SUMMARY: LHC OPERATIONS

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Abstract

The CO-OP forum was held in December 1999 with the aim of identifying the challenges of beam based LHC operations and the consequent implications for the related equipment and the control system. The LHC operations session aimed to provide a summary of the forum, to re-iterate the key issues and explore further matters arising.

1 INTRODUCTION

Operation of the LHC will be, if not difficult, then at least challenging. The need to deal with the changing multipole components of the superconducting magnets in the presence of high energy, high intensity beams; the extremely low tolerance to beam loss; the novel machine design; the large energy swing and subsequent large range in the powering of the magnets; the limited dynamic aperture and tight constraints on the key beam parameters combine to provoke serious consideration of the way the machine will be operated even at this early stage.

With this in mind, the CO-OP forum held at CERN in December 1999 [1] aimed:

- to examine the demands on equipment and control as the LHC follows its duty cycle with beam,
- to investigate the requirements and services which impact on machine availability, preparation and recovery from fault,
- to prepare for the inception phase of a formal controls specification.

The talks in this session provide a summary of the forum, re-iterate the key issues and explore further matters arising.

2 OPERATIONS WITHOUT BEAM

Here the concern is with systems that support the operation of the superconducting magnets and concerns mainly cryogenics and powering. Analysis so far is based on experience at String 1, the engineering specification on the general parameters for equipment installed in the LHC and experience gleaned from elsewhere.

It is already possible to define the approximate sequence through which the systems will be driven: to prepare for beam, in standard operation and in situations where recovery, maintenance or repair is required.

When considering these sequences several key features quickly become apparent.

- The need for multiple system cross-checks.
- Equipment safety demands verification that all protection and interlock systems are operational.
- Several quenches per week are expected, therefore good diagnostics and recovery procedures are vital.
- Access will, perhaps, be required on a daily basis. It is clear that associated overheads should be reduced to a minimum.
- Interventions will be prohibitively long. For example, 24 to 35 days for the exchange of a magnet.
- Following an intervention or quench, cycling will be required to re-establish an appropriate magnetic history. This could vary depending on the circumstances.
- The huge number of components mean that availability will be seriously dependent on equipment reliability.

Key issues for operations with and without beam appear to be communication and integration. The role of PCR, TCR and cryogenics control rooms clearly needs to be established.

2.1 Vacuum

There will be three main vacuum systems: the beam vacuum, the insulation vacuum in the magnet cryostat and the insulation vacuum in the cryogenic distribution line. Monitoring of all three vacuum systems will be required including the state of sector valves and pumping systems. Fast acquisition for short term logging, long term logging and appropriate time stamping will needed. Clearly an interface to the interlock system will be required.

3 DIAGNOSTICS AND PROTECTION

The cold mass instrumentation provides signals for cryogenics, powering, protection and vacuum with in all some 10,000 sensors. Much of the data is closely linked to accelerator operations and will need to be well understood in the control room. Protection of the components also relies on the instrumentation.

3.1 Protection systems

There appear to be 3 main areas of concern:

1. The power abort system which will stop the power and discharge the magnets, and the beam abort, which will dump the beam. There is a clear need for coherence between the two systems.
2. Beam enable: verification of pre-requisites before systems can be started.
3. Capture, analysis and display of post-mortem systems.

4 TRANSFER AND INJECTION

The transfer lines from the SPS pose significant challenges in terms of control requirements to ensure safe and efficient beam transfer. Tests in TI8 will start in 2004 so someone better get moving.

The main goals of injection are precise injection to avoid quenches and material damage, and transverse emittance preservation. The dangers are large and much care will be required, however the TDI and effective collimation should protect against all failure modes of the injection kicker system. Analysis has been performed for all foreseen failure modes.

The injection sequence maybe enumerated and the demands on control and operations outlined. These demands are high and will required comprehensive and user-friendly tools which integrate the whole accelerator chain. A high degree of automation will be required, along with surveillance, and good post-mortem facilities. Interlocks will be vital.

5 ACCUMULATION AND RAMPING

Among the challenges of accumulation, ramping and squeezing are included:

- the wide range of optics with β_y^* ranging from 18 m. to 0.5 m (and, perhaps, ultimately 0.25 m.) This range demands very flexible quadrupole powering,
- the large energy swing,
- the danger of beam loss which implies mandatory collimation at all times,
- persistent current decay at during injection, snapback at the start of the ramp,
- the small mechanical aperture with implications for control of orbit, beta beating and dispersion,
- lifetime control implying good control of tune, chromaticity, dynamic aperture and beam separation,
- very tight demands on orbit stability required for collimation,
- and control or compensation of multipoles effects.

The tolerances on the main beam parameters have been established and given these it is possible to examine the expected variation of the low order multipole components and to check whether or not they will pose problems. From the analysis it is clear that:

- Compensation of the systematic b1 decay on the injection plateau will be required to hold the energy of the beam to within the demands of the RF system,
- on-line control of b2, or its effects will be required,
- b3 correction and/or chromaticity correction during decay and snap-back will be absolutely vital.

6 DEMANDS ON EQUIPMENT

6.1 Reference magnets

From consideration of the tolerances applicable during injection and snap-back it's clear that the reference magnets will provide a key role in beam control. A so-called multipole factory is foreseen which will provide:

- a linear model of reproducible effects
- a non-linear model of decay and snap-back
- real-time feed-forward at around 3 to 10 Hz of corrections calculated from on-line measurements

It is hope that the above measures will initially provide correction that will account for about 80% of the foreseen dynamics effects. With experience this figure should get better.

6.2 Beam dump

The key concerns here are reliability, availability and redundancy. The beam dump must work, It must be self-triggering if it detects a fault in any of its main components. The system needs input of the revolution frequency, the energy of the beam and synchronisation with the abort gap. Again these signals must be extremely reliable.

6.3 Power converters

A large and vital system, the power converters again have to provide excellent reliability and availability. The demands for high accuracy have provoked the use of digital control techniques which provides excellent resolution.

The demands on the low-level control system have been enumerated and as such it will provide among other novel features sophisticated function handling and real-time support for feedback and fast adjustment of user defined variables.

7 BEAM INSTRUMENTATION

Here the focus was on the key systems for injection and ramping:

- **Ring loss monitoring** An absolutely key protection system linked to beam abort and the potential source of a large amount of data. It will provide vital input into the post-mortem system.
- **Beam loss at collimators**
- **Local orbit stabilisation** This will provide orbit stabilisation in the cleaning sections. There are very demanding stability requirements. A 50-100 Hz local system is envisaged.
- **Global orbit acquisition** running at a maximum of 10 Hz. A control loop running at up to 1 Hz might be required during snapback.
- **Tune** There is a wide range of excitation and measurement techniques foreseen with R & D in progress. Feedback is foreseen with a 10 Hz sampling frequency.

- **Chromaticity** Measurement of the chromaticity is a challenge and any sampling rate will be low. The potentially low accuracy of the measurement will provide a challenge for any feedback system.

8 CONTROLS

8.1 Challenges

At the CO-OP forum, one of the express purposes was to identify the particular challenges that will be faced by the LHC control system. Here a lot of the usual adjectives are bandied about: powerful, flexible, rigorous, integrated, coherent, fast, safe. Whatever the adjectives it is clear that LHC operations will demand a much more rigorous and professional approach than that given to, say, LEP. This is as much a question of safety as anything else.

Some decisions and developments need to be made in a reasonably short time-frame, for example the injection tests in TI8 and the choice of front-end(s) for beam instrumentation.

The use of formal methods in capturing requirements and subsequent development was recognised to be mandatory. Particular features pertaining to LHC controls were identified:

- The ability to perform real-time time control at the high level,
- The need for tight integration of technical controls. As highlighted above, operation with beam will be closely dependent on, for example, protection, powering and the cryogenic system.
- Monitoring: intelligent treatment of large amounts of data to provide good beam-based and equipment diagnostics.
- Effective integration of the reference magnet system.
- Extremely good post-mortem facilities.

8.2 Work in progress

Development is already underway in the following areas: distributed real-time control where a prototype based on ATM, Lynx-OS and WorldFIP to provide hard real-time control is being tested and the the timing system where the requirements have been specified but the overall philosophy is yet to be defined.

Work on a JAVA API (an object oriented equipment interface and middleware (a software bus for distributed applications) is also under development. With the LHC control system requirements still yet to be anything like fully defined it is not clear whether the these will have a place in the architecture of the LHC's control system.

9 CONCLUSIONS

The session was largely based on material presented at the CO-OP forum in December 1999. The main aim of this forum was to distill from perceived operational requirements the implication for equipment and controls. Several key points keep re-occurring and if addressed promptly and properly will impact positively on LHC operations.

- Cross-system integration.
- Coherent treatment of cold mass instrumentation signals.
- The need for a coherent interlock system
- Failsafe beam and power abort systems
- Recovery, diagnostics and post-mortem analysis.
- Integration of BI into the control system
- The requirements for beam-related equipment control appears to be specified or understood, in particular, the need to support real-time capabilities However, the interfaces into an interlock system need to be defined.
- **Dynamics effects**
  - multipole behaviour is becoming well-understood, as is the impact on the key beam parameters,
  - a clear need for integrated reference magnet system,
  - feedback requirements for beam based measurements have been established.
- **Controls**
  - the need to support real-time,
  - integration of technical controls,
  - fully capture high level control requirements for input into the development of the application software layer,
  - appropriate technical solutions in networks, field buses, front-ends, timing. These should be available in time to allow standard use by beam instrumentation and equipment groups,
  - evaluation of API and middleware options in the light of requirements in order to choose an appropriate solution.

Both the forum and the session have provided the chance for a first across the board look at the challenges of LHC operations and will hopefully provide useful input into the development of the control system that LHC will clearly need.

10 ACKNOWLEDGEMENTS

This summary is based on the talks given by Paul Proudlock, Roberto Saban, Volker Mertens, Oliver Brüning, Rudiger Schmidt, Alan Burns, Quentin King and Robin Lauckner. My thanks to them.

11 REFERENCES

[1] LHC Controls-Operation Forum, http://nicewww.cern.ch/LHCP/TCC/PLANNING/TCC/Forum99/Forum.htm, Ed. J. Karlson Forestier.