Report of the Preliminary Design Review (PDR) of the ATLAS Strips Local Supports Cores and Module Loading

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1. Introduction

The Preliminary Design Review (PDR) of the ITk Strips Local Supports Cores and Module Loading was held on October 1st 2018, with the agenda listed in Appendix A and available at https://indico.cern.ch/event/734211/

The review panel was composed of:
- J.Batista (CERN)
- D.Ferrer (UNIGE)
- S.Michal (UNIGE)
- O.Rohne (U Oslo)
- E.Vigeolas (IN2P3)
- Review Office: Mar Capeans (CERN) – Chair
- Ex-officio: K.Einsweiler (LBNL), B.Gorine (CERN), T.Affolder (US), S.McMahon (UKRI-STFC)

The basic mechanical building block of the ITk Strips system is called a stave in the barrel region, with petals being the equivalent structure for the end-caps. This mechanical building block consists of a low mass central stave/petal core that provides mechanical rigidity, support for the modules, and houses the common electrical, optical and cooling services. All the power and data links are channeled through an End-of-Substructure (EoS) card, which forms the interface to the outside. The so-called Module Loading is the process of bonding the modules onto the Local Support structures.

The review covered the stave and petal cores, the mounting of modules/EOS, and the electrical, thermal and mechanical evaluations of the loaded staves and petals.

The review panel received the Specifications documents for Petal Cores (EDMS AT2-IS-ES-0011), Stave Cores (EDMS AT2-IS-ES-0005) and Module Loading (EDMS AT2-IS-ES-0001), complemented with a comprehensive list of documents and drawings.

The panel was requested to verify that prototype designs of the Local Supports and Module Loading process meet all aspects of the specifications, demonstrating the technical feasibility of the designs. The successful completion of the PDR would give approval for "complete prototype" which can be basis of a Final Design Review (FDR), currently planned for July 2019.

The review panel thanks the ITk Strips team for the effort invested in the preparation of this review, which presented effectively a very mature state of designs. The specifications have been mostly complete for years, prototyping of staves and petals began more than 10 and 8 years ago respectively, resulting in a huge amount of experience and homogenization of processes in the project. The working atmosphere looks optimal and the community is working with a team spirit defending the project in a unified way.

Given the very mature state of the developments and qualification of the Local Supports for both the petals and staves and Module Loading, this report focuses on open questions needed to be solved before FDR. They are listed in the form of observations, recommendations (R) and actions (A). Identified actions (A) will be actively monitored by the Review Office and should progress and be completed before the next review milestone. The report ends with the final recommendation, which will be sent for approval to the ATLAS Upgrade and Technical Coordinators.
2. Report

2.1. General comments

(A) The strip community is assuming that rework is not considered but this has not been explicitly included in the requirements. A clear statement at the FDR should be made. In case the rework is not foreseen, then a risk matrix will have to be addressed with respect to a tolerable level or threshold of defects for pass criteria that will release the integration. A list of possible failures will be needed, as well as the agreement on the level of rework ability for each of the failure type, if any. In addition, the risk assessment at any of the assembly and QC steps will have to be made allowing the community to identify the weakness and work on the proper mitigation actions in order to maximize the production quality.

The project has decided on not potting the wire bonds, and so cleanliness becomes a major concern.

(A) Organic contamination would show up as poor bondability during loading. Industry increasingly recommends oxygen-plasma treatment. It is recommended to fully study the feasibility of this process in all the assembly sites, and to present the implementation procedure at the FDR.

(R) Inorganic (ionic) corrosive contamination is not necessarily detectable at wire bonding time. Hygroscopic salts are a special concern, since non-condensating atmosphere is not sufficient. Consider cut-off test coupon for "Resistivity of Solvent Extract" (IPC-TM-650).

(A) Corrosion risk is also linked to the loss of the environmental control at shipping, testing or thermal cycling steps. Contamination could be also caused by “leaks” from disposable support material e.g. protective films. Consequently, any material coming in contact with cores and modules should be specified and qualified.

(R) In general, experience has shown that is extremely difficult to identify that a bond foot corrosion process has started. It is therefore suggested to have several dedicated wire bond test pads in the service bus. This could serve as a test coupon at any stage after the assembly, the QC, the thermal cycling, shipping in order to identify if a real issue is gauged. In particular, cold tests of assemblies must be prepared very well; test pads with wire bonds could be subject to cold test conditions, analyzed and give clear for cold testing the whole stave.

(A) The question and scope of wire bond encapsulation has been largely debated in both the ITk Strip and Pixel communities. For the Strip system, the decision to not encapsulate has now been taken primarily due to the large range of difficult geometries present in the strip detector and the large estimated cost involved. The argumentation has been presented in the Strip Modules PDR follow up and mentioned during this review.

An ITk-wide discussion should take place in the next 2 to 3 months in order to fully develop and review the strategy of Strips and Pixels. The argumentation should include the evaluation of all possible risks: technical (electrical stability, mechanical protection, corrosion protection) and schedule-wise, and where needed, proposals for alternative protection methods in different regions of the two systems. Strips and Pixel teams should come up with their complete strategy that will guarantee wire-bond protection at all phases of the project: QC and environmental control throughout the construction process, testing, system commissioning and operation.

(R) Results from the tests of two electrical staves were shown. Additional noise was observed in the modules on-stave, compared to the original measurements of the individual modules before they were mounted on the stave. The pattern of noise increase observed seems to be related to the shield box for the DC/DC converter located on the Powerboard. Further studies and measurements should be made to check whether this is related to reduced shielding of the powerboard (looking for leaking E/B-fields near the shield box), or further checks and evaluation of the grounding and shielding
implemented on the staves to identify the reason for the noise increases. Results should be presented in the follow-up before the FDR.

(A) While most significant inputs to the Local Supports cores and module loading are well known, it is clear to the project that the largest uncertainties are the power-load provided by the modules and EOS, and the maximum bias voltage required for modules at end-of-life. These uncertainties are foreseen to be solved in early in 2019, when most of the qualification efforts will be done; therefore a thorough analysis of possible impact on heat dissipation, EoS geometry, module geometry is expected at the FDR.

2.2. Stave/Petal Assembly and Manufacturing

(A) Stave Core: The locking points are critical items and are part of the local support assembly, not part of the global mechanics (they are bonded on the plank). The assembly process, and more generally the design of the connection of the locking point onto the plank, was not detailed enough during the review and raise few concerns which are listed below. Overall, it is highly recommended that the locking points are integrated into the core construction with mechanical reference allowing reaching the desired precision:

- The locking points guarantee the precise positioning and the final geometry of the plank on the global structure, thus a default in the bonding position of one of the locking points will introduce a deformation of the stave, as it has been stated that the stave was not stiff enough on its own. The positioning tolerances of the locking points is therefore critical, as shown in the assembly drawing (NP49-01-200 sheet 4), where a concentricity of 100 µm has been requested in between the 4 locking points. The tool used to reach such an assembly precision has not been showed neither the locking point precision achieved on the presented prototypes.

- Careful attention must be paid in the design and the choice of the material (very low CTE, creep). Thermo-mechanical qualification of the stave-assembly in its final configuration (including locking point with final material) is a key element to fully qualify the design.

- The process that will be used to assemble the locking point on the plank will define the module placement accuracy, thus it should be very well defined and controlled.

- As for integration, the bracket locking points are not mechanically referenced during the core stave construction and this could be potentially an issue that can result in either over constrained or adding extra clearance to allow smooth insertion. The latter could be an issue with respect to the limited envelope.

(A) The conductive adhesive Hysol EA 9396 loaded with graphite powder (20% in weight) creates contact between the carbon fiber facings and core components. This is a customized mixture calling for a complete set of quality control and application procedures (that will have to be completed for the FDR) to guarantee that the adhesive meets all characteristics needed for the assembly, and it does so in all assembly sites. The full-area irradiation or representative area of local supports should complete the qualification process.

(R) The low-density carbon foam used in the two local support designs is extremely brittle and fragile. The pipe/foam interface is critical to guarantee the thermal performance of the local supports. While it has been demonstrated that the thermo-mechanical stresses were not inducing any noticeable defects in the thermal performance, the stresses induced by the pipe connection during QC of the bare local support and during the connection on the service tray during local support integration has not been demonstrated. The implementation of a strain relieve at the stave extremity would therefore secure this very sensitive interface. As presented during the review, such a strain relieve is already implemented in the petal design. A strain relieve is also planned for the stave design but implemented
at a late stage on the global mechanic structure. It would sound judicious to mechanically strain relieve the pipe/foam interface as early as possible (integrated in the stave assembly process).

(A) A temporary fitting is planned to be used for both stave and petal. Design of this temporary fitting must be seriously qualified since it will interface with the sleeve that will be used for final welding (absence of stress that could damage the sleeve).

(A) Orbital welding is the baseline for pipe connection of both stave and petal. The full qualification of the welding process in terms of impact on module and services is extremely important. It is to be noted that the Pixel system is also considering orbital welding to connect pipes and manifold without qualifying the process since it has been stated that it was demonstrated by the Strip community.

(A) The copper pipes in the petals are bent just before local support integration. The bending tool must be solidly tested and qualified, since operation will be performed on a fully loaded local support. QC after bending is mandatory.

(R) Brazing is used to join the CO₂ piping. Usually halogen based fluxes are used in the brazing process that are known to cause corrosion and residues that can spread in the cooling system and block the capillary pipes. Flux-free brazing is to be used and brazing guidelines be clear. For information, specialized literature on traces of corrosion and procedures for the vacuum and cryogenic environment of particle accelerators are available at EDMS 334543.

(A) Outsourcing the petal production to industry requires a careful and solid documentation effort. In this respect, agreeing on standards early enough is extremely relevant. For instance, the current version of the petal assembly drawing (D10000000081502-A001) must reflect the positioning and geometrical specifications of the petal described in AT2-IS-ES-0011 using the standard Geometric Dimensioning and Tolerances (GD&T). It is very important since this assembly drawing is the document that will be used as baseline for quality control, or more specifically to accept or reject the petals after the assembly step. Other details relevant for production should be carefully evaluated, as for instance, it may be also necessary to check if the foam and core drilling removal after face sheet gluing, as requested by the proposed company, has an impact on performance.

(A) Related to the point above, the project should keep ownership of the QC process at the outsourcing company, and define the rate at which project members (“inspectors”) qualify and accept produced sets. The QC model should be presented at the FDR.

2.3. Bus tapes
The bus-tape co-cured on CFRP is a critical item.

(A) Co-curing will happen at 5-6 different assembly sites. A very solid procedure for this process is expected at the FDR.

(R) Long-term reliability: the dimensions of the bus-tape Cu-traces are frozen-in during co-curing at 120 °C but during operation at -30 °C the traces are statically elongated by about 2/1000. Possible adverse effects could include accelerated electro-migration (into the dielectric) and material fatigue fracturing (of the traces). It is recommenced to verify that the static mechanical stress cannot negatively impact bus tape lifetime.
(A) Linked to the point above, as part of the QA, local support assemblies with co-cured bus tapes must be thermally cycled (420 cycles at the OTR as proposed) and verified for integrity of the co-curing interface and the electrical functionality.

2.4. Thermo-mechanical behavior of Stave and Petal

(A) The temperature distribution on the staves and petals was determined by analytical and FEA calculations. Additionally, experimental methods were performed to validate the calculations. The number of results is impressive and calculations and experiments match well. Based on this well-understood temperature distribution, the ITk should perform thermomechanical analysis in order to understand the effects on the thermal and static loads in the structural integrity of the staves and petals. This analysis should be based on all the foreseeable load scenarios expected during the life cycle of the detector.

- All thermo-mechanical deformations measurements should be done with real stave and petal fixations conditions. All structures are symmetric so in theory no deformations should appear, but small differences could involve deformations. It could be necessary to define the stability requirement, daily and monthly as done on the current ATLAS Pixel system.
- It was presented that the stave is inserted into its final position by being slid into the previously installed supports. At z=0 the stave is supported on both sides; therefore this may over constrain the stave and prevent its contraction during cooling down. A FEA analysis should be performed to understand this behavior. Additionally, these supports are made of materials with CTEs different of those used in the sandwich construction. The effects of the temperature in these supports should be determined. It is also recommend verifying the capacity of these supports by testing.
- The adequacy of the system used to clamp the cooling pipes in the stave should be verified with FEA.

(R) It was mentioned during the review that one of the petals delaminated. The cause of this failure mode should be identified. A FEA analysis will show the stress distribution on the cross-section of the sandwich and give an indication on the region that failed. This analysis will also serve to validate the material properties of the materials selected to make the sandwich.

(R) Even if the presented thermal results are very satisfactory, it’d be useful to assess the contribution of the convection coefficient and its impact on the temperature distribution. The convection coefficient will be inflated due to large temperature fluctuation across the module surface that can trigger local turbulences. For instance the apparent difference in the EC petal measurements is about 30 °C deltaT in a surrounding area of less than 10 cm² which is significant enough to see potential effect of the convection coefficient.

2.5. Module Loading

Module loading has been developed and tested for many years, and there is a high level of confidence in process. The qualification programme is also very complete, as it addresses all relevant aspects and it has been tried out with several prototypes. Results are consistent with expectations.

(A) Both petal and staves are using SE4445 adhesive to load the module on local support. It will have to be fully qualified for the expected radiation level before the FDR. A backup solution could be investigated, as any change will impact module loading and possibly the production rate.

(R) A plan to guarantee that all Module-Loading sites reach same level of expertise when they start pre-production would be needed.
2.6. QA/QC Plans

The steps and the equipment necessary to assemble the staves, petals and to perform their QA and QC are clearly identified. The project has also identified a reasonable granularity of tests and the criteria that should be met in order to identify the products that meet the project requirements.

(R) The project is also recommended to identify and record: i) the measures to take in case a defect on a part is identified, and ii) any foreseeable fault that is expected during assembly and QA&QC. Documenting the experience acquired during the production of the prototypes will permit to subsequently share the lessons learnt with all the institutions performing the final assembly.

(A) The delamination specifications (e.g. Stave Core spec 4.6) refers to the maximum delaminated area, but the relevant test refers to the resulting hotspot in the QC thermal test. Either change the specification into something that can be tested or implement a test for the actual specification, e.g. industrial ultrasonic microscopy.

(R) There are a number of standards and guidelines that can be consulted to optimize and finalize the QA/QC strategy:

- MIL-HDBK-17 guideline for characterization provides guidelines on the design and manufacturing (QC&QA) of composite structures. This could help on the identification of tests necessary for i) characterization (design stage) and ii) acceptance (module production) of the staves. This guideline is really long and requires a selection of the parts that apply to this project.

- Materials (pre-preg and core materials) should be used and stored according to manufacturer specifications (pre-pregs have an expiry date).

- Materials can be tested by tensile tests. D-3039-8 is the Standard test method for tensile properties of polymer matrix composite materials:
  (https://cds.cern.ch/record/848305/files/ASTM%20D3039-M.pdf)

- For qualification of the sandwich a bending test up to rupture can be performed.


- Any equipment operating at a pressure greater than 0.5 bar has to comply with the following CERN rule: https://edms.cern.ch/ui/file/875610/LAST_RELEASED/GSI-M-2_EN.pdf.

3. Summary and final recommendations

In view of the presented documentation and discussions held during the Preliminary Design Review of the ITk Strips Local Supports Cores and Module Loading, the review panel acknowledges the maturity of the Local Support designs and Module Loading process. Numerous prototypes have demonstrated adequate performances and fully validate the designs.
The panel considers that the PDR is passed, and this recommendation will be submitted for approval to the Upgrade and Technical Coordinators.

The panel has identified a number of technical issues that should be addressed before the next milestone review, the FDR currently planned for July 2019.

4. Follow up

Several recommendations and concrete actions have been identified during the review, and the latter shall be resolved before proceeding to a FDR. Following the ATLAS Review Strategy for Phase 2 (EDMS 1979229), the actions to follow up and their tentative reporting mechanisms and dates will be agreed between the Review Office and the Activity Coordinators.
Appendix A: Agenda

ITk Strips Local Support Cores and Module Loading Preliminary Design Review
1-2 October 2018, CERN

https://indico.cern.ch/event/734211/

- Introduction, scope of the review - Tony Affolder (University of California, Santa Cruz (US))
- Description of local support core design: barrel staves - Jeffery Loyd Ashenfelter (Yale University (US))
- Description of local support core design: endcap petals - Sergio Diez Cornell (Deutsches Elektronen-Synchrotron (DESY))
- Bus tapes co-curing - Carl Haber (Lawrence Berkeley National Lab. (US))
- Cooling loop including E breaks - Paul Neil Kemp-Russell (University of Sheffield (GB)), Richard French (University of Sheffield (GB))
- Manufacturing procedure: endcap petals - Dario Eliecer Ariza Alvarez (Deutsches Elektronen-Synchrotron (DE))
- Petal specific: industrialization of petal cores - Carlos Lacasta Llacer (IFIC/CSIC-UV)
- Interfaces and integration: barrel staves - Georg Viehhauser (University of Oxford (GB))
- Interfaces and integration: endcap petals - Jose Bernabeu Verdu (IFIC (ES))
- Transport and logistics - Andrej Gorisek (Jožef Stefan Institute (SI))
- Results on stave core prototypes - Soeren Andre Prell (Iowa State University (US))
- Results on petal core prototypes - Miguel-Angel Villarejo Bermudez (Univ. of Valencia and CSIC (ES))
- QA/QC plans - Jeffery Loyd Ashenfelter (Yale University (US))
- Schedule discussion - Sergio Diez Cornell (Deutsches Elektronen-Synchrotron (DESY))
- Staves thermal Finite Element Analysis - Dr Graham Beck (University of London (GB))
- Petals thermal Finite Element Analysis - Yu-Heng Chen (Deutsches Elektronen-Synchrotron (DE))
- Results on thermo-mechanical stave prototypes - Laura Jean Bergsten (Brandeis University (US))
- Results on thermo-mechanical petal prototypes - Claire David (Deutsches Elektronen-Synchrotron (DE))
- Summary of LS cores part - Jeffery Loyd Ashenfelter (Yale University (US)), Sergio Diez Cornell (Deutsches Elektronen-Synchrotron (DESY))
- Module Loading - Design Overview - Jens Dopke (Science and Technology Facilities Council STFC (GB))
- Module Loading - Procedures including QC - Daniele Madaffari (IFIC - Valencia)
- Module Loading - QA Results - Hannah Elizabeth Herde (Brandeis University (US))
- Summary of LS module loading part - Bernd Stelzer (Simon Fraser University (CA)), Jens Dopke (Science and Technology Facilities Council STFC (GB))