"DFX Detailed Design Review" Report

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This document reports the outcome of the *"DFX Detailed Design Review" (DDR)* held on **20 June 2019** (https://indico.cern.ch/event/821876/)

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 follows:

Scope: Review the detailed design of the DFX with the purpose of validating maturity and confirm readiness for starting production of the prototype DFX.

Mandate of the Review Committee:

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

2) Review the detailed design wrt cryogenic design and operational aspects, mechanical design and interfaces, electrical design and interfaces;

3) Review the integration and installation sequence in the LHC machine and the compatibility of the DFX location wrt the tunnel environment (including 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 and schedule for prototype production, including production of prototype lambda plate;

6) Review strategy and plan for QA and QC, as well as plan for intermediate and final acceptance tests.

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

Scientific Secretary: M. Mendes

Presentations:

- *Welcome: Luca Bottura (CERN)*
- *DFX in WP6a, Master Plan, Speaker: Dr Amalia Ballarino (CERN)*
- *Follow up from Conceptual Design Review, Speaker: Vittorio Parma (CERN)*
- *DFX Functional specification, Speaker: Yann Leclercq (CERN)*
- *DFX Final cryogenic cooling and flow scheme, Speakers: Antonio Perin (CERN), Serge Claudet (CERN)*
- *DFX Detailed Design–including production plan, assembly steps, cryogenic instrumentation, connectivity and routing for electrical instrumentation (IFS) and aspects for maintenance and repair in the LHC underground areas, Speaker: Yifeng Yang (University of Southampton (GB))*
- *Manufacturing Plan; Intermediate and Final Test Plan; Acceptance tests, Speaker: Yann Leclercq (CERN)*
- *Integration of DFX in the LHC tunnel, Speaker: Maria Amparo Gonzalez De La Aleja Cabana (CERN)*
- *Transport and installation of DFX in the LHC underground areas, Speakers: Robin Betemps (CERN), Vittorio Parma (CERN), Yann Leclercq (CERN)*
- *Mechanical interfaces of the DFX to the SC Link, Lambda-plate and DCM, cryogenic equipment, Speaker: Yann Leclercq (CERN)*
- *Status of CAD drawings, Speaker: Yifeng Yang (University of Southampton (GB))*
- *Design and integration of safety equipment and safety aspects in the LHC tunnel, Speakers: Thomas Otto (CERN), Vittorio Parma (CERN)*
- *Electrical requirements of DFX components: specification and tests, Speaker: Amalia Ballarino (CERN)*
- *Instrumentation requirements and Busbars in DFX, Speakers: Jerome Fleiter (CERN), Dr Simon Hopkins (CERN)*
- *DFX Technical Specification status and QA/QC aspects, Speaker: Yann Leclercq (CERN)*

Acknowledgement

The Review Panel would like to thank all 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.

Executive Summary:

Context and main remarks:

The Review Panel would like to acknowledge the good design advancement of these last 4 months (after the 1st Conceptual Design Review (CDR) of end of January) towards a more detailed design of the full system.

After the CDR it was decided to submit the "UK-2 Agreement" for the collaboration with Southampton University (SOTON) to the Finance Committee (FC) of September 2019 (instead of June 2019). This seems very positive, since should permit to arrive at the FC submission phase with a more complete and validated technical documentation (Functional Specification, Interface Specification and Technical Specification).

The DFX 3D detailed model was developed by SOTON colleagues in close collaboration with CERN. The SOTON resources allocated to the project are limited and it is now urgent the production of the complete folder of 2D drawings "for Tendering". It was reported that there is a plan, with resources already allocated, to proceed on this task with CERN resources (Design Office). The Panel supports this

plan; it should allow a faster and more efficient finalization of the technical design phase and so moving to the next critical phase: the prototype procurement.

A part-time presence of SOTON colleagues at CERN seems nevertheless necessary to finalize in a more efficient way the last open points (e.g. final technical design details, assembly and maintenance plan and sequences compatible with integration in HL-LHC Tunnel, etc.). During the Conceptual Design activities phase, it seems that the presence of SOTON colleagues at CERN has worked very positively. The collaboration already provided a solution for hosting a representative from SOTON at CERN, and a similar solution seems to be available also for this second phase.

Concerning the Procurement phase, the Review would like to stress the importance to have adequate resources allocated by SOTON for the industrial follow-up phase.

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

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

The Functional specification (as well as the Technical specification and Interface specification) DRAFT presented, seems clear and close to completion. With respect to the 1st Review (CDR) report, several points are now clearly specified; e.g. the number of required dismounts (main welds) was clarified (5 times); the minimum operation time without LHe supply was clearly specified and sized in the cryogenic scheme (10 minutes); the interface with the WP3 (Lambda-plate) is now officialised, etc.

→ ***RECOMMENDATION N.1:*** *Pursue on the finalization of the reference documents (Functional, Interface and Technical specifications), interacting with ALL interfaces (WP9, WP15, WP3, WP17.1, HSE, etc.) in order to have these documents fully checked and approved possibly BEFORE the FC of September 2019.*

2) *"Review the detailed design wrt cryogenic design and operational aspects, mechanical design and interfaces, electrical design and interfaces":*

I. The cryogenic design developed and presented during the CDR was consolidated. All functionalities seem correctly addressed and sound. There are still some details to be clarified in order to proceed with the detailed design "for manufacturing".
Interfaces with other WPs and services seem correctly addressed.

→ ***RECOMMENDATION N.2:*** *Finalize the last open questions of the conceptual and cryogenic functional design e.g. (not exhaustive list, please refer also to the "Contribution Review" section):*

- *The decision on the redundancy of the LHe heaters (to provide the GHe for DSHX cooling)*
- *The routing of some cryogenic lines (e.g. return of GHe shielding) is not coherent throughout the cryogenic and mechanical conceptual DFX schematics presented.*
- *Converge on the definition on an appropriate He operation pressure (higher if possible), question seems still to subsist:*

  The choice of the design pressure of the cryogenic system, now set to 2.5 Bara, seems low, but it is driven by the design pressure of the DSHX. → Finalize this point among WP6a, WP9 (and HSE) in order to possibly set a higher final design pressure for the whole system (DFX-DSHX-DFHX) considering the specificity and priority for each

subsystem: safety of personnel in UR, safety of equipment in UL and LHC Tunnel, reliable operation of the cryogenic system, and considering ALARA approach to minimize the number of interventions (e.g. changing burst disks, etc.).

- *Evaluate the risk of thermo-acoustic oscillations' cooling effect and ice formation on the safety devices on the final cryogenic layout.*
- *The thermal gradient in the DSHX during cool down is a critical working aspect. It is recommended to carefully check that all needed instrumentation (e.g. temperature sensors) to correctly control the cool-down phase is present in the DFX-DSHX system.*

II. The mechanical design development was presented. Since the CDR review, a lot of aspects have passed through further analysis and detailed design and amelioration.

→ ***RECOMMENDATION N.3****: Finalize the mechanical design of the system/components. Finalize points like (not exhaustive list, please refer also to the "Contribution Review" section):*

- LHe inlet pipe into the "fountain": optimize the piping routing and shape in order to minimize the presence of double-phase He.

- He inlet connection: flexible pipes and cryostats are proposed, it seems that there is room to improve reliability and safe operation with a more "hybrid" design (rigid + flexible parts and connections).

- "O-rings" reliability is a critical issue due to the difficulties linked to any special maintenance or worst (reparation). → Discuss with VSC Group the procurement of "the best possible" O-rings (not the "just appropriate" ones) considering reliability and withstanding to radiation.

- Some welds of the DFX inner part (e.g. weld #3) will be technically very challenging, so becoming indeed a critical issue of the system. → Plan to validate all the critical welds with full size mock-ups and during the system tests recreating the real environment and space constraints of the HL-LHC Tunnel.

- Check the computation and design wrt the finally chosen design pressure value (see previous Recommendation) and versus the Pressure Equipment Directive (PED) requirement. PED must remain the reference standard for the design.

- A reduction of the LHe volumes in the DFX horizontal part would be effective from several points of view. This reduction could be implemented easily with filling pieces (eventually integrated in the busbars supports still to be finalized). Consider this point in the further detailed design development.

- Regarding the 3D Model, SOTON shall provide the mechanical analysis and assessments following to PED requirements (and its related harmonised standards) in order to fulfil the technical and HSE requirements.

- Review the vacuum barrier rod support system that seems complex for the assembly sequence and with potential issues (leak tightness).

- Make, as soon as possible, the transition from conceptual design to a design to cost (i.e. include manufacture reliability, manufacturing techniques, cost implications).

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

HL-WP15 “Integration” is providing a constant follow-up and support to WP6a in order to develop a DFX design compatible with the HL-LHC constraints and boundary conditions. This aspect is critical since DFX installation region will be a completely NEW region from civil engineering and extremely crowded by future equipment installation points of view. WP15 has started “ad hoc” meetings to follows these questions (for DFX and DFM). It is essential to get all concerned Teams participating actively to these meetings/discussion.
Furthermore, the required final assembly of the DFX “in situ” implies a delicate integration aspect that concerns: available space, assembly tooling manipulation and sequence of integration of neighbour equipment (D1, QXL, DSHM, etc.). During the review the specificities of the 4 different installation sites were highlighted. It was also clarified the share of responsibility between SOTON and CERN as concerning DFX design and assembly sequencing and procurement of assembly tooling for the installation in the HL-LHC Tunnel (it was confirmed that the installation of the DFX in the tunnel is responsibility of CERN).

→ ***RECOMMENDATION N.4****: For the DFX design finalization phase it will be critical a tight collaboration between WP6a and WP15–Integration with all other concerned Teams in order to finalize the design in a compatible manner with the HL-LHC Tunnel configuration and neighbouring equipment and services.*
The general assembly sequence (for system test and in the HL-LHC) was presented, there is a major open point concerning the assembly of the DFX with the DSHX (the vertical “lowering and raising” manipulation with consequent loads and charges on the system’s main components):

- *As discussed after the review, the present design makes the complex installation sequence not the safest from the handling point of view and does not minimize the risk of future intervention (ALARA approach). The need to “lower and rise” the assemblies is driven by the need to get adequate space for weld #3. The actual space seems too tight to correctly perform the weld.*
- *Analyse and evaluate if in the locations where integration deems it necessary, space could be safely gained. This could be done with an eventual adaptation of the core/LHC tunnel vault interface design, proposing an enlargement of the end part of the core. Discuss this possibility with WP15 and WP17.1.*

The sequence for standard and exceptional maintenance intervention, the development of dedicated tooling, the sequence of neighbouring equipment installation (or de-installation in case of maintenance/reparation) was not yet analysed/developed. These aspects become now critical issues in order to validate the DFX design in terms of assembly and maintenance feasibility. We remind and aware that radioprotection aspects make any intervention (apart from the first installation) critical for ALARA considerations. The Panel recommends to complete the analysis and the consequent design and sequencing.

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

The presentations covered the cryogenic safety aspects (only). With respect to the CDR review, there was a revision of He volumes and the design operating pressure is now proposed to be 2.5 Bara.
With those values, the equipment is now well inside Cat. 3 of PED standard (before it was more at the limit Cat 3-4). HSE was present at the Review, clarifying that, if asked and if necessary, they could act as the “de facto” Notified body, and assume the associated equivalent responsibility and authority (as stated and described in the HSE Memorandum *(EDMS 1698982).*

→ ***RECOMMENDATION N.5****: the DFX 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 role of HSE must be clearly discussed and clarified as soon as possible.
The integration of gas deflectors in the design is a critical integration aspect and should be address and discuss with HSE and WP15 (for their integration in the crowded Tunnel regions).

5) "Review plan and schedule for prototype production, including production of prototype lambda plate":

The "plan&schedule" should consider finalization and procurement of different type of deliverables and equipment:

- General Documentation (e.g. Functional and Technical Specifications, needed for FC and then for industrial procurement and assembly at SOTON and at CERN)
- Technical Documentation (e.g. components drawings folder "for procurement").
- Special components (e.g. IFS systems, lambda-plate, busbars). During the review, the status of the IFS (instrumentation) design and procurement as well as the lambda-plate were discussed (a full scale lambda-plate mock-up was shown).
- Some of the electrical components or aspects linked to them (e.g. the IFS procurement and the redundancy of the instrumentation cablings) are planned to be discussed at the MCF forum.
- The global DFX procurement and testing plans were presented. Some contingency is present in the estimation of the start of LS3 installation phase for WP6a (assumed in Jan 2024 but in reality not possible before the Fall 2024).

→ ***RECOMMENDATION N.6****: at the moment the DFX procurement doesn't show critical aspects.*
A detailed list of supplies (with delivery dates) from CERN and responsibility for minor tooling procurement shared between SOTON and CERN should be established in the Technical Specification.
The procurement of the series components is planned to start before the System Test (i.e. test of the prototype at SM18).
The Review recommends to analyse the possibility to start the series procurement AFTER the System Test (following the presented plan this seems feasible), allowing in such a way the possibility to bring minor modifications to the DFX series design if the System Test performance deems it necessary.
Important aspects concerning prototype production to be fully addressed in the future follow-up plan are:

- *Qualification of all critical welds in a "HL-LHC Tunnel configuration" (including necessary mock-up and tooling test)*
- *On the presented "qualification sequence table", it seems that electrical tests are absent. Even if they will be partial (due to the absence of MgB2 and NbTi leads), plan anyway to include all the possible electrical checks (instrumentations, insulators, etc.) in the qualification list.*
- *An appropriate planning for the tooling procurement should be done in order to use the system test and string test as a validation for the Tunnel installation, which means all tooling must be available for the system test. The cutting machines (since the prototype will become a spare) should also be available by that time.*

WP6a proposes to have in due time a Production Readiness Review (PRR) for the DFX procurement.
The Panel strongly support this proposal.

6) *"Review strategy and plan for QA and QC, as well as plan for intermediate and final acceptance tests":*

The QA and QC plans are under definition. A (not exhaustive) list of QA requirements with reference to applicable standards was presented, as well as reference to other general applicable standards, like PED, EN12300 (cleaning requirements), MTF (for documents traceability and follow-up). All these aspects will be part of the finalization of the TS that is undergoing.

The Intermediate and Final test plans are under definition too. The responsibility between SOTON and CERN seems clear considering also the different assembly phases and consequent test plans: in industry (under SOTON supervision), at SM18 (for system test and on the String), and finally in the HL-LHC Tunnel.

There is an open point regarding the DFX acceptance test:

1. The baseline (CERN) is to weld the full DFX assembly in order to perform full leak and pressure tests. This configuration would be fully representative of the final object, providing an accurate check on the forces and stresses of the real object. This should be done in industry, and the test reports would be part of CERN's acceptance criteria.
   SOTON proposes an alternative plan, where the final assembly test in industry is done without welding the main subcomponents, but with the use of bolted joints tested by clamshells. This would allow saving the cut of one weld, but CERN does not consider this option fully representative of the real assembly.

→ ***RECOMMENDATION N.7****: It will be essential to clarify the exact responsibility, technical requirement (sequence and tests) for the different assembly scenarios:*

- *in industry (under SOTON supervision);*
- *at WP6A System Test;*
- *at the following installation on the String;*
- *and finally in the HL-LHC Tunnel.*

The final agreement on how acceptance test in industry will be conducted (assembly with clamshells vs welds) should be found.

A complete QA/QC plan must be agreed between CERN, SOTON and HSE for the pressure vessel requirements and implemented in the TS

→ ***RECOMMENDATION N.8:*** *As already remarked at the CDR review, the strategy and policy for the DFX spares procurement and spare assembly in the Tunnel must be properly defined and included in the procurement strategy.*
In the current plan the prototype will become a "universal DFX spare", but it must still be proven that it is not necessary to have specific spare components to then assemble the "Right" or "Left", "IP1 or IP5", spare, since the layouts in the tunnel (connection to QXL, and other cryogenic connections.) are specular.
Also the different tunnel slopes at IP1 and 5 and between R and L sides, could create variants that must be analysed if compatible with only one spare type.

Since the DFX spare is the prototype that will be used in WP6A system test and String test (thus welded and cut 3 times), a reconditioning of the flanges subject to welds will be necessary to prepare it as an appropriate spare.

Review of Contributions:

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

Most relevant findings:

- The DFX prototype, scope of UK1 contribution to HL-LHC by Southampton University (SOTON), is planned to be delivered in March 2020. This DFX prototype is also a spare unit for HL-LHC.
- The UK2 contribution to HL-LHC project will consist of the 4 DFX series units, 4 DFM series units and 1 DFM spare. The current plan is to approve the funding of these 9 objects in the Financial Committee (FC) of September 2019, which means the collaboration has to be fully confident that they can build the 9 objects within the funding presented in September.
- The DFX prototype will be tested in the SM18 at the end of 2020 as part of the system test of all WP6A components that provide cold powering to the Inner Triplet. The installation for the system test will start a few months earlier. The delivery by SOTON in March 2020 is not absolutely strict and one or two months of delay are acceptable without compromising the system test planning.
- The λ-plate that was presented in the Conceptual Design Review (CDR) as part of the WP6A scope was moved to the scope of WP3 under the coordination of Ezio Todesco. Physically, it will be integrated in the diode cold module (DCM).
- In the CDR, it was presented the goal of going to the FC of June 2019. This was not done and the current goal is to go to FC of September 2019.

Comments:

- There was a discussion on the string program and how to profit of this test for the DFX. A. Ballarino confirmed that the DFX prototype will be used in the string which means the string configuration in SM18 will have to adapt to the DFX vertical configuration. Work is still on going with WP16 team, but WP6A wants to maximize the usability of the string to test as much as possible everything related with DFX, thus including the restrictions imposed by the LHC tunnel.
- The system test will be completed when the series production of the components will be on-going, and no time window is foreseen today in the WP6A master schedule to allow for eventual corrections/changes in the series based on results of the system test.
- It was understood that the functional specification and technical specification of the DFX must be the supporting documentation to go to the FC of September: this has to be clarified and confirmed, in particular concerning the technical specification.

Recommendations:

- Pursue the works to use system test / string assembly in SM18 to replicate installation in the tunnel, using the same tooling, imposing the same space constraints for the welding, etc.

- Investigate the inclusion of a buffer time before the series production to allow for changes that would be identified based on the results of the system test.

2. *Follow-up from Conceptual Design Review (**V. Parma**)*

Most relevant findings:

- Regular meetings have been established with WP15/Integration to converge on Integration.
- The resources of SOTON are, for the moment, 2 engineers and 1 technician (part-time). The UK-2 collaboration foresees additionally funding for 2 fellows, part of the time of the present 2 engineers, and in addition 1 full time technician.
- The vacuum barrier position was not changed following the recommendation of the CDR to review its position; discussions took place with TE-VSC and WP6A is convinced that the current position of the vacuum barrier, although not ideal, is the best.
- A new document covering all instrumentation needs of 6A has been prepared and MCF is now involved in the discussions.
- There is no technical design report nor manufacturing drawings at the level of this Detailed Design Review.
- The spare policy is still not fully developed since differences between different IP sides have not yet been studied / reflected on the current policy of having only one spare DFX.

Comments:

- The resources of SOTON that are working on the design of such challenging equipment (DFX and DFM) seem perhaps underestimated, mainly considering the procurement follow-up phase.
- There are still missing points to be defined of key auxiliary components of the DFX, like the cryogenic jumper or full definition of MLI blankets.
- The spare policy must be reviewed to account for differences between IP sides.
- Some of the previous CDR recommendations are still pending follow-up.

Recommendations:

- Complete (or answer justifiably, if there is no agreement) all CDR recommendations;
- Evaluate the possible shortage of resources on SOTON side;
- Fully complete the design of DFX and its ancillaries;
- Review spare policy to incorporate differences between IP sides.

3. *DFX Functional Specifications **(Y. Leclercq)***

Most relevant findings:

- New specification on mechanical interfaces: the DFX shall be assembled and disassembled up to 5 times.
- By moving the plug to the DCM, the loads are taken by the DCM cryostat. This relieves the design constraints on DCM.
- There has been an increase of estimated heat loads to the liquid helium from 20W to 30W.
- Electrical heaters were added at the lowest position of the vessel for Liquid Helium (LHe) vaporisation during warm-up.

- It was defined to have 10 min of nominal supply of Gaseous Helium (GHe) to the SC link, and immersion of MgB2-NbTi splices, in case of liquid supply stop;
- There are still discussions on going regarding having an outlet magnet line included in the DFX jumper.
- A new chapter about integration was added to the Functional Specifications.

Comments

- The output magnet cryogenic line was shown here as under discussion but it was not included in the cryogenic flow presented afterwards in the review; both schematics should be coherent.

Recommendations

- Mention the following aspects in the functional specification:
  - Safety: PED requirements; safety of the DFX itself but also the surroundings;
  - The reviewers do not see in the document that the DFX has to be dismountable and re-mountable 5 times as said during the presentation.

4. *DFX Final cryogenic cooling and flow scheme* ***(A. Perin)***

Most relevant findings:

- Double concentric bath system is now an agreed concept;
- The thermal shield of DFX was removed, allowing a reduction of the jumper vacuum jacket. However, lines E and F are still needed for the GHe heater (redundancy with respect to electrical heaters).
- The low design pressure revised to 2.5bara can be a challenge in terms of overpressure protection and operation; TE-CRG team is not particularly satisfied with this choice.

Comments

- The output magnet cryogenic line is not included in the cryogenic flow presented, but it is included in the functional specification talk. The schematics should be coherent;
- A discussion took place regarding the added value of the redundant GHe. The position of WP6A is that the GHe heater should be qualified, tested and validated before taking the decision of adding it to the DFX prototype, while WP9 insists that it is important and relatively easy to have it.
- The design pressure of 2.5bara is indeed low, it will create operation challenges, but it is in fact manageable.

Recommendations

- Include the GHe heater as redundancy to the electrical heaters;

5. *DFX Detailed design – including production plan, assembly steps, cryogenic instrumentation, connectivity and routing for electrical instrumentation (IFS) and aspects for maintenance and repair in the LHC underground areas* ***(Y. Yang)***

Most relevant findings:

- A top flange was added to facilitate hose connection and to align DFX during installation. The design foresees at the moment that the 4 lines coming from the cryogenic jumper are integrated in flexible lines, passing through the top flange and entering the dome-like superior part of the DFX.
- The vacuum break structure was revisited and it incorporates now a convoluted profile and pillars were added to give the assembly additional rigidity, forming a cage structure. This external solution minimizes the heat load impact. The vacuum barrier is also used as fixed point mechanical support.
- A weld prep for cutting in case of major repairs to be done in the tunnel was added.
- A buffer was added on the vacuum vessel to limit the bending moment of the vertical vessel during the PED test pressure of 3.5bar.
- The IFS box is integrated in the horizontal part of the DFX. All the routing of the instrumentation (from vertical and horizontal parts of the DFX) is done to this point.
- In the transition to the horizontal part of the DFX, after the elbow, it was necessary to include an eccentric cone section, which reduces the elbow opening to the nominal bore of the horizontal section of 350mm.
- The NbTi-NbTi splices are done inside the splice box, which can be exposed by sliding the outside vessel towards the plug into a parking position.
- Several design studies were presented to validate the design choices.
- The Quality assurance plan was presented, confirming the pressure qualification at the required level of all parts and components of DFX (cold tube sections with welded flanges required for the integration) and DFX sub-assemblies (upper vertical inner vessel, and IFS subassembly). The mock-up assembled DFX module will go through a cryogenic shock test, vacuum tightness test and pressure verification. The welding to be performed by CERN during LHC tunnel integration will be clamped via metal O-rings.
- The sequence of assembly in five main steps was presented, together with the 8 in-situ welds needed. The DFX installation sequences imposes the DCM already installed. All welds will be individually leaked tested and properly qualified using clamshells.

Comments

- The reliability and feasibility of having the flexible pipes for the cryogenic lines was discussed and it was mentioned the possibility to integrate them in rigid pipes. It was understood that some flexibility is required by the designers next to the connection on the top flange, but it could be studied the use of rigid pieces.
- The pressure considered for the vacuum scenarios of the design studies was 1 bar while it should have been 1.5bar since 1 bar is only at commissioning.
- The insertion of the SC Link in the vertical DFX upper section might need revision/agreement between SOTON and CERN since lowering the link to perform weld nr 3 and sustaining the system on the link might create unacceptable charges.
- Risk of thermo-acoustic oscillations' cooling effect and ice formation on the safety devices had been identified in the CDR and it was re-discussed again, as it seems that it was not addressed between the CDR and this DDR.
- It was confirmed the existence of welds cutting machines for the presented welds.

Recommendations:

- The volume of LHe could eventually be further reduced with the addition of fillings in an appropriate material.

- The liquid inlet position on the bottom of the vessel could form bubble gas inducing complications in operations. It could be studied the possibility of integrating it on top.
- It should be studied the inclusion of spare O-rings and the radiation tolerance of the O-rings to be used.
- It should be demonstrated in a mock-up assembly the feasibility of the most difficult welds, particularly weld #3. If this weld is too difficult and space is not available, evaluate the possibility to have an adaptation of the geometry of the core to provide the extra space needed. This could avoid the manipulations of the SC link.
- The design studies performed should be redone with the proper external pressure of 1.5bar.
- As general suggestion, keep the design and implementation as simple and standardized as possible, putting emphasis on the development of adequate tooling, pre-qualification and string tests.

6. *Manufacturing Plan; Intermediate and Final Test Plan; Acceptance tests* ***(Y. Leclercq)***

Most relevant findings:

- There is a clear list of items supplied by CERN for the production of the DFX, presented in chapter 7 of the technical specifications (items for insulation vacuum, cryogenic instrumentation, instrumentation feedthroughs, etc.), to be integrated during production of the components / subassemblies.
- All components will be delivered to CERN compliant with PED requirements (in terms of tests reports and documentation).
- It is CERN responsibility to qualify the weld procedures and welders for the specific 8 welds required during installation.
- The required qualifications for CERN acceptance of the DFX prototype and series were presented.

Comments:

- The tooling used to weld the DFX components during the system test and string should be the same that will be used in the tunnel, which means all tooling must be available by end of next year. The cutting machines (since the proto will become a spare) should also be available by then.
- Discussions on how to comply with PED standards took place during the safety presentation so specific discussions on this topic are included on that section of the report.
- SOTON and CERN do not agree with the way acceptance tests will be done. SOTON proposes to perform the acceptance test in industry without welding all components into their final DFX form. Instead, they want to use clamshells to put the components in their final place and perform subsequently the leak and pressure testes. This approach allows saving one weld, but on the other side the tests performed are not as complete as those done in the final welded assembly (not all forces are present when the assembly is clamped, the thermal behaviour of the welds cannot be accessed, etc.). CERN's baseline would be to do, in industry, a full assembly of the DFX so that the tests include as many features as possible and the tested assembly is as close as possible to the final one. Doing this also serves as a "feasibility of assembly" test. Agreement on the strategy to be followed must be taken.

Recommendations:

- Agree on the best strategy for the acceptance tests (full assembly welded vs clamped). If the full assembly is clamped for the acceptance test, a careful study on how to account for extra forces (that appear only when welding) should be done.
- On the presented "qualification sequence table", it seems that electrical tests are absent. Even if they will be partial (due to the absence of MgB2 and NbTi leads), anyway plan to include all the possible electrical checks (instrumentations, insulators, etc.) in the plan.

7. *Integration of DFX in the LHC tunnel* ***(M. Amparo)***

Most relevant findings:

- Differences between the four locations where the DFX will be installed were highlighted: different slope between sides of the same IP, different beam heights of IPs, different tunnel sections.
- The work methodology followed by Integration team was presented.
- At the moment, the integration seems globally feasible but experience shows that problems often appear with the integration of the "ancillaries", with accessibility considerations and supporting systems integration (none of these are yet known or fully defined).

Comments:

- Concerning expected interventions in the Tunnel, to be reminded that today's baseline is: interventions during Technical Stops (TS) should be considered exceptional. Standard and preventive maintenance should be performed during YETS, not during TS. This aspect has to be implemented in the ancillaries design.
- TE-CRG Team is studying a possible platform on the T-module of QXL that could be useful also for DFX installation and maintenance.

Recommendations:

- Study and provide as soon as possible to WP15 the "ancillaries" systems, their space requirements and the DFX supporting systems design. The integration of the new proposed solution for the safety release valve and burst disk seems critical and to be study with high priority.
- The needed space for routine maintenance and for extraordinary maintenance should be defined together with the design evolution and presented to the technical meeting with WP15

8. *Transport and installation of DFX in the LHC underground areas (****V. Parma****)*

Most relevant findings:

- It was clarified that it is CERN responsibility to study everything that is related with tunnel installation.
- Clamshells will have to be developed for intermediate testing and validation of all welds.
- The sequence of installation presented by SOTON was presented considering the tunnel environment and constraints become clearer: the cryogenic line, the DCM and some services (e.g. cable trays) will be in place at the time of installation.
- For the moment there is no clear preference on order of installation of the two SC Links.

Comments:

- The discussion on how to weld the SC link inner wall to the DFX inner vessel continued, it seems that the space available to perform the weld nr 3 in the option presented by SOTON is very tight.

Recommendations:

- ➢ It is recommended to study and review the steps of installation concerning the assembly of the SC link to the DFX (lowering SC link vs lowering the plate).
- ➢ The support of the SC link on the core during the installation phase (before it is mechanically linked to the DFX supports) should be carefully investigated.

9. *Mechanical interfaces of the DFX to the SC Link, Lambda-plate and DCM, cryogenic equipment (**Y. Leclercq**)*

Most relevant findings:

- The design of supports between bus bars was de-scoped from the prototype deliverables of SOTON.
- A demonstrator of the plug was presented. The plug prototype production is ongoing.
- The IFS will contain 3 flanges and 5 tubes sorted by functions (V-taps, T-wires and power).
- A conceptual proposal for supports design to ceiling and ground is being discussed, the interface with Civil Engineering on top is through threaded blocks.

Comments:

None.

Recommendations:

None.

10. *Status of CAD Drawings (**Y. Yang**)*

Most relevant findings:

- It is proposed that the generation of 2D drawings will be made by CERN EN-MME resources, using the 3D model from SOTON and a software to convert automatically most of the features from 3D to 2D.
- The procurement and manufacturing design will be based on the 2D drawings. The components and parts will be procured in batches instead of a single package.
- Procurement work with visits and discussions has started.

Comments:

- EN-MME confirmed the resources needed are available and that the estimation done is correct for the task.

Recommendations:

None.

11. *Design and integration of safety equipment and safety aspects in the LHC Tunnel (**V. Parma**)*

Most relevant findings:

- Only the cryogenic safety aspects were discussed.
- A design pressure of 2.5bara for the DFX helium volume is now considered, to align with the design pressure of the SC link.
- There has been a reduction of helium inventory and the insulation vacuum volume.
- With the updated values, the DFX falls now safely within Cat. III of the PED (in the CDR it was close to the CAT IV limit).
- The safety devices were properly sized with conservative estimates;
- A rating valve was added to avoid unnecessary/accidental bursting in case of pressure fluctuations.
- The DFX is considered an mSi since it contains pressure vessels that do not possess a CE mark.

Comments:

- CAT III of PED involves a third party organization to certify the design of the equipment, the manufacturing and the qualification. HSE can assume the role of *de facto* notified body as requested by the PED, if the HL-LHC project formally requests so, as it was done for equipment of other Work Packages (WP3, WP11). HSE will require that all PED directives are followed (documentation, tests and qualifications). A list of tasks will be soon agreed upon between WP6A and HSE, defining who needs to do what and when.
- The eventual need of deflectors, which seems necessary to avoid spilling helium on the concrete of the tunnel/core and other neighbouring equipment, was an issue identified at the time of the CDR but remains unaddressed.
- Similar observations go to the issues with thermal-acoustic oscillations given the reduced length of the safety valve.

Recommendations:

- Include HSE requirements derived from PED on the technical specification.
- Study the integration of deflectors.
- Address thermal-acoustic oscillations.

12. *Electrical requirements of DFX components: specification and tests* ***(A. Ballarino)***

Most relevant findings:

- It has been clarified that the routing of the Vtaps of the SC link are also done through the IFS existing in the horizontal part of the DFX
- To integrate the IFS box in the DFX prototype, the IFS should be ready towards the end of this year. It is a CERN supply to SOTON. It remains to be decided if IFS connectors are included on the supplied IFS. The wires will be integrated but not connected.

Comments:

- Discussions with MCF are currently on going to finalize the electrical requirements, so these must be finalized as soon as possible to make sure there is no impact on the prototype plan.

Recommendations:

None.

13. *Instrumentation requirements and busbars in DFX (**S. Hopkins**)*

Most relevant findings:

- The electrical protection requirements are implemented with voltage taps monitoring and protecting individual splices of the 19 circuit branches.
- Cryogenic instrumentation is also included (temperature probes, level gauges, pressure gauges, 1 heat exchanger and 4 resistive heaters).
- There is no vacuum instrumentation routed in the vessel.
- It was decided to use round bus bars for the SC link. The present design includes a double bend S shape in the transition from vertical to horizontal. The feasibility of such bend has been demonstrated. The hot spot temperature during quench remains below 100K as required.

Comments:

- The baseline does not foresee redundancy on the v-taps dedicated to monitoring. This should be clarified under the discussions taking place on the MCF.

Recommendations:

- Feedthroughs for voltage taps: an external procurement line should be activated as soon as possible since their design might be complicated. Other HL WPs need the same type of product. Coordinate the design through MCF forum.

14. *DFX Technical Specification status and QA/QC aspects **(Y. Leclercq)***

Most relevant findings:

- The Technical Specification is being finalised including all aspects that are relevant for the DFX production in the frame of the CERN-SOTON collaboration.

Comments:

- The Technical Specification mentions generally the CE certificate but since this is not applicable to all components, it could be substituted by the list of HSE requirements.
- The Technical Specification includes the radiation tolerance and hardness of the materials but it should also mention neutron fluence.

Recommendations:

Include neutron fluence and list of HSE requirements in the Technical Specification.