DCM : Engineering Detailed Design


*Engineering Design Review of the D1-DFX Connection Module (DCM) 15.04.2021
Overview of DCM history

- **2017/2018:**
  - First studies position the cold diodes at the extremity of D1 (key arguments: integration & radiation levels)
  - The progressing design of the cold Powering System identifies the need for an extension between DFX and D1 of about 6-8 meters
  - Several conceptual designs are considered converging to a dedicated module parallel to the beam tube

- **End 2020:**
  - ECR is Approved
  - F. Mateos, “HL-LHC ECR - WP3. NEED OF A CONNECTION MODULE LDQD (D1-DFX)”, EDMS 2210558
DCM Overview

Main Stream

Periscope

Diodes cryostat

D1 module

D1 Jumper

0.7m

Ø 0.7m

DCM-Diodes Interconnexion

Cu-Cu Splices

DCM-Diodes Interconnexion

NbTi NbTi splices

DCM Engineering Design Review – 15.04.2021

DFX

Lambda Plate : AX Dedicated Review

NCT Busbars

Services

Cu Busbars

Diodes Stack

Diodes services

DCM-D1 Interconnexion

NCT NCT splices

Frame

Beam Reservation

5.5 m

Vacuum Vessel

Thermal Shield

Helium Vessel

Lambda Plate

Adjustment & support systems

Dedicated Review

Diodes services

DCM

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 Cu

 NbTi NbTi splices

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 Ø 0.7m
Electrical Design

Busbars (see review)
- 19 NbTi busbars, 8 m long, fixed in a Lambda Plate connected in DFX/DCM
- 5 Cu busbars 50 mm², 2.5 m long, connected to Cold diodes/NbTi branches

Soldered Splices:
- 19 NbTi-NbTi splices at DCM-D1 interconnect
- 5 Cu-Cu splices at the DCM-Diodes interconnect
- 2 NbTi-NbTi splices in D1 end module

Cold Diodes: 6 cold diodes with 5 copper busbars, see dedicated session

Environment: Busbars, splices & diodes nominally immersed in superfluid

Instrumentation: Layout according to [1]
Electrical Design

- Busbars are twisted as for IT, protected by sheath (design in progress)

- Busbars Guides
  - Lambda Plate side guides to transfer Lorentz forces
  - Additional Guides to be developed (know-how from magnet solutions). Tested in mock-up

- Splices supports to be designed

- DCM IFS tube manufactured as for WP6a
Cryogenics

Purpose: ensure operating temperatures of busbars & diodes

DCM shares the SFHe volume with IT, thermal shield circuit in series with IT, see [2]

SFHe volume performances
- Heat loads to 1.9 K : < 16 W within budget (> 50 % through cables)
- Superfluid phase ensured up to 150 % of functional requirement

Transient Cool Down
- DCM is in a dead end ➔ no convective flow ➔ cooled from D1

Transient Warm up
- Liquid Vaporisation: No heaters (use of gravity)
- WU By static heat loads to 300 K
**Cryogenics**

**Thermal contractions strategy : Structures**
- Fixed point @ Vacuum barrier & D1 side support
- No preference in the CD/WU sequence between thermal shield and cold mass

DFX/Magnets can be **individually cooled**
- For a DFX at 4.5K and a D1 at 300K, conduction heat load through cable is 30 W (DCM as buffer)

**Thermal contraction Cables Vs Cold Mass**
- in DCM, Flexible & D1:
  - splices fixed to He V
  - → cables follows the He V
  - → no friction
- The extra length to cover the bellows expansion is contained in the flexible

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*Nominal configuration Courtesy of F. Di Ciocchis*
Cryogenic : thermal shield

- **Purpose**: reduce radiative heat loads from 300 K walls to 1.9 K volume
- Bolted Aluminium rolled sheets covered with 30 MLI
- Actively cooled in series with main cryostat thermal shield circuit
- Heat transfer performed by conduction with copper braids

Thermal Shield temperature distribution
In nominal operation. Courtesy F. Di Cicchis

13 mm during CD

Sleeve

Sliding interface

Inlet & outlet
Thermal shield circuit

Thermalization of supports
To reduce heat loads

Cooling circuit
ID 20 mm : 5 g/s

4 mm thick Al plates

TS fixed point

Thermalization CC design based
Test campaign to validate torque & reliability
Insulation Vacuum & external interfaces

Insulation vacuum
- Extremity of IT common insulation vacuum
- Vacuum Barrier with DFX
- Port for installing non-permanent pumping system & Vacuum gauges
- Reservations for pressure relief devices, no clear request so far

Mechanical design approach
- Vacuum vessel acc to EN 13445-3 standard, bellows to EN 14917+A1

### Insulation Vacuum design properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insulation Vacuum Volume</td>
<td>[m³]</td>
<td>1.5</td>
</tr>
<tr>
<td>Maximum allowed leak rate at RT</td>
<td>[mbar.l.s⁻¹]</td>
<td>(1.10^{-9}) (1.10^{-8})</td>
</tr>
<tr>
<td>Helium volume to insulation vacuum</td>
<td>[mbar.l.s⁻¹]</td>
<td>(1.10^{-9}) (1.10^{-8})</td>
</tr>
<tr>
<td>Air to insulation vacuum</td>
<td>[mbar.l.s⁻¹]</td>
<td>(1.10^{-9}) (1.10^{-8})</td>
</tr>
<tr>
<td>Nominal pressure</td>
<td>[mbar]</td>
<td>(1.10^{6})</td>
</tr>
</tbody>
</table>

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[1] YL, AVC “Interface definition WP6a-WP3”

EDMS 2429304
He Vessel mechanical design: process and assessment

Design for all P-T config. acc. to EN-13445-3

- Methods, configurations, safety factor & acceptance criteria defined by standard (Annex B & C: by analysis)
- Verification of stress distribution
- Verification of structural instability
- Non-standard welds pre-qualified by Annex C

A. Vacuum barrier instability assessment (Annex B)
   1. Linear buckling analysis
   2. Geometry exported in model
   3. Non-linear buckling assessment

B. Lip weld to flexible assessment (Annex C)
   1. Linear stress distribution
   2. Linearization of stress path
   3. Lip weld assessment

C. Cold Mass – IFS interface
   1. Design not compliant with standard
   2. Design change
   3. Assessment
Safety wrt overpressure

Mechanical integrity
- Vacuum & Helium Vessels: designed, manufactured and tested acc. to PED
- Frame: designed acc to Eurocode 3 to withstand all P-T configurations
- All materials compliant with radiation levels (see Plate review)

System Safety Assessment supported by detailed calculations

Lambda Plate specific case:
- Risk Assessed in EDMS 2303664 & 2365987: DFX safety device sized accordingly, see Lambda Plate EDR

Lambda Plate
- EDMS 2518554

Stainless steel closing tap
Soldered cable
Cold Powering
He vol.

Lambda Plate degradation

S1: Loss of insulation Vacuum
Contribution to flow through QRV: 0.6 kg/s

S2/3: Electrical SC, Arc
1.6 kg/s through VV relief plates

S4: Lambda Plate degradation

S5: Quench of magnets
P_{DCM} < P_{magnet}
Design optimization wrt cost optimization & reliability

Few examples of design optimizations for a production of 5 units (collaboration with Main Workshop)

- **T connection to diodes**: Bulk machining Vs reinforcing ribs (welds qualif., induced deformation)
- **D1 fixed point**: Support resistance wrt instability Vs thermal shield thermalization reliability
- **Elbow**: internal available space Vs nb of manufacturing operations (welds qualifications, deformation)

He Vessel T connection optimization  
*Courtesy of F. Di Ciocchis*
Interfaces & Limit of supplies

- Diodes stack
  - Supplied with 4 meters long instrumentation wires
  - Integrated with mechanical locking system and insulation sheath
  - Interfaces to be validated with Mock-up
- Mechanical interfaces DFX/D1 fixed
- Standard equipment interfaces fixed
- Interface to ground (see integration presentation)
Mock-up

Objectives:

- Qualification of Copper busbars bending tooling and procedure
- Validation of mechanical assembly procedure
- Demonstrator of “loop IFS tube” design feasibility
- Supports of soldering process validation
- Validation of interfaces with the diodes stack
Assembly sequence

- See MIP presentation
- 2 DCM sub-modules + frame

Main Stream Activities
- Welding
- Soldering
- Aligning
- Testing

D1 Module activities
- Testing

Frame activities
- Reception

Main Stream Assembly overview

- A Plate assembly
- Cables fixing
- He V insertion
- TS Assembly
- VV insertion
- Periscope assembly
- Diodes stack
- He Insertion
- IFS manufacturing
- TS & VV assembly
- QC
- QC
- Diodes assembly
- He & VV extensions assembly
- QC
Installation sequence

1. Frame & D1 installed
2. Pulling cable through IT
3. Installation of D1 module
4. Positioning of D1 module (with BE-GM)
5. Installation & positioning of DCM+DFX extremity
6. Electrical & mechanical connections
Maintenance

LHC principle for repairing splices in Diodes and DCM-D1 interconnects
- Bolted Vacuum sleeve slid over vessel
- Disassembly thermal shield sheets
- Cut Lip welds, slide He sleeve and access splices

IFS, vacuum equipment accessible from transport area

Note1: D1 flat to flat splices are not accessible
Note2: Plug or Lambda Plate can not be repaired in the tunnel, need to be brought at the surface (or install spare unit)
Replacement of diodes covered in the Diodes session
Assessment for pressure application

Pressure envelope: PED CAT IV
- Stainless steel envelope compliant to CAT IV
- Plugs are made of cable + PEEK insulating part, not covered by PED

Strategy for helium vessel (following preliminary discussions with HSE)
- **Design**
  - Stainless steel envelope: calculations acc to EN13445-3 ➔ Assessment by HSE
  - Plug: test campaign to be agreed w HSE ➔ Assessment by HSE
  - Non standard weld: burst test campaign ➔ Assessment by HSE
- **Procurement**
  - Technical Specification to be discussed and agreed with HSE ➔ Assessment by HSE
  - Bellows & flexible hoses: supplied with CE marking
- **Manufacturing**
  - Welds qualifications and operator qualifications certified by external notified body
- **Pressure testing:** ➔ witnessed by HSE
- **Conformity Assessment delivered by HSE**
Conclusions

- The engineering design is complete, some qualification in progress
- Built to print drawings of the vacuum vessel are signed
- Built to print drawings of the helium vessel shall be signed by end April
- Detailed assembly sequences and interfaces are being qualified with mock-ups
- Busbars supports and protection shall be finalised
- Reservations are made for the safety relief device layout
- A strategy for the safety assessment wrt to pressure is defined, details need to be agreed with HSE
Thank You
Construction aspects

- Cost optimisations
- Material definition
- Drawings to ISO GPS

- 3D forged: 316L
- Laminated ring: 304 L mini
- Seamless or roll/weld tubes: 304 L mini
- Seamless or roll/weld tubes: 316 L
- Walls with continuous fibers: 316 L
- Forged: 304 L
- Structural: 304 L