RF PREPARATION FOR BEAM IN 2009

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Abstract

Modifications to the ACS cavity tuning systems should be completed early in 2009. First tests on the power and low level RF systems will be done with waveguide shorts, as the cavities will be warm and the RUX45 tunnel roof blocks will still be open to allow transport of quadrupoles into sector 3-4. Any co-activity with magnet transport will need to be avoided till the installation of sector 3-4 is completed. Well before beam, the cavities will need to be cooled down and tuning and calibration checked. A period of cavity conditioning will certainly also be required. After cavity conditioning there will be a final check on the cavity tuning and RF feedback systems. These activities all require availability of 4.5 K cryogenics, in sectors 3-4 and 4-5. The beam control systems in UX45 will also be checked as far as possible before beam, together with remote controls and signal monitoring systems. A description of this work, the times needed for the various activities and a planning will be presented. Work on the ADT systems will be carried out in parallel.

RF SYSTEM – STATUS UP TO SEPT 19TH

By September 2008, in the process of hardware commissioning, all klystrons, controls and low level RF electronics in UX45 cavern had all been fully commissioned. The 16 ADT transverse damper kickers and amplifiers, four modules left of IP 4 and four right of IP4 had all been tested to full power.

The 16 SC cavities, in four cryomodules- two on each side of IP4, had all been conditioned to nominal gradient in 2008. However just before beam operation a problem was found with the tuning mechanism on one cavity. The APW longitudinal wideband monitors, three left and three right of IP4, were set up and used for beam measurements. With beam in early September the SR4 beam controls for RF synchronization, capture, and transverse damping were tested with beam. Beam 2 was successfully captured, on the first few attempts and shown to have reasonable lifetime. Synchronization controls for setting collision points. Hardware and software for acceleration and radial loop control were prepared but could not be tested due to the September 19th incident.

INCIDENT OF 19TH SEPTEMBER

At the time of the incident in sector 3-4, all cavities and dampers were running. The eight cavities on the Sector 3-4 side cut due to helium pressure from the automatic closing of the valves to the QRL D-Line, normally and without opening of safety release valves. The cavities on the 4-5 side continued to run; they were switched off manually ½ hour later. The transverse dampers continued to run on both sides; again they were switched off manually later.

From the vacuum logging, no significant pressure rises were observed on cavity gauge recordings at time of the incident. The sector valves on the modules, which had been open, were closed manually later. Following the incident the ADT kickers were taken to full power, without problem. It was therefore concluded that contamination of the APWs, cavities or ADT kickers did not seem likely. This was further confirmed by recent opening up of LSS vacuum sectors in the straight section, where no signs of pollution or MLI fragments were found [1].

Following the incident, a thin layer of dust on all the RF equipment in IP4 was cleaned. The opportunity was taken to remove the ADT kicker amplifiers to carry out minor modifications, in addition to a thorough internal cleaning.

RISKS & POSSIBLE PRECAUTIONS FOR PROTECTION OF SC MODULES

The Sector 3-4 incident can be regarded as near miss situation, i.e. two unexpected abnormal situations occurring simultaneously to result in potentially serious consequences. The sector valves were open, since the access system was in beam mode. The incident itself was not an expected risk, and had it occurred closer to point 4 rather than to point 3 as it did, contamination of the cavities would certainly have occurred. Furthermore, with opening of both vacuum pipes there would have been a serious chance of pressure in the cavities reaching values above the mechanical limits both of the cavities and their helium tanks, with irreparable damage to some or possibly even all of the cavities and tanks. A risk analysis done on the SC cavities with the safety commission and cryogenics specialists[2], shows that mechanical damage can be expected to result for a full vacuum aperture opening (100mm) near the cavities. In this case 12 bars would be reached in the helium tanks. However a 50 mm opening would be protected by the rupture discs mounted on the modules, releasing at 2.1 bars.

With the safety measures now being in place recurrence such an incident is to be regarded as highly unlikely. However the rule of keeping sector valves closed whenever possible must always be followed, particularly when the adjacent sectors are being taken to new current levels.

The use of fast sector valves has been proposed. These can close in several 10s of ms, compared to the 1 s taken by normal valves. This solution brings other risks, e.g. accidental closure when beam is present and limited tolerance to high pressure waves. The subject is under study with the Vacuum Group.

CAVITY TUNING SYSTEM REPAIR

The difficulty with cavity tuning found just at the end of hardware commissioning in 2008 was due to breakage of a cable on one side of the tuning mechanism. The cavity tuner could be moved by manual intervention. The broken side was taken to a position near resonance, such that the tuning range needed for operation could be covered by the movement of the other side of the mechanism.

Figure 1 shows the principle of operation of the cavity tuner system. A tuning frame consisting of two solid end plates held together by four bars is suspended in the cryostat. The cavity is fixed to one end plate. Another plate is fitted to the other end of the cavity. Two torsion bars are fitted between this plate and the end plate. These provide vertical support of the cavity. When rotated the plates are pulled together, stretching the helium tank and the cavity inside, changing its resonant frequency.

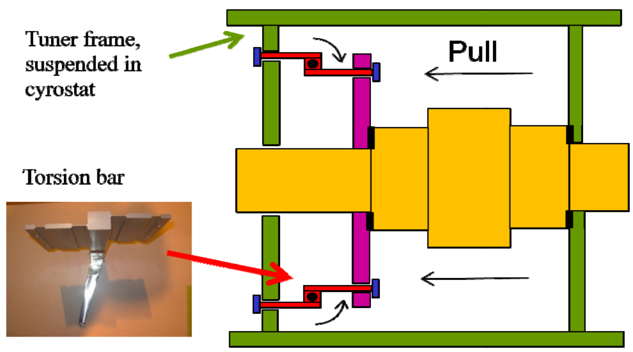

Figure 1: SC Cavity Tuning Schematic (Top View)

Figure 2: Open SC Cryostat Module, showing Helum Tank and Tuning Frame.

On dismantling, the problem was found to be the breaking of a cable pulling the torsion bar. This break was near the dowel which fits into the end of torsion bar, and was certainly due to lack of free movement of the dowel in its seating in the torsion bar. New sets of cables and modified dowels were made for all cavities. Fortunately replacement was possible in-situ, thanks to the removable covers on cryostat. Lack of space made the job difficult, but by the end of February all cables had been remounted, the cavity covers replaced and the insulation vacuum pumped down.

Figure 3: Replacing Tuner Cables in RUX45.

UNDULATOR IN P4

Opening of vacuum in Sector 3-4 to change the undulator would have major consequences for RF equipment. Baking ADT kickers and APWs would bring risks. The electrodes on the damper kickers need to be carefully protected against overheating. Feed-throughs on the APW are a known weak point; it is planned to change all of these in a future long shut down. If the undulator has to be taken out it is strongly recommended to investigate ways of doing it without removing the sector valves on either side, avoiding letting the adjacent sectors up to atmospheric pressure [1].

RF SYSTEMS RE-COMMISSIONING BEFORE BEAM

The work to be done on the ACS system before beam is listed below:

- Power Systems: Full check-out all of all klystrons, power converters and HV equipment with RF power into waveguide shorts, to be done before the cool-downs.
- Cool-downs: Before cool-down of Sector 4-5 the RUX45 roof blocks need to be put back in place. This expected for week 15 (Mid April). During cool-down of the cavities, close monitoring and full test of interlocks & cryo control will be done.
- Low power tests & measurements: These were done last year for first commissioning and will not be repeated in 2009. This avoids removing measurement transition waveguide pieces and reconnecting the waveguides while cryogenics is in operation.
- Cavity conditioning: Conditioning to 2 MV/cavity, the value reached last year, is expected to progress quickly - i.e. 1 to 2 weeks per sector. It will start with Sector 4-5

- Set-up of cavity controllers and RF loops. This expected to take 1-2 days/cavity i.e. a total of ~2 weeks per side. Note that this setting-up is performed in the UX45 Faraday cages. ACCESS in UX45 is therefore ESSENTIAL during this work.
- Running in: Continued stable running, preferably right up until beam is available, is needed for testing of cavity and power system software and SR4 beam control electronics. All sector 3-4 work will clearly take place at the end of the commissioning period. A thorough check out of 4-5 equipment will certainly help to allow rapid testing and commissioning of 3-4.

For the ADT systems, the check of powering to nominal levels after the amplifier work has already been successfully completed. The complete system, including the SR4 beam control electronics, will however be re-tested and calibrated before beam.

The SR4 beam control electronics for ACS and the synchronization systems will also be re-checked, together with the necessary front-end and applications software. This includes injection bucket control, cavity voltage control and frequency ramping.

For the APW, no modifications are planned, however setting up of OASIS facilities, remote oscilloscope controls and CCC displays are required.

NEXT STAGES OF BEAM COMMISSIONING

With pilot beam, the first step will be to capture beam 2 again, then to capture beam 1. This involves setting injection delays, checking the RF frequency, checking operation of phase and synchro. loops and measuring beam lifetimes. The delays for setting the collision point will be set up, using the dedicated PUs equally spaced around IP2, as well as the damper PUs, for which signals are accessible in SR4.

First acceleration will be done with the beam control systems on synchro loop only, observing orbit changes and the radial displacements measured on the radial PUs.

Should separate acceleration of the two beams be found necessary, the procedure of re-synchronizing Beam 2 after acceleration will need to be tested. Before physics, it will also be necessary to check the switch over to the low noise fixed reference synthesizer at top energy. (This reference is in fact the one from which the 40 MHz reference sent to the experiments is derived).

The established plan for commissioning to higher intensities, with increasing numbers of bunches and bunch currents will follow once ramp and collisions have been established with pilot. It is important that operation with different filling patterns is fully checked out, at each stage, before higher bunch intensities are attempted. Studies on requirements for LHC synchro diagnostics should be done soon so that any necessary software can be developed and tested. A longitudinal damper feedback loop on the ACS cavities is being developed to damp phase error of successive newly injected batches, to give minimum disturbance to the existing beam.

The lack of dynamic reloading of kicker settings 2008 prevented alternate injection and dumping in Ring 1 and Ring 2. This slowed down commissioning and it needs to be resolved early in 2009. Definition of separate Beam 1 & Beam 2 cycles can be done by using the “Dynamic Destination” in the timing system telegram.

RISKS AND SPARE PARTS SITUATION

In addition to vacuum pipe break, there are other important risks to the SC cavities. The most likely and known is a break of the ceramic window in the power coupler. The couplers have been carefully designed and constructed to withstand full forward and reflected RF powers. They have all been tested under these conditions before they were fitted to the cavities. The risk of breakdown is therefore low, but nevertheless exists. Failure in LHC could result in the contamination of two modules, i.e. eight cavities.

The cavities are not cooled independently, but via the QRL. The cavities and the helium tanks cannot withstand the high pressures that could occur, for example in the case of D-line overpressure in the case of a multiple magnet quench. A number of measures have been taken to minimise the risks [2] . These are: fail safe operation of the cryo control system, automatic valves closing in the event of overpressure, and non-return valves in the QRL D-line. Hence the maximum foreseeable precautions have been taken, and there is redundancy. Nevertheless, it is vitally important that all systems be pre-checked before cool down, and closely monitored during running.

Down time due to cavity damage:

In the event of pollution, or mechanical damage to a cavity, the entire module would need to be removed and taken to SM18. Here it would be dismantled and the polluted cavities taken to B118 for rinsing. A damaged cavity could be re-coated but if damage is severe, it may need to be replaced. Vertical cryostat low-power testing of the cavity to check its performance must be done before re-assembly into the module. Clean room re-mounting of the cavity or cavities in the cryostat with all the ancillary components would follow, then RF conditioning would need to be done in SM18, one cavity at time, before it could be taken back to the machine and re-installed. The whole process would take a minimum of roughly ½ year to 1 full year. This time would considerably more if new cavities had to be procured.

There is one complete spare module in SM18, but this is not yet fully RF tested due to competition for cryogenics with magnet activities. It should however be completed by the end of 2009. It should be noted that final testing of all the four installed RF modules in SM18 took over three years.

At the time of cavity construction it was considered that one spare module was adequate. This was based on the sole source of risk being damage through coupler breakage. We now have additional risks. A proposal has therefore been made to construct three cavities in addition to an existing one, all having helium tanks fitted, to avoid the extra delay in the event of a major incident for which four new cavities would need to be fitted to an existing module.

In the worst operational case LHC could run with one module per beam, with an absolute maximum of 12 MV total at top energy. Longitudinal injection damping would be impaired due to the limited power available.

Spares situation for other LHC RF systems

The overall situation is just satisfactory but not at all 'comfortable'.

- Klystrons & power equipment: Three spare klystrons plus 2 in test stands, one spare circulator/ load assembly, two in test stands.
- ADT kickers: Two spare modules (four kickers).
- ADT amplifiers – In the process of assembling four from prototypes and spare parts.
- APW – Two spares being built from parts in the Lab.
- Beam control & electronics: Very limited spares at the moment. There is a proposal to build a complete set of spares for the SR4 beam control systems and for one of the two UX45 Faraday cages.

CONCLUSIONS

Important milestones were passed in for the LHC RF systems in 2008, both in hardware commissioning and in the first beam tests. All equipment was successfully commissioned to nominal performance levels. With beam, successful capture with promising lifetime was demonstrated. The APW monitors saw the first beam passages through IP4. The ADT was practically ready for operation with beam.

No major problems are anticipated for RF commissioning for beam in 2009. There are nevertheless concerns on possible access restrictions in UX45. If access is to be restricted during magnet powering, it would be necessary to define and implement safety measures to exclude the UX45 lower level from this.

Extreme care needs to be maintained to minimise cryo and vacuum accident risks for the SC cavities.

Finally, each stage of beam commissioning to higher bunch intensities and increasing numbers of bunches must be preceded by the appropriate RF tests, both on the ACS and ADT systems.

ACKNOWLEDGEMENT

This presentation is based on input from the large number of people in the BE RF group who are actively involved in LHC RF.

REFERENCES

[1] V. Baglin, "Reinstallation and Interconnections", this workshop.

[2] E. Ciapala, "Justification for derogation to fit 1.8 bar pressure release valves Safety Derogation for SC Cavities on SC Cavities". CERN EDMS document 880723, 2007.