diagnostics.

Without being exhaustive the following definitions may be applied.

Alarms are fixed format messages that are generated asynchronously upon the occurrence of some unwanted incident which is considered to be a fault by the message recipient.

Logging is the systematic collection of information either synchronously or when some input value changes by some predefined quantity referred to as a deadband or epsilon.

Fast Transient data is collected from a wide variety of sources when a predefined incident occurs. It is typically data originating from fast acquisition into circular buffers. The incident generates a Post Mortem Trigger which freezes the acquisitions. Buffering ensures pre- and post-trigger data.

3 WHAT DATA IS NEEDED?

An overview of data requirements for Post Mortem at the accelerator level is given in the Table. Systems have been classed into four types. Services are the technical systems which are essential for accelerator operation although they can be operated with essentially no feedback concerning beam processes in the accelerator. Post Mortem information is mainly supplied by specific logging facilities. Protection systems group elements that must work properly in order to trigger and execute Beam Aborts and Power Aborts. These systems include the proper functioning of Post Mortem facilities as a critical objective and, for this reason, they are characterized by being self-triggering. The third system encompasses all

System	Transient Recorder	Logging	Alarms	Post M Trigger	Self-Trigger	Commission Date	Type
Summary of PCR Post Mortem Data Requirements							
Access System	n	y	y	n	n	Sector	
Cooling and Ventilation	n	y	y	n	n	Sector	Services
Cryogenics	n	y	y	n	n	Sector	
Electrical Network	y	n	y	?	n	Sector	
Beam Dump	y	n	y	?	y	Beam	
Beam Loss Monitors	y	y	y	y	y	Sector	
Energy Extraction Switches	y	y	y	?	y	Sector	Protection
Machine Protection	?	y	y	n	y	Sector	
Quench Protection	y	y	y	?	y	Sector	
Aperture Kickers	y	n	y	y	n	Beam	
Beam Feedback Systems	y	?	y	y	n	Beam	
Collimators	?	y	y	?	n	Sector	
Inflector	y	n	y	y	n	Sector	
Power Converters	y	y	y	y	n	Sector	Act on Beam
RF Power & Low-Level	y	y	y	y	n	Beam	
Reference Magnet Signals	y	y	y	y	n	Sector	
Transverse Dampers	y	n	y	y	n	Beam	
Vacuum	n	y	y	n	n	Sector	
Beam Current Monitors	y	y	y	y	n	Beam	
Beam Position Monitors	y	y	y	y	n	Sector	Monitors
Beam Profile Monitors	y	y	y	y	n	Beam	
Cryostat Instrumentation	?	y	y	?	n	Sector	

equipment that can directly induce a beam loss. Data acquisition is typically triggered by the Post Mortem Trigger. Collimators are included in this class even if their main role is to prevent damage. The final class contains the instrumentation which will be used to provide general diagnosis of incidents. Beam Loss monitors will also fulfill this role but, more critically, they belong to the protection class.

The table indicates systems which must capture fast transients. Information on self-triggering and response to the Post Mortem Trigger is included. The penultimate column shows that many systems must be operational for the Sector Test.

Several open points require further discussions with system experts, for example, concerning triggering for protection systems. The following summaries are a first attempt to describe data requirements at a system level and need further elaboration with specialists and users.

3.1 Data from Services

Data from the following services is necessary to understand indirect causes of incidents. All systems are expected to generate alarms destined for the system specialist and the end user. They are therefore not mentioned systematically although they are expected to be a valuable source of Post Mortem information.

3.1.1 Access System

This system must be able to create Beam and Power Aborts to ensure personnel safety. The status of all access chains must be logged.

3.1.2 Cooling and Ventilation

Air temperatures in all equipment areas and cooling circuit flow rates and temperatures should be collected. An industrial supervisor is being supplied with these systems and it is anticipated that extensive logging will be available.

3.1.3 Cryogenics

Again, an industrial supervisor is being supplied and this will provide extensive logging with a depth of some hours. Experts anticipate that information concerning incidents will be stored for longer.

3.1.4 Electrical Network

It must be expected that perturbations in the form of spikes and voltage drops will continue to disturb operation with potentially serious knock-on effects. Recordings of these events will be necessary in order to understand their origins. Accelerator level analysis will be through alarm information.

3.1.5 Safety Systems

Fire detectors, gas detectors, emergency stops and red telephones should supply information through the CERN Alarm System.

3.2 Data from Protection Systems

These systems must always be self-triggering and may also be required to respond to the Post Mortem Trigger. Equipment level Post Mortem is a primary concern but is outside the current context.

3.2.1 Beam Dumping System

This includes kicker systems, magnets and power converters for beam transport and the absorber block. Transient recordings of the circulating beam, extracted beam, the extraction kick and profiles are essential to demonstrate correct beam dumping.

3.2.2 Beam Loss Monitors

They are included here as it seems likely that they will become a critical part of the Machine Protection System providing information to trigger a Beam Abort. Their performance in this role must be systematically recorded.

These elements will also provide general diagnostic data; information should be recorded at 100 Hz with a depth of 20 seconds to monitor events leading up to the Post Mortem Trigger.

3.2.3 Energy Extraction Switches

The status of these switches must be logged and, in addition, transient recording of their temperatures and the voltages across the parallel resistors provided. Loss of redundancy of these systems will generate alarms.

3.2.4 Machine Protection System

A comprehensive logging of all status information will be of key interest to the Control Room.

3.2.5 Quench Protection System

Transient recordings of active voltage taps and heater discharge voltages will be required. Loss of redundancy in the heater power supplies will generate alarms.

3.3 Systems that act on the Beam

These systems will be the primary suspects in the case of a Beam Abort or important beam loss.

3.3.1 Aperture Kickers

These are designed to kick the beam to the machine aperture. Kicks must be properly synchronized and at the correct voltage. Discharges must be recorded.

3.3.2 Global Feedback Systems

These will be used to autonomously control critical beam parameters such as orbit, tune and chromaticity. All sensors and actuators must be equipped with recorders. A combination of sampling speeds are needed, fixed rates to track long term effects and more rapid recording when the errors are large.

3.3.3 Collimators

These are slow devices. All movements must be recorded with adequate resolution; this might be achieved by logging techniques.

3.3.4 Inflector

This must be equipped with recording equipment to demonstrate the correct synchronization and voltage of all discharges.

3.3.5 Power Converters

Transient recording of the currents is required. The sampling speed for circuits with long decay times will probably have to be reduced after a Post Mortem Trigger to cover long decays; the information is needed to check that electrical breakdown does not occur in the gaseous helium. All status and interlock information should be logged.

3.3.6 RF Systems

The correct operation of the RF can be demonstrated by the absence of beam in the abort gap and the evolution of the mean radial position. The group is considering acquisition of many fast signals for tuning and diagnostic purposes. Hardware interlocks will be logged and time stamped building on the experience gained at LEP.

3.3.7 Reference Magnets

This system will provide control signals for feedback to power converters (see Global Feedback Systems Section). Information to be recorded will include predicted and measured multipoles. A direct recording of the measurement coil signal and a comparison with an independent measurement, a hot spare, should be considered. Logging will track drifts over time, the frequency would depend on the machine state: faster on the ramp.

3.3.8 Transverse Dampers

A recording of the damping of each injection should be available. Additionally, wideband transverse signals should be available to check for instability growth. As with the RF system a large amount of data will be required to diagnose faults at the equipment level.

3.3.9 Vacuum System for the Beam

The status of all valves and pumps should be logged. Slow logging of pressures will be sufficient in the LHC.

3.4 Beam Monitors

The stored energy in the beam will be the source of most incidents during LHC operation. Comprehensive diagnostics of beam parameters will be essential. The following list of instruments is preliminary.

3.4.1 Beam Current Monitors

Transient recording of both the DC and 40 MHz BCT systems will be required. The slow system will follow currents over periods of many seconds. The fast BCT will follow the evolution of intensity within a turn, for a period of typically 1000 turns.

3.4.2 Beam Position Monitors

These will be essential for the diagnosis of beam induced quenches. It is currently being considered to store 1000 turns for each pick-up and 1000 closed orbits. The latter are integrated over about 20 ms, thus providing about 20 seconds of history.

3.4.3 Beam Profile Monitors

Knowledge of the beams' profiles before and after a Post Mortem Trigger will provide information concerning machine acceptance and transverse behaviour. More slowly varying information should be logged for comparison.

3.4.4 Cryostat Instrumentation

Operational conditions inside the accelerator cryostats will be of interest to the Control Room; this information includes temperatures, pressures and heater status. It appears that quench events can be recorded with adequate granularity by periodic logging from the cryogenic control system which has a bandwidth approaching 1 Hz.

As a final remark on data needs, it should be accepted that the complexity of the machine will certainly lead to oversights. Thus, a standard hardware solution for rapid connection of currently interesting information will be very useful.

4 DATA ANALYSIS

A two-level approach is recommended for the analysis of Post Mortem data. At the LHC, the Control Room software will be required to support models of machine systems which provide insight into the underlying frozen when a Post Mortem Trigger occurs. These specific applications must be fully integrated into the Post Mortem Facilities. In particular they must be able to interface to Post Mortem data management and archiving.

The second level approach to data analysis will be the use of generic tools to compare information across many sub-systems. If a satisfactory analysis of an incident cannot be provided by the first level, then this more laborious approach will be necessary. Two well-known

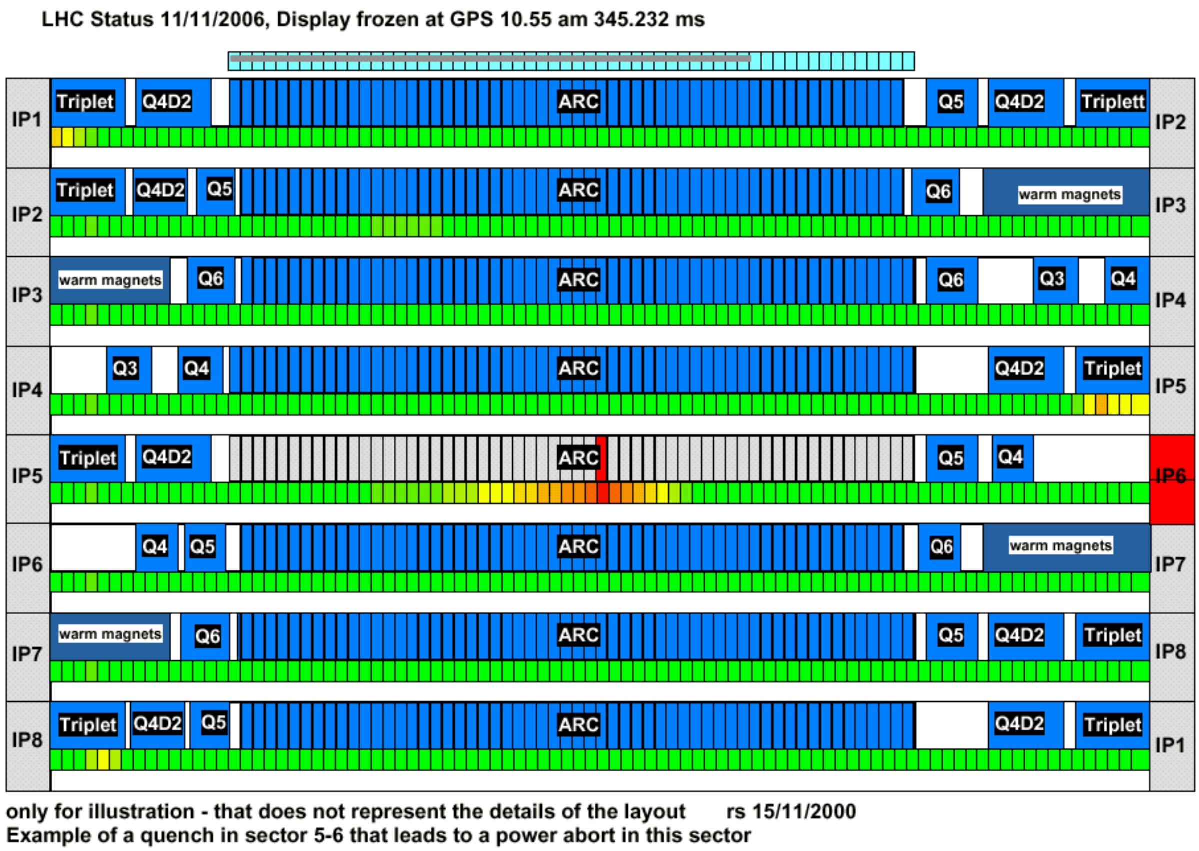

Figure 1, Post Mortem Display from Machine Protection System

processes that need to be adjusted for optimum accelerator performance. This specific software will also be used for first level diagnosis of Post Mortem information. Well-known applications that are required here include the closed orbit analysis and correction package and the 'thousand turn' package which provides diagnostics of the accelerator optics. Many other examples exist and the applications must be designed to support Post Mortem as well as beam tuning and other requirements.

Another important example of specific software is the Machine Protection System which must provide a summary overview and the possibility to drill down to more detailed status information. A view of how this might appear is shown in Figure 1. This is expected to be permanently displayed to the machine operators and tools for this type of analysis are the correlation plot and the event sequence. A correlation plot allows information from all systems to be represented on the same graph. Taking into account the large number of input channels such an analysis can only be used to confirm or illustrate an observation. The event sequence is a chronological ordering of event information which could be used to search for the original cause of an incident. This is very similar to the alarm displays used by the Control Room now. A future Post Mortem event sequence should integrate data from logging and alarm sources. The refinement of such tools and the elaboration of algorithms to search Post Mortem data will certainly accompany the initial period of operation. More urgent issues to be addressed are the collection and management of the information using common triggers, time standards, data interfaces and perhaps standard hardware.

5 TRIGGERS AND TIME STAMPING

Beam Aborts and Power Aborts are expected to provoke the large majority of Post Mortem Triggers. As knowledge of the LHC grows, then less serious incidents will become the major obstacles to machine efficiency. Partial beam losses must be detected and used to create a Post Mortem Trigger. Finally, a flexible means to generate conditioned triggers will be necessary for understanding other phenomena and for machine development. The Post Mortem Trigger will freeze transient recorders and invoke a snapshot of logging and alarm systems for longer term storage. It will also initiate the transfer of data to the Control Room.

Because of these less critical applications of the Post Mortem Facilities the need arises for a dual Post Mortem capacity for protection systems. Under no circumstances should one of these systems be unable to record its own operation because its recording system has been fired by a Post Mortem Trigger. Furthermore, a self-trigger may be a useful data reduction tool; it seems unnecessary to collect quench protection information from thousands of channels where no quench has occurred.

In order to correlate information all data must be time stamped with a common clock. The Timing Working Group has recommended[1] that UTC should become the standard for time keeping at the LHC. Effort is needed to define how systems will acquire this information but it is important that the time stamping is performed at the source and not added when data is passed up towards the Control Room.

Many processes are 'slow' and do not need high resolution time stamps. Time in some PLCs is accurate to about 10 ms and the proposed distribution of time using GPS receivers and IRIG B is accurate to about 1 μs. These values are suitable for time stamping cryogenic and beam processes respectively. Time could also be calibrated by requiring all systems to receive and time stamp a Post Mortem Trigger event transmitted by the machine slow timing system. However the precision of this system has not yet been defined

6 DATA REPRESENTATION

Having ensured a common clock it is still necessary to define how Post Mortem data will be represented. Experience from running Strings at CERN and from HERA operation reveals that:

- data sets must be self-describing,
- a data set should only contain information from one sensor,
- a sensor may only have one time base but several amplitude channels, and
- data should be in ASCII!

These recommendations are illustrated in Figure 2 which includes some of the data interfaces used at the Strings.

Time base information can describe a constant interval or different sampling rates which are used to obtain better resolution for faster parts of a process, but slower sampling in order to capture a long decay. Many different calibration techniques have been used for dependent variables including polynomials and look-up tables. Information about physical units is included. Error bars have not been foreseen and, if required, should not prevent the data from being pasted into common desktop tools.

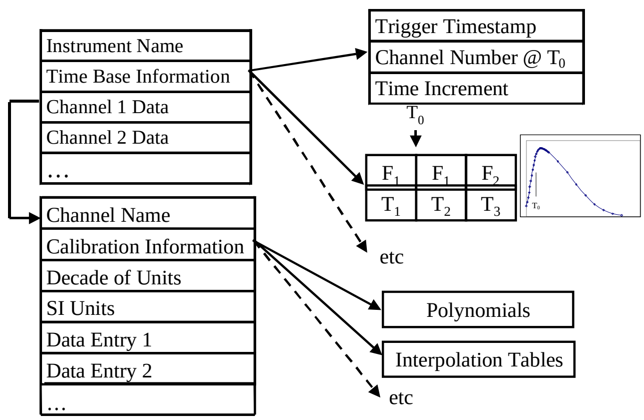

Figure 2, Data Representation Interfaces used at the Strings

7 DATA MANAGEMENT

Figure 3 presents an overview of the LHC Post Mortem Facility. It illustrates the various sources of data that will be used to build a complete explanation of an incident at the LHC. Additional sources to those discussed so far will certainly include the machine's nominal settings, indicated as Operator Transaction.

For these sources to provide coherent information, the design and management of these systems must be coordinated. Aspects to be considered include the organization of information from the different sources and the management of long term archives. As the volume of accumulated information is certain to expand to fill the available techniques, neglect in this area will compromise the long term improvement of LHC performance.

[1] Minutes of SLTC (http://lhc.web.cern.ch/lhc/sltc/sltc.htm), Dec 6, 2000.

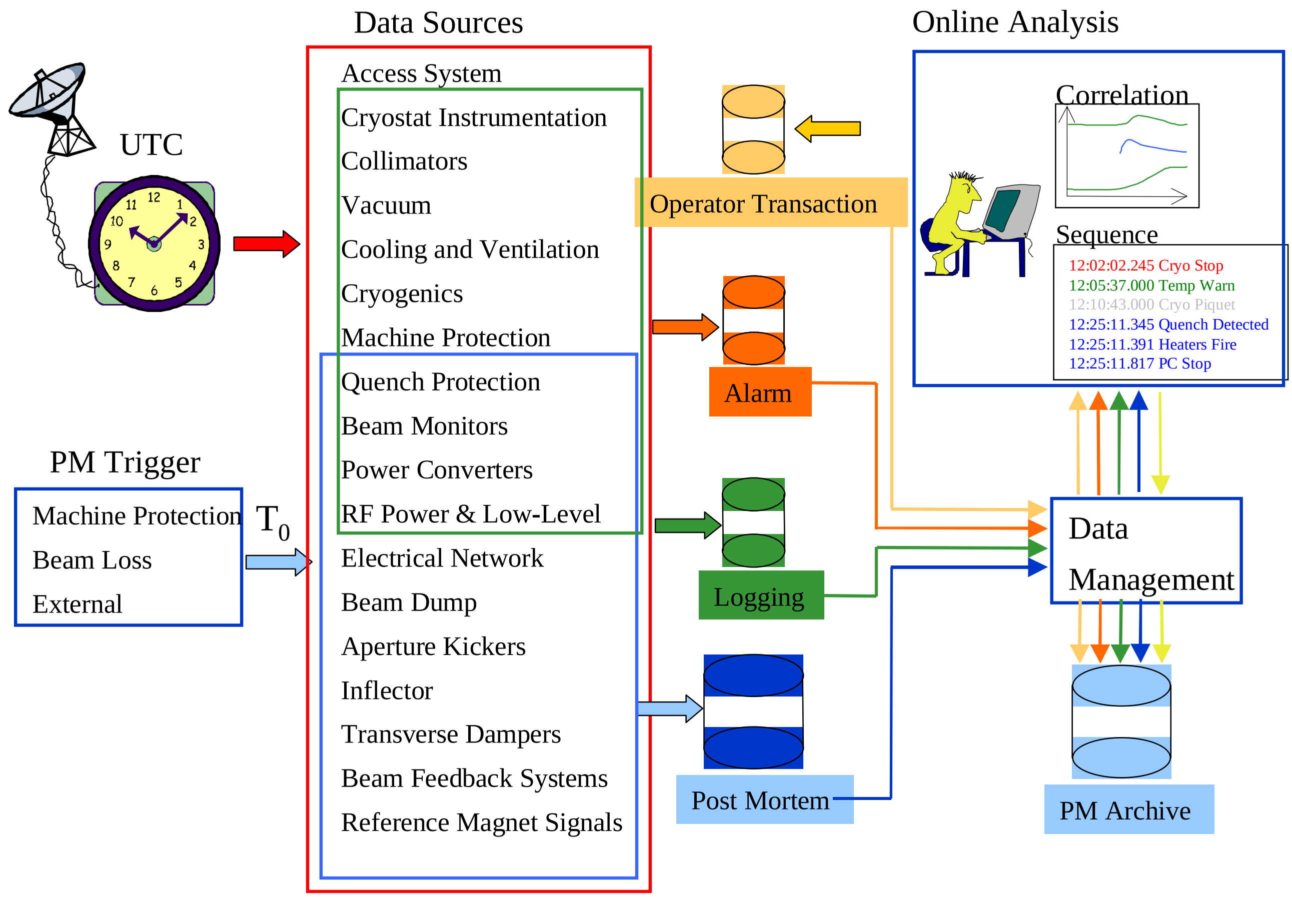

Figure 3, Post Mortem Facility Overview

8 CONCLUSIONS

Post Mortem will be an essential tool at the LHC from the initial hardware commissioning through to attainment of the design goals and beyond. Facilities must be complete and coherent across all systems and will rely on careful consideration not only of the information that is to be collected but also on the rigid application of common time stamping and data representation techniques. The system has overlapping functionality with the alarm and logging techniques as used at SPS and LEP, and the design of the systems must be coordinated.

Work is required to refine the signal definition which is outlined here and to clarify the recording frequencies and depths. Hardware interfaces must also be defined; common hardware should be considered that has the capacity for addition of signals, perhaps on a temporary basis.

The problem of managing the Post Mortem archives must be addressed to provide rapid access to data and to build the long term reference needed to improve machine performance.

ACKNOWLEDGEMENTS

I should like to acknowledge the extensive contributions of R. Saban, R. Schmidt, K.-H. Mess (DESY) and J. Wenninger in discussing the basic ideas and describing experience from the Strings at CERN and HERA operation. Several LHC Controls Project linkmen have collaborated in initial discussions on their systems. Figure 1 was provided by R. Schmidt.