WHAT ELSE NEEDS TO BE DONE TO REACH 5 TEV AND BEYOND, CONSOLIDATION AND COMMISSIONING OF ESSENTIAL MAGNET POWERING SYSTEMS

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Abstract

In this miscellaneous contribution the engineering changes introduced after the September 19 incident are revisited, in the light of a possible 5 TeV physics run, and beyond. Some of these measures need consideration as they were adapted to, or only commissioned for the initial low energy run. Also, the non conformities that need to be closed in order to be able to run at 5 TeV will be reviewed.

INTRODUCTION

The title of this paper might look odd when thinking that the LHC was designed and built to accelerate protons up to 7 TeV. The reason why we have now to consider what needs to be done to reach 5 TeV is twofold. After the accident of 19th September 2008, several hardware modifications were introduced in order to prevent such events to repeat themselves, or to mitigate the consequences of eventual new accidents. These modifications are, in some cases, adapted to the initial low energy, and cannot be maintained unchanged to higher energies.

On the other hand, in the course of hardware commissioning campaigns, a number of non conformities to the performance specified in the design were found to affect several elements of the machine. Some of these may be critical to reach higher energies.

Among the engineering changes, those that can be relevant in this respect are:

- the installation of DN200 safety valves, or better, the fact that it was not completed
- the deployment of a new QPS to monitor and protect splices and to detect symmetric quenches
- the change of dump resistors to accelerate energy extraction from the main circuits

The discussed non conformities concern magnet circuits, vacuum and cryogenics.

ENGINEERING CHANGES

DN200

The missing safety valves (in the sectors that were not warmed up) do not constitute a showstopper to run at higher energies. Of course the risk of collateral damage in case of rupture of the insulation vacuum will remain higher in the non equipped sectors. However this is acceptable because the probability of the primary events is considerably reduced, among other things, by the nQPS.

Dump resistors

In order to gain some margin on the tolerable joint resistances which are left in the machine, the values of the dump resistors for the main circuits were increased, as summarized in table 1 below.

Table 1: dump resistors parameters

Circuit	R_{dump} old (mΩ)	R_{dump} new (mΩ)	τ old (s)	τ new (s)
RB	73	146	104	52
RQF/RQD	8.4	28.4	31.3	9.2

This option becomes possible because the machine will initially run at lower energies, so that faster time constants can be obtained while still meeting the voltage ratings of the switch and of other systems. Actually, along with clear advantages, the faster energy extraction has drawbacks which are related to the peak di/dt and to the extraction voltages. As an example the switch arc chambers, which must blow off the arc at switch opening, are rated at 1 kV for the RB. Limitations on the values of the dump resistances, coming from various systems, are discussed in [1]. At higher energies the increased extraction voltages will not allow keeping the same time constants, and we will have to roll back to smaller dump resistances.

At 5 TeV the time constant will have to be at least 68 s for the main dipoles (provided that the common mode limit can be raised by 4 % [1]) and 15 s for the quadrupoles.

nQPS

The new quench detection and protection systems (the extended bus bar detector system and the symmetric quench detectors) are the biggest engineering change introduced after the incident and should ensure that it will never happen again. However they also represent possible threats to the machine availability, as they add a large number of channels, each capable to pull powering interlocks and, for the symmetric quench detection, to fire quench heaters.

The extended bus bar detector will trigger a fast power abort if any of the signals goes above the threshold of 500 μV. To buck out the inductive voltage on the bus bar segment and its measurement cabling, a measurement of the current ramp rate must be available, and is derived from the measured inductive voltage of the neighbouring dipole and from the dipole inductance. The change in inductance of the dipole due to the saturation of the iron (1% between 2 and 9 kA) will only marginally unbalance the detectors (by adding, at 10 A/s, about 20 μV spurious voltage on the signals).

The larger dump resistance enhances the sources of electrical disturbances at switch opening, due transmission line effects and transient aperture unbalances in the dipoles, both of which can trigger the (old and new) QPS bridges. Immunity from these perturbations must be developed to reach high operation efficiency.

SNUBBER CAPACITORS

Voltages perturbations over magnet chains when the extraction switches are opened can be mitigated by means of capacitors installed in parallel to the dump resistors (snubber capacitors).

The installation of capacitors in the main circuits of the LHC is foreseen before running above 3.5 TeV

The voltage limits of the extraction switches derive from the initial phase of the commutation process, when the arc must be extinguished: once the switch is opened it can withstand much higher voltages. The capacitors conduct during the transient and delay the voltage peak to later time, when the arc is already spent. As the commutation process is a plasma dynamics phenomenon, simulations are difficult and laboratory measurements are essential to the sizing of the capacitors. These tests will be carried out in parallel with the next beam run.

The installation of the snubber capacitors will take about 2 days per sector, it is incompatible with other hardware commissioning activities on the same circuits, but can be done in parallel in different sectors.

MAGNET NON CONFORMITIES

Weak 120 A orbit correctors

Since the first commissioning campaigns a small number of dipole correctors of the MCBY and MCBC type were found to quench on the flat top or at the beginning of the ramp down when the absolute value of the magnetic field is reduced. Fig.1 shows the current and voltage recorded during the fault.

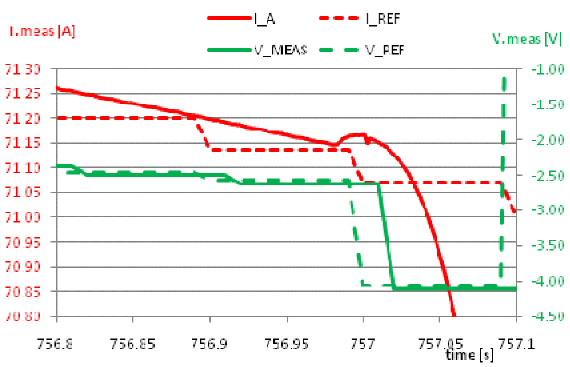

Figure 1: Fault phenomenology of a weak RCBY

The physical mechanism behind this behaviour is not understood, but it was ascertained that the problem is not related to the power converter, nor it seems to depend on the liquid helium level. The apparent impedance and frequency response of the problematic magnets are rather different from the normal ones, pointing to some unknown anomaly in the coil. A detailed summary of all the findings is in [2].

The approach adopted so far has been to reduce the nominal current, or the nominal ramp rate, or both. The most critical case is RCBYHS5.R8B1, which is limited to 30 A, while 48 A would be needed for some of the possible optics at 5 TeV.

Some of these circuits participate in the generation of the crossing schemes, so the issue might put constraints on the physics options of the LHC. It should be noted that as long as the cause of the problem is not understood the risk of an irreversible degradation cannot be excluded. It is therefore recommended to envisage the installation of warm replacements for the most critical locations.

Other 600A issues

Some types of 600A correctors suffer from limitations on the current ramp and acceleration rates, which are a legacy of the chosen quench detection technique [3]. In some cases voltage spikes, generated by the power converter when crossing zero, add to the problem, leading to spurious triggers of the QPS.

One of the most sensitive circuits is the RU (synchrotron light undulator); but this does not pose problems as it is not needed to ramp it with beam.

Particularly sensitive are also the RCBX type circuits, also because, besides the QPS problems, their current leads need careful tuning due to a peculiar regulation. The latter was implemented after it had become apparent that the initial design choice, which was based on flow-meters, would not be available. The new regulation uses the temperature at the top of the lead as a process variable, and the location of the temperature sensor makes the tuning process quite challenging. After some effort the leads could be stabilized in all the – reduced - operational space, which is now only constrained by the above mentioned QPS issues. However, also in consideration of the ALARA principle, it is recommended to carefully reconsider the known alternatives to the presently implemented regulation.

Concerning the QPS sensitivity to transients, a first measure which consists in forcing a calibration of the detectors before starting a pre cycle will be implemented already in the next beam run at 3.5 TeV.

Should these limitations become critical for any beam operations, the possibility of relaxing some of the protection thresholds could be considered by the MP3.

RQX.R1

For this magnet one of the quench heater circuits was excluded from the protection scheme after it failed to pass the electrical quality assurance protocol. As a result, redundancy was lost. Additional tests will have to be done in order to qualify the reconfigured circuit for higher energies.

LEAK IN INSULATION VACUUM IN S34

A vacuum leak of the order of 2 mbar l s^{-1} developed in the insulation vacuum in the middle of arc 34 before the start of beam operations. The vacuum level was stabilized around 10^{-4} mbar by adding two turbo-molecular pumps, thereby using all available ports. As a consequence of the degraded insulation vacuum, an additional heat load of about 200 W insists on the concerned subsector. This is a clear weakness as we rely on the additional pumping speed to keep the heat load to a sustainable level. A detailed record of the problem and of the measures taken is in [4].

The situation could be maintained throughout the 2009 beam run to 1.2 TeV. The local static heat loads do not depend on energy, therefore in this respect the situation should not change at higher energy. There will be still about 70 W cooling power available at the leaky subsector. Concerning the dynamic heat loads, the heat deposited during the ramp by eddy currents will of course be larger. However this load is by design taken by the superfluid He enthalpy, so, as long as the temperature increase is limited below 2.17 K there is no real-time need of cooling power. The design values for the temperature increase (50 mK for the nominal ramp) turns out to be very conservative because the quantity of liquid helium involved was underestimated. Calorimetric measurements showed that the temperature increase is 10 mK for a ramp to 7 kA. The heat load during a fast discharge will also be larger, but in this case there should as well be no problem, as after the energy dump the cryogenics system will have time to re-cool the subsector.

CL REGULATION VALVES

Gas flow regulation valves on current leads have given in some cases mechanical problems (hysteresis, blocks) leading to the loss of the cryogenics interlocks. The phenomenon was aggravated by the change of regulation algorithm from ON-OFF to PID which took place in 2009. In principle the situation will not change at higher currents, and it will still represent a potential limitation to the machine availability.

The problem can be tackled by changing valve design, or by just replacing the faulty items and those which are deemed likely to fail. The first solution is a long term enterprise, as the number of valves is huge. For the time being the second approach is being pursued. A new campaign of preventive maintenance should be foreseen for the next shutdown.

QUENCH LINES

Quench buffers at odd points cannot be used due to non-conform pipe work: the sliding points, which should allow the thermal shrinkage (about 300 mm in total) when the lines are operating, are in reality fixed, and some integration problems have arisen on top of that. With halved quench buffers with respect to design, in case of a big quench the excess helium would be released in the atmosphere, putting the inventory at risk. Solutions are under study, but not likely to be implemented in 2010.

SUMMARY

Most of the issues identified are not real showstoppers for running at higher energies, but rather impact on the machine availability.

Leaving aside all splice considerations, running at 5 TeV will require to

- Bring the main circuits from 6 to 8.5 kA
- Bring MQY circuits from 1.9 kA to 2.7 kA
- Bring MQM circuits from 2.8 kA to 3.85 kA
- Assessing RQX.R1 protection
- Install snubber capacitors
- Increase the RB time constant to 68 s
- Increase the RQF-D time constant to 15 s

The time constants indicated are minimum values.

The installation of snubber capacitors should take at least 2 weeks per sector.

Consolidation works, to improve machine availability and flexibility shall include:

- Repairing the leak in sector 34
- Changing the regulation process for the gas cooled current leads of the inner triplet correctors
- Consolidating the gas flow regulation valves of the current leads
- Reviewing and relaxing when possible QPS thresholds
- Predisposing warm spares for weak RCBY and RCBC magnets

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REFERENCES

[1] K.H Mess "Change of magnetic energy extraction resistors" ECR; EDMS 1013572.
[2] Y. Thurel, EDMS 1053978.
[3] W. Venturini Delsolaro et al: "Performance of the superconducting corrector magnet circuits during the commissioning of the LHC", EPAC 2008, Genova, WEPDO028, pp.2470-2472
[4] S. Claudet, presentation to the 38 LMC meeting: https://espace.cern.ch/lhc-machine-committee/Minutes/1/lmc_38.pdf