LHC RF: PLANS FOR THE LONG 2012/13 SHUTDOWN

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Abstract

The potential limitations for future running of the LHC RF systems are presented. In particular the problems of trips, hardware failures and limitations encountered during 2010 operation period are discussed, with emphasize on the possible hardware modifications and upgrades during the next long shutdown. The main technical challenges as well as the consequences of delaying the shutdown from 2012 to 2013 are highlighted.

INTRODUCTION

In 2010 the energy of LHC has reached for the first time 3.5TeV. The experience gained with the ACS system together the big effort made to improve its reliability has resulted in good performances. The key problem this year was the klystron collector power limitation: all klystrons were limited to 7A and 50kV (instead of the nominal 8.4A, 58kV). A dedicated cavity field dephasing gymnastics was also implemented to limit the DC power in the collectors at injection.

The damper system (ADT) was also extensively used, and all the studies and measurements that could be made with all kind of beam configuration have allowed putting in evidence the good performance of this system. Lessons learned have also shown the reliability of the ADT system.

Some of the potential upgrades, or special maintenance operations, which have been identified during the 2010 operation period, can only be done in a long shutdown.

THE RF POWER SYSTEM

In LHC the RF power source required for each beam comprises eight 300 kW klystrons. The output power of each klystron is fed via a circulator and a waveguide line to the input coupler of a single-cell superconducting (SC) cavity. Four klystrons are powered by a 100 kV, 40 A AC/DC power converter, previously used for the operation of the LEP klystrons.

The HV interfaces are housed in fireproof bunkers in UX45 close to the four klystrons to be powered. It comprises a HV switch, a smoothing capacitor, a thyratron crowbar system and four hard tube modulators to individually adjust the klystron power.

For reasons of HV insulation and/or cooling all HV interface components with the exception of the smoothing capacitor are immersed in silicon oil.

Klystron modulators

The klystron current, and therefore the RF power, is controlled with a modulating anode. This HV control system is embedded in an oil tank which comprises the klystron heater transformer, measurements circuitry, and the modulation anode divider (see figure 1.)

The tetrodes which are used in the voltage divider scheme have a limited lifetime, and are no longer produced. A mid-term replacement solution is therefore necessary. Development of a modulator based on a solid state solution is ongoing and validation tests should take place in 2011.

The modulator upgrade can be done either in series, during a long shutdown, or progressively. The date of the next long shutdown is therefore not critical from this point of view.

Figure 1: Klystron modulator.

The fast protection system (crowbar)

The klystron fast protection system is based on a five-gap thyratron crowbar. In case of an arc occurring inside a klystron, due to the high d.c. operating voltage, the high voltage must be removed from the klystron within less than one microseconds in order to avoid damage.

The diversion of the HV energy is achieved by triggering the thyratron which then becomes conducting and acts as a short circuit to the HV power supply.

Double ended thyratrons require very fine adjustment and are very sensitive to noise. Although they are very reliable from the safety point of view, they suffer, from time to time, from auto-firing, which result in beam dumps.

A solid state replacement s under development and shall be tested during the year. Once fully validated, the crowbar upgrade solution could be implemented either in series, during a long shutdown, or progressively.

Oil re-conditioning

The oil insulating properties degrade with time. For this reason the silicon oil quality of the twenty-four 300 litres high voltage tanks is carefully checked every year.
Reconditioning of the silicon oil must be done every 5 to 6 years. This operation cannot be done "in situ", in the LHC underground. All HV tanks must therefore be disconnected and transported to the surface for reconditioning, re-installed and re-tested. This time consuming operation must be done during a long shutdown.

Although the oil reconditioning should in principle be done next year at the latest, the tests performed recently have not shown any signs of oil quality degradation.

The klystron's collector saga

The premature death of a klystron, in 2007 –due to a severe vacuum leak in its collector-, as well as the sign of overheating observed on all other tubes (see figure 2), were found to be due to a bad design of the water cooling jacket, causing a local water speed deficiency. The so called hypervapotron mode, which is used in these collectors, is indeed not efficient for water speeds below 1.5 – 2 m/s. In the blue zone shown in figure 3 the water speed is less than 1.2 m/s.

Figure 2: Damaged collector.

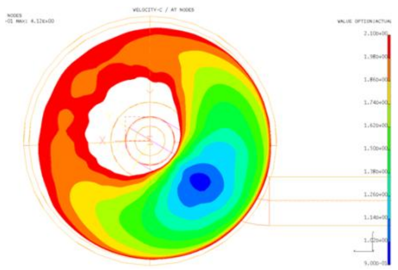

Figure 3: Water speed simulation in the collector region.

Modifications were made to the water cooling jacket by the klystron manufacturer in order to solve the problem and all boilers were replaced in 2008. Investigations made during the 2009 winter shutdown have shown that the situation was not perfect: slight overheating traces could still be observed. Decision was taken to limit the klystrons DC power to 50 kV and 8 A in 2010.

Further improvements were made and validated during the year 2010. Four klystrons have been equipped during the shutdown with the new "boilers". The other twelve tubes will be gradually upgraded during the next shutdown(s) (≈ three months).

THE SUPERCONDCUTING CAVITIES

The 16 superconducting cavities installed in LHC have performed very well in 2010. They have been responsible for a very small fraction of the RF trips. So far two activities have been identified for the next long shutdown:

Cavity tuning system

Following the rupture of one of the cavity tuning system cable in 2008, a campaign was launched to open all sixteen cryostats in order to check, modify and replace mechanical parts of the tuning systems.

Although no problem have been reported during the last operation period, careful inspection of -at least some-cavity tuning systems shall nonetheless be performed. The next long shutdown will be the right moment; whatever is will be in 2012 or 2013.

Cavity 3B2

Since the LHC start-up, in November 2009, a strong field limitation @ 2.2 MV is observed on cavity 3 beam 2 (3B2), leading to sharp helium pressure spikes and relatively high radiation levels.

This cavity is very stable below 1.2 MV, but has a rather unpredictable behaviour between 1.2 and 2.2 MV: long stability periods are interrupted by sudden He pressure spikes and temperatures increase of one of the four HOM antennas. Multipactor in the cavity equator region could be the culprit. Time is necessary to further investigate and try to re-condition this cavity. Eventual replacement of the full SC module could be envisaged for the next long shutdown.

TRANSVERSE DAMPERS (ADT'S)

Replacement of damaged pick up cables

The sixteen RF pick-up cables, which go from tunnel (Q7, Q9) to the SR4 building, at the surface, have been damaged during LHC installation (picture 4). Although the worst segments were replaced during the 2008/09 shutdown, the pick-up impulse response still suffers from periodic reflections: the signals are distorted and their quality is affected.

The impact on the ADT system performances may increase with short bunches spacing & high intensity beams. It is therefore of prime importance to replace these cables during the next long shutdown.

Figure 4: Damaged pick-up cable.

Transverse dampers upgrades

Three upgrades are linked to the next long shutdown:

- Additional pick-ups:

  The use of additional pick-ups (Q8, Q10 or warm section) will further reduction of the signal/noise performance of the whole ADT system. This implies pulling sixteen new cables from tunnel to SR4 (surface).

- Power amplifier RF drive cables:

  The crosstalk between bunches can be reduced by replacing these 3/8" by 7/8" cables. This is an important step towards stronger, cleaner & sharper pulses for abort gap cleaning for higher frequencies (up to 20MHz).

  This concerns 32 cables from UX45 to UX45 and 8 cables from UX45 to SR4 (surface). The integration of these cables is difficult and must still be studied in details.

- HOM observation & diagnostic system:

  This system is used to observe interaction between the transverse dampers and the beam, on a bunch to bunch basis. With better quality cables the signal quality will be improved. This is crucial for ADT setting up and diagnostics. As for the drive cables, 22 cables from UX45 to UX451 (ADTs) and 8 cables from UX45 to SR4 (surface) are concerned.

CONCLUSIONS

Several activities concerning the LHC RF systems have been identified for the next shutdowns. Some of them, e.g. the replacement of the damaged ADT pick-up cables, are very important and require a long shutdown. Postponing the next long shutdown by a year shall nevertheless not affect significantly the performances of the RF systems.