LHC Cryogenics:

What did we learn from cool-down to first beams?

S. Claudet

on behalf of the Cryogenic team
First cool-down of LHC sectors

First beams around LHC

Simultaneous Cryo start/maintain

All sectors at nominal temperature

Christmas and water maintenance shut-down

Short in connection cryostats and repairs

Open Days

Cooling sectors + Cryo tuning + Powering activities

ARC56_MAGS_TTAVG.POSST   ARC78_MAGS_TTAVG.POSST   ARC81_MAGS_TTAVG.POSST   ARC23_MAGS_TTAVG.POSST
ARC67_MAGS_TTAVG.POSST   ARC34_MAGS_TTAVG.POSST   ARC12_MAGS_TTAVG.POSST   ARC45_MAGS_TTAVG.POSST

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Content

- Cool-down and refrigeration issues
- Cryogen management
- Tuning Long Straight Sections components
- Operational stability achieved
- Preliminary availability for beams
- Delays to recover quenches or failures
- Repairs and major consolidations
- Summary
Cool-down & Refrigeration issues

• Efficient purge/flushing before 1st cool-down, as no filter clogging or valves perturbated by dust during operation, even after 56 training quench campaign!
• Cool-down time: target at 8-6-5-4 weeks, updated installed capacity at 3 wks
• Cold compressors and 15 mbar operation: more or less mastered and recovery time improved, but 3 sectors will not yet profit from it (45-78-81) until warm-up of sectors
• Many mechanical components not always in nominal conditions (100s Vac vessels, 64 CP, 2000s PV/CV, 76 Tu, 28 CC), spares not always the solution
• Operation mode “2 sectors on one cryoplant” tested with enough capacity for early beams in some cases


**Corrected cool-down curves**

*Cool-down curves corrected from external aleas or cryo failures*

- \( \approx 15 \text{K/d} \times 13 \text{d} \)
- \( \approx 8 \text{K/d} \times 8 \text{d} \)
- \( \approx 12 \text{K/d} \times 4 \text{d} \)

"25 days for 20K"
+ 3 days for Filling
+ 2 days for 1.9K
⇒ 30 days
(4 to 5 wks)
1.8K Units: Global significant progress!

Bearings/Drive communication problems

Re-connection at lower pressures (70-55-30mbar)

Two Months before manual stop!

Better than 2wks MTBF Spring’08!
Two sectors on one cryoplant

- 4.5K Ref.: ≈10% capacity left per sector for dynamic loads, after specific adjustments made
- ≈ 5MW of power input, instead of 8MW (2x4MW)
- Competitive for recovery after stops (<10hrs for CC, <24hrs after power failure for 2 sectors)

Not valid for large transients, but an interesting feature for low beam loads, or validated fall-back scenario if serious problems with a refrigerator
Cryogen management

- Nitrogen: 10'000t for cool-downs, 55 to 60 trucks (20t) per sector, 5 to 6 trucks (20t) / day and /site, up to 9-10/day achieved, reduced rates for sundays

- Helium: 120t received, 29t back in 2008 (cont’d), 1 to 2 trucks (4.5t) / week achieved, 9t/week (2 trucks) possible in 2009 thanks to additional HW, moderate losses (41t incl. purge & leak tests)

Some flexibility (Nb sectors to be kept cold or time to handle inventory) if more LHe tanks at CERN!
A good basis, but “rather long” logistics

**LHC Inventory:**
- LHC + Cryo: 125 t (= 8 x 16t)
- Required for P control: ≈ 5 t
- Total: 130 t

**Storage capacity:**
- GHe tanks (300K-20B): 45 t (vol. = 51 t)
- LHe P18 (4.5K): 15t end’08, 30t spring’09

**Notes:**
- External storage: Maxi 55 t

**Additional:**
- Quench Tanks (new)
- Quench Tanks (existing)
- Refrigerator Tanks (New)
- Storage Tanks compatible with the “Impact Study”
- Exist. vertical Tanks 75 m³

**Map:**
- Points 1 to 8 with various labels and symbols for tanks and cryogenics systems.
Follow-up of Helium inventory

LHC Cryogenics - Helium Inventory

- Initial Inventory
- Deliveries
- Final Inventory
- Losses

External storage

Similar (reduced ?) losses expected for 2009 due to purges/leak tests
Tuning LSS components

• Electrical Feed Boxes (DFBs):
  – We could operate all of them close to nominal conditions (maximum scenario required so far during HWC)
  – Few delicate cases (heat loads, levels measurements, levelling of sc link to magnets, valves for cooling current leads, thermometers and noise, High Voltage perturbation on instrumentation cards)

• Stand alone Magnets (SAM):
  – Difficult Level measurements due to Cold GHe capillary with too small diameter and possible low points, most delicate cases being treated

• Triplets:
  – DFBX: Commissionned with moderate ramp rates on some leads (Cu)
  – NC found on some Q1 (Missing Cu braid), being treated on critical cases in R1 and 5L

• Superconducting links (DSLs):
  – No problem encountered on four DSLs (<80m), except for DSLC_P3
  – DSLC design/installation weak point being treated
Levels for stand-alone magnets

Consolidation requirements for operation improvement

- New capillary Φ ~ 8 mm (w/o low-point) to have the same free section than in the vertical tube
- Increase gas outlet position
- Increase filling inlet position

Reference: P6 already conform, due to specific design due to beam dump line

Since spring 2008:
- Case by case lengthy tuning AND global QRL_line_D pressure stability required

During present shut-down:
- Pipe work being consolidated, at least for MQY critical cases, 1/3 might not be treated
The DFBLC and DSLC in UJ33

Layer 1 (inner) Wires 1-10:
Layer 2: 11-26:
Layer 3 (outer layer) 27-48:

Cryo instrumentation tuned for larger Helium mass-flow

=> Stable operation now at 9-10 g/s (w.r.t 4.5 g/s before)

Consolidations underway on flexible hoses and supports
Stability achieved

• Issues to be treated:
  – Stable services
  – Global refrigeration mastered
  – 15mbar established
  – DFB’s and current leads stabilised
  – Beam screen cooling loops stabilised

• Once critical points listed above had been treated, we had “rock solid” cryo conditions for powering of a given sector!
Cryo conditions for powering ARC_56

Current in dipoles for training quenches

Cryo maintain
Single failure and repair (Thermometer on current leads)

CC suction pressure

Limited number of short term drops
Cryo start

10 Days, May 2008

10 Days, May 2008

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Preliminary availability for beams

- Not much experience before D-day
- With “skilled-operator” help during D-day
- Promising periods of 4-5 days in a row after D-day for 4 to 7 sectors

- We have now already reached a situation with several days of availability between minor perturbations, and a more serious perturbation after a few weeks

- Some 4000 PID control loops (8x500) to work simultaneously, some efforts to be put on:
  - DFB and current leads control tolerances
  - Selection of magnets to be considered for “Cryo Maintain”
LHC Cryogenics: towards beams

Target for global (8 sectors)
“Cryo OK for Powering”

Cool-down and commissioning
(systems, instrumentation, logic)

UX85 Ph1 works

Electrical Transformers

19 Sept’08

19 Sept 08

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LHC Cryogenics: just after beams

A bit frustrating !!!

Target for 4 sectors tested with calorimetry

Switch EL network

19 Sept’08

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Recovery from quenches or failures

• Quenches:
  – Better understanding of their effects on P, T, m’
  – Procedure established for efficient recovery
  – Procedure being introduced in automatism

• Services:
  – Difficult periods by turns with EL, CV, CO, VAC
  – All being addressed with appropriate studies and mostly followed by consolidation programs
Recovery Time after Limited Resistive Transitions

(Predictions at design stage)

Without losing helium, and powering permit on other powering subsectors

• More than 14 cells or full sector: recovery up to 48 hours
• In case of fast discharge (even w/o quench): 2 h recovery (heating due to eddy currents).

From x3 down to x1.5 w.r.t design values
Analysis of stops

<table>
<thead>
<tr>
<th>Sector</th>
<th>Date</th>
<th>Origin</th>
<th>Description</th>
<th>Stop CC</th>
<th>Stop Duration</th>
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<tbody>
<tr>
<td>56</td>
<td>29-Feb-08</td>
<td>Elec</td>
<td>Stop 400V (Pb AUG loop)</td>
<td>stop CC</td>
<td>168</td>
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<tr>
<td></td>
<td>12-Mar-08</td>
<td>Cryo</td>
<td>Controls CC (AL)</td>
<td>stop CC</td>
<td>not applicable</td>
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<td></td>
<td>14-Mar-08</td>
<td>Cryo</td>
<td>Leak in 18kW Cold Box</td>
<td>stop CC</td>
<td>240</td>
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<td></td>
<td>02-Apr-08</td>
<td>Cryo</td>
<td>Controls CC (AL)</td>
<td>stop CC</td>
<td>not applicable</td>
</tr>
<tr>
<td></td>
<td>04-Apr-08</td>
<td>Cryo</td>
<td>Stop 18kW Comp. (LS oil)</td>
<td>stop entire sector</td>
<td>not applicable</td>
</tr>
<tr>
<td></td>
<td>04-Apr-08</td>
<td>Water</td>
<td>Stop 400V P5 (water)</td>
<td>partly blind</td>
<td>not applicable</td>
</tr>
<tr>
<td></td>
<td>06-Apr-08</td>
<td>Cryo</td>
<td>Stop 18kW Comp. (LS oil)</td>
<td>stop entire sector</td>
<td>not applicable</td>
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<tr>
<td></td>
<td>18-Apr-08</td>
<td>Elec</td>
<td>Low 400kV</td>
<td>stop CC</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>30-Apr-08</td>
<td>Elec</td>
<td>CERN 400kV failure</td>
<td>stop entire sector</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>04-May-08</td>
<td>Elec</td>
<td>US65 400V stop</td>
<td>stop CC</td>
<td>not applicable</td>
</tr>
<tr>
<td></td>
<td>10-May-08</td>
<td>Elec</td>
<td>US65 400V stop</td>
<td>stop CC</td>
<td>not applicable</td>
</tr>
<tr>
<td></td>
<td>10-May-08</td>
<td>Elec</td>
<td>US65 400V stop</td>
<td>stop CC</td>
<td>not applicable</td>
</tr>
<tr>
<td></td>
<td>11-May-08</td>
<td>Elec + Water</td>
<td>1.0 VAR + water perturbations</td>
<td>stop entire sector</td>
<td>120</td>
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<td></td>
<td>22-May-08</td>
<td>Elec + Water</td>
<td>2.0 VAR + water perturbations</td>
<td>stop entire sector</td>
<td>120</td>
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<td>29-May-08</td>
<td>Elec + Water</td>
<td>2.0 VAR + water perturbations</td>
<td>stop entire sector</td>
<td>120</td>
</tr>
</tbody>
</table>

Target Autumn’08:

- < 12 h for stop CC
- < 36 h for full sector stop

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Towards more stable services

• Electricity:
  – 3.3kV input Power, 400V distribution, 24VDC units
  – Spares or fall-back solutions being studied, some implemented (budget tbc)
  – *Specific case of Cold Compressor drives (70-100ms) on UPS to be monitored and evaluated*

• Cooling water:
  – Many consolidations identified and launched
  – Main water pumps MTTR ≈ Cryo tolerance, Test program + study going on

• Controls:
  – Communication cards, PLC arrangement and network being consolidated, always sensitive to IT routers/switches

• Insulation vacuum:
  – Interlocks for “catastrophic rupture” to be simplified: 1 volume <=> 1 signal
  – Gauges to PLC’s to be put on UPS
Cryo repairs and major consolidations

• Mecanics:
  – Repairs of few leaks into cold-boxes insulation vacuum (P2, P6, P8)
  – DSLC_P3
  – Change of 1 control valve for 1.8K units when possible (not for 45-78-81)
  – Change of about 100/2200 valve popets of QRL & QUI

• Instrumentation:
  – Instrumentation on electrical feed boxes (TTs, CVs for current leads)
  – Tuning of valve positioner dynamics
  – Correction of Non-Conformities (LTs, TTs, …)
  – High Voltage compatible instrumentation cards ready for review

• Automatisms:
  – 2nd generation of logic (simplified) for tunnel
  – Standardisation of procedures for interconnection of sub-systems
  – 1.8K units and pump-down
Summary

• LHC Cryogenic system has been put in operation with success and was “ready” for D-day

• With static heat loads and effect of resistive heating lower than specified, we have the foreseen global budget for expected dynamic loads, to be further checked at local levels

• Test programs were conducted to improve our understanding and tuning of sub-systems

• Nominal preventive maintenance and consolidation programs Services-Cryo-Machine are being implemented during this winter shut-down

• Operation with shift (1 x 5x8) to start spring’09, industrial support to help for big transients and possible others for specific cases