Rotating machinery for LHC Cryogenics: first analysis of reliability and origins of downtime


LHC Cryogenics
Content

- Introduction and context

- Analysis of failures and downtime:
  - Operation failures: Availability
  - Breakdown: Reliability

- Summary
Large variety of configuration, with provision to use 1 cryoplant on 2 sectors for helium management and up to “low intensity” physics

*(Flexibility in case of failure of a component, already used before LS1)*
1/8e of LHC: production-distribution-magnets

Total 8 sectors:
- Compressors: 64
- Turbines: 74
- Cold Comp.: 28
- Leads: 1’200
- I/O signals: 60’000
- PID loops: 4’000

- Rotating machinery does produce the required cooling/pumping capacity!
- Large variety of instrumentation mostly underground
- Hundreds of vacuum insulated volumes, with potential risks of helium leaks resulting at least in longer recovery time

x 13.5
Availability, criteria to be used

Set of cryogenic conditions to start powering (CS) or keep the magnets powered (CM)
LHC Cryo global availability

- **2010**: Nice learning curve! mostly Cryo issues treated “on the fly”
- **2011**: Good start before beam induced issues (energetic neutrons), 1st corrections
- **2012**: Effective treatment of beam induced issues,
- **2013**: A global success!

830 cumulated days with an average availability of 91.9%

*(about 99% per independent cryogenic sector)*
Sensitivity to post-LS1 beams

LS1: Long shut-down No1

- Higher energy:
  - x 4 heat load (Ri2 with I x 2), towards nominal
- Higher luminosity:
  - Local effect expected (inner triplets focussing quadrupoles)
- Lower bunch spacing (25ns):
  - Identified valves changed not to limit performance
  - Significant effect expected during scrubbing runs to cure e- clouds effects
  - No effect expected during “physics” operation
- Expected effect: periodic capacity change
  - Cabled signal “ramp” expected to help tuning cryo-controls

=> We should be able to handle the corresponding transients

Less capacity margin (installed-required) => sensitivity to previous “near-miss”
Content

• Introduction and context

• Analysis of failures and downtime:
  • Operation failures: Availability
  • Breakdown: Reliability

• Summary
Screw Compressors + motors

With less capacity margin, some compressors failures would induce downtime

6% of cryo downtime

Availability

Number of stops

Instrumentation:

2/10

7/10

Time to recover [hr]

Instrumentation:

Filter
SEU
MAG. BER.
PROFIBUS
MECA
INSTRUM
UTILITIES
CRYO
AV losses
Screw Compressors + motors

Specific oil injection (22bar) to balance axial forces, Need to send more oil than passes through to screws!

No issues since, and findings during major overhaul under investigations (no major issues so far)
Turbines

Low temperature turbines issues will become more visible

≈0% of cryo downtime

Availability

Turbines

Number of stops

Instrumentation:

Filters clogging:

1/35

22/35

9/35

Time to recover [hr]
Turbines, breakdowns

Origin of failures:
- 5 bearings blocked, mostly due to impurities
- 2 process or control issues with inlet valve
- 1 external items in wheel

Issues, but no clear data
Turbines, breakdowns

Clear effect of the transients and massive start/stop of turbines on the breakdown statistics (could be expected, but demonstrated here!)

Counters and warnings could be established to help operation team

Christmas break

Technical stops

Number of start / stops

Reliability
Cold Compressors

Multiple efforts to help reducing cold-compressors related failures (on-going process):
Process controls algorithms, Relocation of sensitive electronics (P4, P8)

≈60% of cryo downtime

18/18!

Only one way out: Avoid stops!
Cold Compressors

Better control and possible anticipation for bearings required (periodic bearings checks)

Diam: 250mm

3-phase induction Electrical motor (rotational speed: 200 to 800 Hz)

Fixed-vane diffuser

Spiral volute

Axial-centrifugal Impeller (3D)

Active magnetic bearings

Bearing

Cabling

Outlet

Inlet
Cold Compressors

After each stop of cold compressors, an analysis of the digital input and speed signal is performed and logged with categories:
- smooth and nominal stop
- assisted landing
- emergency landing on touch down bearings

<table>
<thead>
<tr>
<th>No</th>
<th>Machines</th>
<th>Date</th>
<th>Error categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>QURCA_P8</td>
<td>08.02.12</td>
<td>smooth and nominal stop</td>
</tr>
<tr>
<td>2</td>
<td>QURCA_P8</td>
<td>08.02.12</td>
<td>assisted landing</td>
</tr>
<tr>
<td>3</td>
<td>QURCA_P8</td>
<td>08.02.12</td>
<td>emergency landing on touch down bearings</td>
</tr>
</tbody>
</table>

Periodic tests to evaluate the status of the bearings have been started together with the manufacturers, with plans to use the outcome for conditional maintenance.
Summary

• The availability and reliability have been improved during run 1 with results fully compatible with LHC physics program. However, increased beam performance will require continued efforts!

• For each type of rotating machinery, an analysis of operation failures was performed, with identification of possible improvements to be done, mostly instrumentation and filters, plus specificities for cold compressors

• For each type of rotating machinery, an analysis of breakdown was performed, with identification of possible additional criteria to be looked at, mostly a start counter for turbines and stop analysis for cold compressors

• Efforts in logging data and events with appropriate signification should be reinforced, both from operation (e-logbook with dedicated sheet including origin of failure) and maintenance (methods, breakdown reports and analysis)

Thanks for your attention!
Selection of typical LHC cryogenic hardware

33 kW @ 50 K to 75 K - 23 kW @ 4.6 K to 20 K - 41 g/s liquefaction

Diam: 250mm

48 boxes
Systematic analysis of downtime

From the books:
- Immediate effect of (good!) practice
- Annoying if frequent, to be kept low with moderate efforts
- Serious cases requiring specific monitoring and significant efforts
Criticality Analysis

- Summer student: Jimmy MARTIN
  - Functional analysis
  - Critical analysis

Data analysed from e-logbook & CM files

![Lambda (t): failure rate function](image)

\[ \lambda(t) = 0.0078t^{-0.184} \]

- Being continued:
  - Analysis by individual failure mode for few significant components
  - Cryo-Maintain loss table to be detailed down to component failure (mode)

A nice try which confirmed the observed tendency, but stored data not adapted for such a treatment

Useful anyhow to get familiar with the field, with required tools improvement identified
Screw Compressors + motors

Number of start / stops

Jan  | Mars  | Mai   | Juillet | Sept  | Nov   
---   | ---   | ---   | ---     | ---   | ---   

Screw Compressors A
Screw Compressors B
Cold Compressors

Number of start / stops

<table>
<thead>
<tr>
<th>Month</th>
<th>Cold Compressors A</th>
<th>Cold Compressors B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Mars</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Mai</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Juillet</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Sept</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Nov</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
Turbines

Maximum monthly number of start for a turbine

Threshold for warnings?