"DFM Conceptual Design Review" Report

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This document reports the outcome of the *"DFX Detailed Design Review" (DDR)* held on **21 June 2019** (https://indico.cern.ch/event/821879/)

The Report is structured in:

- *Introduction*
- *Executive Summary with main Recommendations*
- *Review of Contributions (providing for each presentation: "Findings", "Comments" and "Recommendations").*

Introduction

The Review Scope, Mandate and Program were defined, by TE-MSC in agreement with HL-LHC Project, as following:

Scope: Review the conceptual design of the DFM with the purpose of validating maturity and confirm readiness for starting detailed design.

Mandate of the Review Committee:

1) Review the functional specification and confirm their completeness in terms of cryogenic, mechanical and electrical requirements;

2) Review the functionality of the design concept wrt cryogenic design and operational aspects, mechanical design and interfaces – including the lambda plate;

3) Review the proposed integration and installation plan in the LHC machine and the compatibility of the DFM location wrt the tunnel environment (including preliminary plan for maintenance and repair interventions during operation);

4) Review cryogenic requirements for safety aspects and compatibility of safety equipment with tunnel environment;

5) Review plan for detailed design development;

6) Review schedule for prototype production, including strategy for intermediate validation.

Review Committee: S. Atieh, G. Ferlin, M. Modena (chair), F. Rodriguez Mateos.

Scientific Secretary: M. Mendes

Presentations:

- *Welcome: Luca Bottura (CERN)*
- *DFM in WP6a: Dr Amalia Ballarino (CERN)*
- *DFM Functional specification, Speaker: Yann Leclercq (CERN)*
- *DFM Conceptual Design, including integration and interfaces in the tunnel: Yann Leclercq (CERN)*
- *DFM Safety aspects, Speakers: Thomas Otto (CERN), Vittorio Parma (CERN)*
- *Production Plan, Speaker: Yann Leclercq (CERN)*

Acknowledgement

The Review Panel would like to thanks the Speakers for the provided presentations clear and concise.

A special thanks to M. Mendes for his clear and careful annotation of all comments&questions and help in the reviewing phase.

Executive Summary:

Context and main remarks:

The DFM procurement strategy and plans and the differences in comparison to the DFX procurement were clarified to the Panel.

We understood that, despite the different advancement of the 2 projects (DFM design and procurement will follow on the time-scale the DFX one), the plan is to have the two procurement proposals approved as part of the "UK-2 Agreement" at the next Finance Committee (FC) of September 2019.

Given the still conceptual status of the DFM design and also looking at the procurement plan (for both DFM and DFX), it seems eventually feasible to present the proposal to the FC of December 2019 instead of September. Even if not mandatory to have a finalized design with all technical documents completed and released for the FC, this would allow arriving at that stage with a more sound, and validated DFM design and integration. *Evidently these remarks do not consider any eventually existing Managerial consideration that would push for the presentation to the September FC.*

Due to the relative less complexity of the DFM respect to the DFX and to the fact that a similar DFM distribution box was successfully tested in the "DDFX" demonstrator at SM18 in 2018, WP6a proposes to skip a (Global) System Test phase after the procurement of the 1st unit (pre-series and future spare).

The knowledge on the DFM concept and details by the SOTON colleagues is less comparing to the DFX. This is due to the fact that for the DFM, SOTON will be not responsible of and will not develop the Conceptual design as done for the DFX. SOTON will be responsible for the procurement of five DFM units (1 pre-series and 4 series) based on design and drawings "for procurement" developed and provided by CERN.

Anyway, looking at the experience with the DFX conceptual and detailed design, the Panel support the proposal of WP6a to have a part-time presence of SOTON colleagues at CERN during the finalization of the DFM Conceptual Design. The collaboration should discuss and agreed on this aspect.

Referring to the six **Review Mandate specifications**, the Review main conclusions and recommendations are here presented:

1) ***"Review the functional specification and confirm their completeness in terms of cryogenic, mechanical and electrical requirements":***

The functional specification draft presented seems clear and to contain all the expected interfaces. Similar boundary conditions and constraints like for the DFX exist.

→ ***RECOMMENDATION N.1:*** *pursue on the finalization of the reference documents (Functional Interface and Technical specifications), interacting with ALL interfaces (WP9, WP15, WP3, HSE, etc.) in order to have these documents fully checked and approved possibly BEFORE the FC of September.*

2) ***"Review the functionality of the design concept wrt cryogenic design and operational aspects, mechanical design and interfaces – including the lambda plate":***

The electrical/powering scheme of the DFM is simpler with respect to the DFX one (10 cables respect to 19).
Despite the DFM design being composed by two distinct modules, the cryogenic and mechanic design presented seems also simpler respect to the DFX one. The functionalities of GHe generation (for the DSHM cooling) and LHe bath for the MgB2/NbTi splices are separated. The DFM configuration is very similar to the one tested in the DDFX in SM18.

→ ***RECOMMENDATION N.2:*** *Even though the cryogenic functional scheme is clear and quite advanced, there are still parts to be completed (jumper and interlink) and some questions were raised mainly about aspects and details linked with the transitory phases and operation (not exhaustive list, please refer also to the "Contribution Review" section):*

- *The thermal gradient in the DSHM during cool down is a critical working aspect, GHe will be originated from the 2 main DFM vessels. It is recommended to carefully analyse this aspect and implement all the needed instrumentation (e.g. temperature sensors) to correctly control the cool-down phase (if this not fully implemented in the DSHM design).*
- *In a similar way the presence of an 8-m "interlink" between DSM and D2 magnet working in superfluid Helium (object formally in the scope of WP3, but mechanically and cryogenically interfacing the DFM design) needs a study and integration of temperature sensors for the cooling down and filling operation.*
- *As reported for the DFX, it is needed a decision on the redundancy of the LHe heaters (electrical and by heat exchanger).*
- *The specificities of the 4 installation location for the DFMs (with different geometries of the Tunnel, height of the beam and QXL) could probably bring to minor differences in the design of the DFMs or at least in their integration. This aspect is critical and needs a careful study.*
- *Some mechanical/assembly aspects bring to common recommendation as for the DFX: LHe inlet pipe design, O-ring procurement, IFS and redundancy of instrumentation wiring, etc. Please refer to the DFX Review report (EDMS 2175576) for more details.*

3) ***"Review the proposed integration and installation plan in the LHC machine and the compatibility of the DFM location wrt the tunnel environment (including preliminary plan for maintenance and repair interventions during operation):***

For this aspect, only preliminary and conceptual assembly sequences were presented.
The integration of the DFM modules: above the D2, connected to the DSHM on one side and to the interlink for D2 magnet on the other side, will be a complex operation also from equipment transport point of view.
The DFM design contains a "20 degree elbow" element where there will be the inter-connection with the DSHM.
This inter-connection operation will include a critical "pivoting operation" of the "20 degree elbow" element.
Safe manipulation of the DSHM with its connection will be the critical aspect to be mastered during this operation.

→ ***RECOMMENDATION N.3****: it will be critical in the next DFM detailed design phase a tight collaboration with other WPs (WP9, WP15, HSE, Transports and other LHC Services,) in order to develop a final design and tooling fully compatible with: the neighbour equipment, difference sites constraints, installation and maintenance sequences.*

- *Specificities of the different installation sites must be included.*
- *At least a conceptual design of the "interlink" with D2 is necessary to finalize the DFM detail design and assembly sequence in the tunnel (the rigidity and the "interlink" assembly sequence could impact on the DFM and supports design).*

As for the DFX we remind and aware that the radioprotection aspects make any intervention (apart from the first installation) critical for ALARA considerations.
The plan for maintenance and reparation must be developed taking into account this aspects too.
More detailed sequence for all these operations are expected at the DDR review.

4) *"Review cryogenic requirements for safety aspects and compatibility of safety equipment with tunnel environment":*

The presentations covered only the cryogenic safety aspects. The design of the DFM is analysed highlighting the most important aspects (operating, design and test pressures, fulfilment of PED requirements, and a 1st risk assessment evaluation).

→ ***RECOMMENDATION N.4****: the DFM design and its technical documentation has to coherently address the point of the design standard applied (PED) and consequent requirements all along the procurement, assembly and testing phases.*
The exact role of HSE should be identified and clarified.
The integration of burst disk, rated valve and relief plates must be done together WP15 and HSE.

5) *"Review plan for detailed design development":*

The design of the DFM will done by CERN in collaboration with SOTON.
When the design completed, CERN will produce the manufacturing drawings which will then be used by SOTON for the procurement.
A Detailed Design Review is planned to be hold around October 2019.

→ ***RECOMMENDATION N.5****: following the presentations, the DFX design plan doesn't show today critical aspects but design is still at initial phase.*

As already mentioned, a DDR Review is planned and the WP6a proposes also to have later a Production Readiness Review (PRR). The panel support this plan.

Very important in the incoming detailed design phase is to address all the important aspects like:

- *Design done considering the accessibility for execution, test and eventual reparation of all critical welds in a "HL-LHC Tunnel configuration" (including necessary mock-up and tooling design and qualification).*
- *Investigate the minimisation of the LHe volumes in the DFM that would be advantageous from several points of view. Evaluate if this reduction of volume could be implemented in the design of the busbars supports.*
- *The specificities of each installation site (IP1 and 5, R and L side) must carefully analyse with the help of WP15 in order to check their eventual impact on the final design.*

6) *"Review schedule for prototype production, including strategy for intermediate validation":*

The pre-series unit of the DFM should be ready by March 2021 (thus one year after DFX). The complete series of DFM should be ready by March 2023.

→ ***RECOMMENDATION N.6****:*

Being the design still at the conceptual phase, a lot of aspects/activities are on-going or planned and need to be carefully implemented. The responsibility of CERN and SOTON must be clearly stated and coherently reflected in the technical and procurement documentation. Those aspects should be fully clarified and presented at the DDR review (not exhaustive list):
- Development and completion of detailed Design and all Technical Specification (by CERN)
- Detailed list of CERN supply (with delivery dates), responsibility for minor tooling procurement shared between SOTON and CERN as well a complete and sound QA/QC plan (by CERN/SOTON)
- Preparation of Procurement Documentation (technical, QA/QC, follow-up, test plan required, etc.) (by CERN/SOTON)
- Final acceptance test (at CERN and by CERN)
- It is not planned to perform a DFM System Test. Looking at the presented time plan it seems that eventually there should be time for that. Considering the importance and critical issues link with the DFM, WP6a should evaluate this opportunity.

→ ***RECOMMENDATION N.7:*** *The strategy and policy for the DFM spares procurement (with the eventual "site specificities") and spare assembly sequence in the Tunnel should be defined and presented at the DDR review.*

Review of Contributions:

1. *DFM in WP6A (**A. Ballarino**)*

Most relevant findings:

- The DFM makes the connection between the Superconducting link and the D2, powering the D2 magnet and its correctors, thus a total of 10 cables (2 x 13kA and 8 x 600A) will have to be routed through the DFM. If compared to the DFX (19 cables), the difference allows for having a conceptually less complex design. However, the tunnel environment is different (no cores, DFM to be placed on top of D2, etc.) so different challenges exist wrt DFX.
- The lambda plate separating the 4.5K and 1.9K baths was moved to WP3 scope, as it had been done with the DFX.
- There is no specific contract for the construction of a DFM prototype as in DFX. The UK-2 collaboration will construct 5 DFM objects, one of them is considered pre-series and it will become a spare for the HL-LHC project.
- It is not foreseen to test the DFM in nominal cryogenic and electrical conditions, as no prototype system test is foreseen for the Matching Section elements (only for the Inner Triplet). However, the critical components of the Matching Section cold powering system (DSHM and HTS current leads) will all be tested individually before installation in the tunnel. The only foreseen tests to be performed on the DFM will be the required acceptance tests which normally apply to cryostats. The knowledge gained with DFX testing will be extrapolated to DFM so WP6A team does not feel the need to fully test the DFM.
- The design of the DFM is being done at CERN, in collaboration with SOTON. Once the design has converged and approved by both CERN and SOTON, CERN will make the manufacturing drawings which will then be handed over to SOTON for Procurement.
- The pre-series unit of the DFM should be ready by March 2021, thus one year after DFX. The complete series of DFM should be ready by March 2023.

Comments:

- The cryogenic requirements of DFM might be similar to those of DFX and the demonstrator used in Demo-1, but the integration and installation is very challenging for the DFM. Assuming that, accordingly to what it was presented, a system test is definitely excluded, at least a mock-up of installation should be considered.
- A discussion took place on cost estimation of the 9 objects which are the scope of UK-2 collaboration for HL-LHC (4 DFX series, 4 DFM series, 1 DFM pre-series/spare). It seems the design of the DFM will not advance significantly until the FC of September. The cost estimation was done by CERN a long time ago, assuming the same complexity for DFM and DFX, so WP6A and SOTON are confident that the global envelope of the agreement is feasible, but SOTON did mention the need to have a matured DFM design before the financial commitment in September.
- The series production is foreseen to finish in March 2023 which leaves more than one year before installation, in components that will not be tested (other than regular acceptance tests) before installation; it is also not clear the need to have the pre-series unit in March 2021 if there is no system test for the Matching Section. All things considered, it is not clear the need to rush into the FC of September 2019 and what would be the implications of going to FC of December 2019, after a Detailed Design Review of the DFM. A more mature design would

allow a more accurate DFM cost estimate which would improve the confidence on the project. It was mentioned that this must be decided at the HL-LHC project level.

Recommendations:

- Investigate the cost vs added value of performing a system test for the cold powering of the Matching Section.
- Perform mock-up of tunnel installation.
- Study the possibility of going to FC of December 2019 instead of pushing for a rushed DFM cost evaluation for September based on a conceptual design.

2. *DFM Functional Specification (**Y. Leclercq**)*

Most relevant findings:

- The DFM Functional Specification is similar to DFX, so only the differences were highlighted.
- The area in which the DFM is located will be one of the most radioactive in the machine due to the proximity of the collimators. The levels of radiation affecting directly the DFM end up being similar to those of DFX. However, given the high slope in radiation levels existing through the length of D2, there will be a significant variation over few meters. Therefore, to define ordinary and extraordinary maintenance operations minimizing impact for people is mandatory in an ALARA approach to the design.
- As in DFX, there will not be any cold feedthroughs, all instrumentation shall be routed to feedthroughs on a dedicated patch panel at the level of the vacuum vessel interface.
- The plug will be in a cryostat directly fixed to the ground, so there will not be induced loads on DFM.
- There will be 10 minutes of nominal supply of GHe in case of LHe supply problems.
- A constant slope between the coldest point and the LHe-GHe interface is needed, which means the DFM must compensate for the different LHC Tunnel slopes in the 4 places of installation.
- All PED Requirements will also be fulfilled with respect to DFM (further discussed in Safety talk).

Comments:

- A discussion took place regarding O-rings and their radiation hardness/tolerance. The O-rings to be used in DFM will be similar to those of the inner triplet, and developed/procured uniformly for the HL-LHC Project by TE-VSC. The foreseen material is Viton (even if PDM might be better). Radiation hardness is being tested by the team of C. Garion. It was mentioned that the levels of radiation are particularly high for electronics but not so high for mechanical interfaces. Nevertheless, the possibility of adding spare O-rings in the vacuum volume should be considered. Also, a careful assessment should be done of the added value of using the best material (PDM) from a radiation hardness perspective, particularly considering the possibility of having to perform unexpected mechanical interventions in highly radiated equipment.
- The different intervention scenarios were presented but no time duration was given. Given the high levels of radiation, it would be wise to study the possible duration of interventions in the LHC tunnel.
- There was no specific presentation of cryogenics, under the justification that the cryogenic flow is the same as the DFX.

Recommendations:

- The possibility of adding spare O-rings in the vacuum volume should be considered.
- Estimate time that different interventions would require so that dose can be evaluated and, if too high, serve as input for design changes.

3. DFM Conceptual Design, including integration and interfaces in the tunnel ***(Y. Leclercq)***

Most relevant findings:

- The DFM has two main vessels, one vaporisation module located on top of the QXL that provides the gas flow to the link, and one cable module where the splices are done in a LHe bath. The restricted height does not allow a safe levelling operation of the splices for a DFX-like design, thus there is the need to place the vaporisation vessel on the side. The connection of the cable module with the SC link is done with an angle of ~20 degrees to allow proper LHe-GHe separation. The SC link has 1.5m of bending radius.
- There is a dedicated jumper (position and configuration not yet fully agreed with cryogenics) for the DFM.
- In terms of vacuum barriers, the link is isolated from the DFM, which in turn is isolated from the interlink via the plug.
- The requirements, functional specification and conceptual design of the interlink is still to be defined. It belongs to WP3 scope.
- The LHe is being injected from the bottom (similarly to DFX) which might cause excessive bubbles which can make operation very challenging.
- There are two gas outputs from the vaporisation vessel, one for the SC link and one for the cool down which is just used in transient.
- The same concept for the IFS used in DFX will be used in the DFM.
- In terms of installation order, the goal is, for now, to be independent of other machine elements (crab cavities, D2, …). The distance between DFM cryostat and D2 is 100mm, which is very tight. It was mentioned that work is on-going with EN-HE to analyse installation sequence and procedure.
- It was clarified that all tooling for installation is part of CERN scope and thus out of the FC of September / the UK-2 collaboration.

Comments

- The interlink will take a long time to cool down, given that it is 8 meter long and with one meter of vertical displacement.
- There seems to be a very high volume of liquid helium in the DFM. The dimensions of the cryostat are perhaps fixed and cannot be further optimized, but it was not clear if the possibility of using proper filling material had been study. Doing so would reduce the LHe inventory, which would be beneficial from operational and safety point of view.
- The thermal gradient on the SC link during cool down should be limited. A. Ballarino mentioned that they are not considering more than 20K per hour in the tests that have occurred in SM18. This raises concerns on the level of balance between gas flows of the two outputs of the vaporisation vessel to guarantee that the SC link does not cool down too fast. It is recommended to add temperature sensors on the entry of the link.
- It was not clear how the overflow of the SC link would be avoided.

- There are differences in integration on each of the 4 locations, with different height of the beam line and the cryogenic line, different slopes, different tunnel areas and different services present. All these must be taken into account as they might impact the design.
- The full list of instrumentation and strategy for V-taps will be discussed through MCF, but the global strategy of Machine Protection is to force redundancy on protection V-taps but not necessarily on monitoring V-taps.
- The list of pending points of the functional specification seems sufficiently big to think about not going to the FC of September but December.

Recommendations

- Study possibility of reducing LHe inventory through use of appropriate filling.
- Study possibility of adding temperature sensors on the entry of the SC link to make sure it is not cooling down too fast.
- Show feasibility of conceptual design in all 4 locations of the LHC tunnel.

4. *DFM Safety Aspects* ***(V. Parma)***

Most relevant findings:

- Only cryogenic safety was mentioned.
- In the vaporisation vessel there is one burst disk and one pressure relief device.
- In the cables vessel, there are 2 pressure relief vessels, on either side of the vacuum barriers.
- The helium cold volume is 360 litres, with a design pressure of 2.5bara. This makes Ps x V=900 bar.L, which falls within Category II of the PED standards. This is more relaxed in terms of inspections and quality requirements than the DFX, but HSE is still required as notified body and design and qualification will be done accordingly to PED directives.

Comments

- The bursting disks and relief valves should be integrated in such a manner that they do not pose risks to neighbouring equipment, or diverters must be used.

Recommendations

- Study how to accomplish safe release of Helium in the tunnel.

5. *Production Plan* ***(Y. Leclercq)***

Most relevant findings:

- CERN is directly responsible for all the Design Phase, in direct collaboration with SOTON. The design phase should be approved by a Detailed Design Review.
- The Manufacturing preparation phase, which should be validated through a Production Readiness Review, is responsibility of SOTON via UK-2 collaboration.
- The Manufacturing is responsibility of SOTON, with CERN approving the proper qualification of the series equipment.
- Installation in LHC tunnel falls within CERN responsibility.

Comments

- It was clarified that MTF upload of manufacturing phase is within SOTON and its subcontractors.

- It was confirmed that the CERN resources are available and seem enough to do the work planned.
- There was a discussion regarding acceptance tests of the series units. These acceptance tests did not seem fully defined from the reviewers point of view.

Recommendations:

- Fully define acceptance tests for DFM series.