Internal monitoring for HL-LHC

Low-Beta Quadrupole

Crab-Cavities
Outline

- Internal monitoring
- Crab-Cavities project
- Dipole-Test project (for HL-LHC quadrupoles)

Crab-Cavities in SPS accelerator

Dipole-test in SM18
Internal monitoring

Objective: determine the position of inner component inside a vacuum vessel (Cryostat, Cryomodule)

Environment:
- Temperature: 1.9 K (Cryogenics conditions) ≈ -271°C
- Vacuum: 10-6 mBar
- Radiation: 1 MGy / year

Accuracy:
- 0.1 mm w.r.t. vacuum vessel
**FSI : Frequency Scanning interferometry**

Absolute distance measuring interferometric technique

**Vacuum Vessel**

- Vacuum : Ambient
- Temperature : Ambient

- Vacuum : $10^{-6}$ mbar
- Temperature : 1.9 K

**Reference interferometer**

**Measurement interferometer**

Measures phase changes in a measurement and reference interferometer as frequency is scanned

\[
\Delta \text{Phase (meas.)} = \frac{2\pi}{c} * L_M * \Delta \nu
\]

\[
\Delta \text{Phase (ref.)} = \frac{2\pi}{c} * L_R * \Delta \nu
\]

\[
\frac{\Delta \text{Phase (meas.)}}{\Delta \text{Phase (ref.)}} = \frac{L_M}{L_R}
\]

**Accuracy :**

0.5 µm per meter

Absolute distance : deduced from the ratio of the phase change between the 2 interferometers by frequency scanning
Crab-cavities
Configuration

8 FSI distances by Cavity

- Vacuum: Ambient
- Temperature: Ambient

Cryomodule

- Vacuum: $10^{-6}$ mbar
- Temperature: 4 K

Thermal shielding
Cooling down in SPS: From 293 K to 4 K

Accuracy: < 50 µm (1σ)
Conclusion

Since April 2018, the monitoring of the Crab-cavities worked correctly.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Precision (1σ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tx (radial)</td>
<td>+/- 25 μm</td>
</tr>
<tr>
<td>Ty (longitudinal)</td>
<td>+/- 45 μm</td>
</tr>
<tr>
<td>Tz (vertical)</td>
<td>+/- 10 μm</td>
</tr>
<tr>
<td>Rx (pitch)</td>
<td>+/- 30 μrad</td>
</tr>
<tr>
<td>Ry (roll)</td>
<td>+/- 150 μrad</td>
</tr>
<tr>
<td>Rz (yaw)</td>
<td>+/- 70 μrad</td>
</tr>
<tr>
<td>Scale</td>
<td>+/- 60 ppm</td>
</tr>
</tbody>
</table>

During the cooling-down:
- a reduction of the feedback signals has been observed → Cryo-condensation ?
- loss of 1/16 optical view → Cryo-condensation / Obstacle ?
Conclusion

- Successful cross comparison at warm and cold condition
- Accuracy of absolute position of Crab-cavities inside cryomodule: +/- 50 μm
- Relative precision: Few microns
- Repeatability of several heat-up and cool down sequences: Below 10 μm
Dipole test
In order to choose the internal monitoring for the Low-Beta quadrupoles, a dipole has been used as test setup.

- 12 distances measurements (FSI system)
- 3 sections

- Vacuum: $10^{-6}$ mbar
- Temperature: 1.9 K
Cryo-condensation on the laser reflectors is a main showstopper for optical distance measurements in “dusty” cryostat.
Insulated support
**Test : October / November / December 2018**

**Vacuum**
- Ambient Temperature: Ambient
- Vacuum: $10^{-6}$ mbar

**Cold mass**
- Temperature: 4 K

**Cryostat**
- Thermal shielding
- Vacuum: $10^{-6}$ mbar
- Temperature: 180 K

**Target Support**
- Insulated target
- Nothing

**Acquisition system**
- FSI
- Commercial: Etalon
- CERN

**FSI Head**
- Feedthrough (adjustable)
- Feedthrough (fixed)
- Window

**Collimator**
- Parallel lens
- Divergent collimator

**Targets**
- Newport reflector (3 mirrors)
- Glass sphere without coating
- Glass sphere with coating

17.06.2019
3 Cooling-down

Date

0  50  100  150  200  250  300  350

TEMPERATURE [K]

1-Oct-18  1-Nov-18  1-Dec-18  1-Jan-19
Section 2

Legend

- ETALON (commercial)
- Convergent collimator
- Window (crossing)
- Newport prism

- Laser tacker
- Newport prism / Glass sphere

- Multi-targets
- Divergent collimator
- Window (crossing)
- Glass sphere

- Multi-targets
- Divergent collimator
- Window (crossing)
- Newport prism

17.06.2019
Conclusion

CERN Acquisition system

- Feedthrough
- Divergent collimator
- Glass sphere WITH coating
- Insulated target

Cold mass

Acquisition system : FSI
- Commercial : Etalon
- CERN

Divergent collimator

FSI Head
- Feedthrough (adjustable)
- Feedthrough (fixed)
- Window

Collimator
- Parallel lens
- Divergent collimator

Targets
- Newport reflector (3 mirrors)
- Glass sphere without coating
- Glass sphere with coating

Target Support
- Insulated target
- Nothing
Thank you for your attention

On behalf of:
- Mateusz Sosin
- Hélène Mainaud Durand
- Thibault Dijoud
- Mathieu Duquenne
- Anna Zemanek
- Kacper Widuck
- Jan Gabka
Thermal contraction: From 293 K to 4 K

<table>
<thead>
<tr>
<th></th>
<th>Cav 1</th>
<th></th>
<th>Cav 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Simulation</strong></td>
<td>1.097</td>
<td>0.678</td>
<td>1.097</td>
</tr>
<tr>
<td>SM18</td>
<td>1.321</td>
<td>0.843</td>
<td>1.295</td>
</tr>
<tr>
<td>SPS</td>
<td>1.310</td>
<td>0.834</td>
<td>1.320</td>
</tr>
</tbody>
</table>
Calculation

Cryostat

Z

X

COLD mass
Phase 4: Results (Warm condition)

Section 1
A / B / C / D

Section 2
I / J / K / L

Section 3
E / F / G / H

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Etalon (convergent beam) + Window + Newport reflector
Multi-targets (divergent beam) + Window + Newport reflector
Multi-targets (divergent beam) + Window + Glass sphere High
Multi-targets (divergent beam) + Window + Glass sphere Low
Etalon (convergent beam) + Window + Glass sphere with coating
Multi-targets (divergent beam) + Window + Glass sphere with coating
Multi-targets (divergent beam) + Feedthrough + Glass sphere with coating
Phase 4 : Results (Warm condition)

Etalon (convergent beam) + Window + Newport reflector
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Multi-targets (divergent beam) + Window + Glass sphere with coating
Multi-targets (divergent beam) + Feedthrough + Glass sphere with coating
Phase 4 : Results (Cold condition)

Cold 1

Cold 2

Cold 3

Etalon (convergent beam) + Window + Newport reflector
Multi-targets (divergent beam) + Window + Newport reflector
Multi-targets (divergent beam) + Window + Glass sphere High
Multi-targets (divergent beam) + Window + Glass sphere Low
Etalon (convergent beam) + Window + Glass sphere with coating
Multi-targets (divergent beam) + Window + Glass sphere with coating
Multi-targets (divergent beam) + Feedthrough + Glass sphere with coating
Phase 4: Results (Cold condition)

- Etalon (convergent beam) + Window + Newport reflector
- Multi-targets (divergent beam) + Window + Newport reflector
- Multi-targets (divergent beam) + Window + Glass sphere High
- Multi-targets (divergent beam) + Window + Glass sphere Low
- Etalon (convergent beam) + Window + Glass sphere with coating
- Multi-targets (divergent beam) + Window + Glass sphere with coating
- Multi-targets (divergent beam) + Feedthrough + Glass sphere with coating

Section 1

Vertical [mm]: 71.4 to 71.8
Radial [mm]: 0.3 to 0.7

Section 2

Vertical [mm]: 73.8 to 74.2
Radial [mm]: 2.1 to 2.5

Section 3

Vertical [mm]: 75.8 to 76.2
Radial [mm]: 3.9 to 4.3