LHC Operation without Beam

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Abstract

LHC will enter a complex operational stage well before beam can be accepted. The preparation of the machine in terms of cool-down, verification of the active protection systems and precautions before powering can be permitted is discussed. The pre-requisite conditions for taking beam are outlined. The scenarios envisaged to recover from equipment faults in the minimum of time are discussed, as well as the risks to equipment. The importance of procedures and monitoring, and the required interfaces between the systems concerned (what data is required, what data will be provided) are highlighted.

1 INTRODUCTION

The first ideas of the steps required to prepare LHC for injection, to diagnose the causes and recover from a quench, to carry-out interventions and prepare a shutdown are based on our experience with String 1 [1] but extrapolated to LHC. The analysis work which resulted in the Engineering Specification on the General Parameters for Equipment installed in LHC [2] has also been a valuable input.

This paper concentrates only on the systems which support the operation of the superconducting magnets and attempts to highlight all the operations specific to preparing, operating and repairing a superconducting collider.

2 THE OPERATION PHASES

Fiagure 1 shows the successive phases which LHC will undergo during its operation. The phases involving operation with beam are only mentioned since they are not the subject of this paper.

The middle sequence will yield the highest efficiency in terms of hours for physics. The two side sequences represent events which are inevitable when operating a superconducting collider. Namely, beam aborts to avoid a quench or damage to the collider and the quenches. Both can either happen during the injection phase, the preparation for physics or with colliding beams.

The operation scenario which is foreseen for LHC considers at least one fill per day. This implies the dumping of the circulating beam and the ramping-down of the magnets, the possibility of a daily one-hour access for eventual maintenance and repair, the setting-up without beam and the injection followed by the preparation of the beam for physics. This gives an overhead of 5 hours thus reducing the hours for physics to 19. In the likely event of a beam abort or a quench, this time will be further reduced to 16 hours due to the repetition of the steps preceding the injection or because of the cool-down in case of a quench.

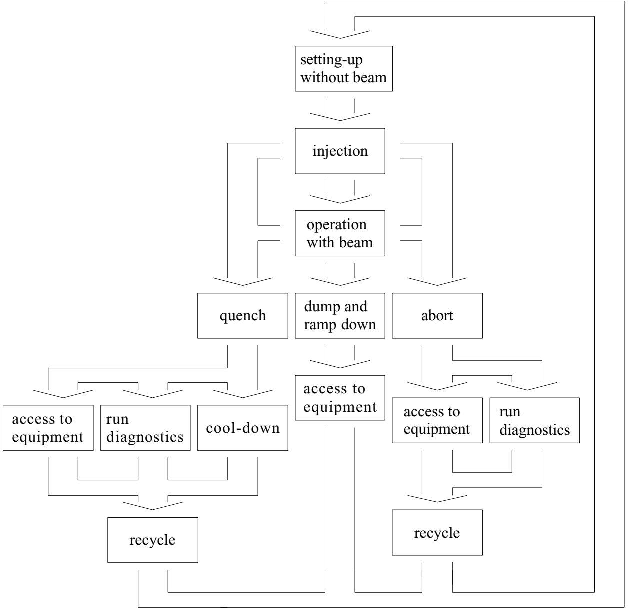

Figure 1 : The operation phases

2.1 Setting up without beam

This phase consists in checking that equipment is in nominal operating conditions and verifying protection systems and interlocks are armed.

The insulation vacuum systems (cryomagnets, electrical feed-boxes, cryogenic distribution line) are continuously monitored and interlock the cryogenic system.

A degradation of the insulation vacuum due to helium leak will increase the load on the cryogenic system. However, cryopumping on the cold surfaces inside the cryostat can absorb a leak of $5{\cdot}10^{-7}$ Pa m^3 s^{-1} per LHC half-cell during 200 consecutive days of operation with the equilibrium pressure rising to $1{\cdot}10^{-2}$ Pa. Interlocks with cryogenics are broken at 10 Pa. Below that, pumping groups are started at $8{\cdot}10^{-3}$ Pa and stopped at $5{\cdot}10^{-4}$ Pa.

The evaluation of the status of cryogenics is obtained from the cryoplants, the temperature of magnets in the tunnel and the helium level in the feed-boxes.

The power converters must be on and ready to execute the pre-injection cycle.

The protection of the components of the collider is ensured by the quench detection system and the energy extraction system. A post-mortem data acquisition system is included in these systems, which coupled to other system related to the operation with beam, help the diagnostic of the event. A verification that all these systems are properly armed must be made before permission to power the magnets is given.

2.2 Quench

From experience with the operation of other superconducting colliders, it is expected that quenches will occur several times per week. Each sector of the collider is independent from the others and is composed of several independent continuous cryostats. In addition the continuous cryostats are sectorized. Therefore, a quench in a part of the collider affects only its immediate neighbours.

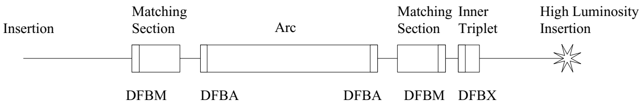

Figure 2 : The separate continuous cryostats with their independent electrical feed-boxes

With the present understanding, a quench can propagate to up to 4 cells thus involving 32 magnets. During experiments on String 1 [3,4], the propagation of the quench to neighbouring magnets has been observed to be caused by the warm gaseous helium expelled from the first quenching magnet. The phenomenon takes tens of seconds.

1.3 GJ are stored in the magnets of one sector when they are powered at nominal current. This energy is extracted in a controlled manner to prevent damage to the coils, helium vessel, piping, etc. Quench relief valves vent the expanded helium in the cryogenic distribution line and, the energy extraction system switches into the circuit a resistor where almost all the energy of the non-quenched magnets is dumped. However, only about 15% of the energy stored in the quenching magnets will be extracted by this system.

The time scale of the event are summarised in Table 1:

10	ms	the detection of the quench
50	ms	the heaters become effective and the thermodynamic process starts in the magnet cold-mass
120	ms	the converters are stopped and the energy extraction system has been activated
10-20	s	the quench, eventually propagates
200	s	the sector has been discharged

Table 1 : Time Scales for the Dipole Circuit

The average temperature of the cold-mass of the quenched magnet reaches 30 K if the quench occurred at nominal current.

2.3 Diagnostics

Following a quench the operations team must be able to readily identify the cause of the quench and assess that no damage was caused to the equipment.

A set of tools will be available to localise the quench and automatically collect the post-mortem data. A detailed map of the neighbourhood of the quenched magnet together with the status of the automatically started recovery procedures will be presented to the operators in the PCR. Summary information of the rest of the collider must also be presented to exclude the masking of other failures or minor malfunctions by the quench event.

These requirements must be taken into account for the choices of communication infrastructure (dimension and functionality) as well as the for the ergonomy of the data presentation mechanisms.

2.4 Cool-down

Depending on the number of magnets which quenched and the current in the magnets, 2 to 8 hours are needed to reach operating temperature (1.9 K). The cool-down is performed in three distinct phases. The magnet cold-masses are first cooled-down to 4.5 K with a forced flow of gaseous helium. They are then filled with liquid helium, which is finally cooled to 1.9 K.

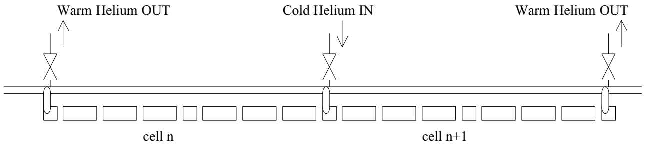

Figure 3 : The cool-down of the cells is done in parallel

Because each LHC cell is connected to the cryogenic distribution line, the cool-down of the cells is done in parallel [5,6] figure 3.

2.5 Recycle

This phase is always needed after a quench and perhaps after a beam abort to bring back the magnets on a known magnetic state. It consists in ramping up the magnets to nominal current, waiting for about 15 minutes then ramping down with the nominal ramp rates. The operation takes about one hour per cycle. However, depending on the circumstances of the interruption (quench, abort), the time the magnets have spent at a given current, different cycles will be applied.

Therefore a choice among pre-programmed cycles must be possible. Because with experience, the behaviour of the magnets will be better known, it must be possible to modify these cycles to optimise the time for physics.

2.6 Access to Equipment

In order to minimise the cost of the equipment by, for example, reducing the redundancy installed in the tunnel, a daily technical stop of about one hour for minor maintenance of equipment and instrumentation is planned. The access can be extended for distant or vital repairs or it can be cancelled if no access is required on a particular day to optimise time for physics.

In order to preserve the magnetic history of the machine, during the access, the power converters will be at a stand-by current.

Access to all LHC areas will be controlled at all times even during shutdowns and it will not be possible to remove equipment from LHC without individual measurements of the remanent dose. Furthermore, personnel going in the tunnel must be checked with appropriate dosimeters. Therefore, in order to optimise the effective intervention time, people needing the one hour technical stop must prepare well in advance of the beam being dumped and must follow a procedure similar to boarding an aircraft.

3 INTERVENTIONS

Interventions on the LHC continuous cryostats suffer from a tremendous overhead due to warming-up and re-cooling the two-cell sub-sector containing the failed element and some or all of its neighbours. Depending on whether, in addition to the insulation vacuum, the beam vacuum and the cylindrical heat exchanger have to be vented to atmosphere, two types of interventions have been defined.

Short interventions

A typical example of a short intervention is the exchange of a diode or repair of a leak in the magnet interconnect area. In addition to the two-cell sub-sector containing the faulty element, the two-cell sub-sector on either side of the latter have to be warmed-up. The insulation vacuum is broken following the warm-up. After the intervention, the helium piping and the insulation vacuum are leak tested. The time required for this type of intervention has been estimated to 10 days.

Long interventions

A typical example of a long intervention is the exchange of a magnet. Because the beam tubes and the cylindrical heat exchanger have to be vented, the whole sector needs to be warmed-up. The vacuum systems are broken following the warm-up. After the intervention, all the vacuum systems are leak tested and the helium vessels and piping are pressure tested. The time required for this type of intervention has been estimated to 24-35 days.

4 SHUTDOWNS

Only those parts of the machine which require an intervention will be warmed-up for the yearly shut-down. The rest of the collider will be left to naturally warm-up. The insulation vacuum will be kept throughout the shutdown to minimise heat inleaks. During the natural warm-up process however the helium will change phase in less than a day. Because the storage capacity installed on the site is not enough for the helium contained in the cold LHC, it is planned to trade-in the liquefied helium to the suppliers and refill the machine at the end of the shutdown.

5 CONCLUSIONS

Novel aspects linked to operating a superconducting collider exist. The expected interruptions of physics runs due to a quench result in long recovery times because of the need to re-cycle the magnets and then cool them down. These incompressible dead times following a quench are important: they range from 4 to 10 hours depending on the extent of the quench.

Given the lengths of the intervention times, equipment safety is of paramount importance to avoid the need for replacement.

The domino effect of a peripheral system (eg. mains, water cooling, etc.) failure on the systems more closely supporting the operation of the superconducting magnets (eg cryogenics) can lead to a major disruption on the operation of the collider (eg venting of helium to atmosphere). The availability of the collider can only be improved with an increase of the reliability of the peripheral systems.

6 REFERENCES

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