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Referee's Comments on SCT End-cap Engineering Paper

Report (pdf) corresponding to the Submitted Paper.

Responses to Referee and Revised Paper (significant changes in red).

We must respond by 5 Feb.

Key:
= dealt with to Stephen's satisfaction
= to be discussed with Pippa
= awaiting feedback
= ask Referee/Editor

Referee's comments are in bold.
Responses are in italics. Please indicate initials and add under any other corresponding comments.
Proposed approach is indicted in normal type.

General Comments

This is a very detailed report on the construction of the ATLAS silicon tracker end-cap and contains a lot of engineering details.

My impression is that the paper was written by quite a few groups and so there are some repetitions (e.g. YSH-50-A fibers was repeated as a footnote a couple of times.

SH1: Is this a problem? I think most of the repition is intentional. Just trying to be complete and remind readers if they have forgotten or skipped sections.

Remove repetition in footnotes.

Besides being a record of what was done and what drove the decision, its important to have a section on lessons learned. The authors have included an appendix to describe some alternatives. I think for the benefit of other people who are going to build a large tracker like this, it'd be useful to summarize succinctly the difficulties encountered, the yield, cost vs benefit of some of the solutions.

SH1: So does the Appendix constitute what the Referee envisages as this section? (I assume this is a response to the JINST Editor.)
Have we not summarised the difficulties? I could produce a summary: 5 bullet points (see below). I am not sure one can readily indicate the yield (?) and cost vs benefit without following alternative solutions through to the end.
Cannot be sure that alternatives are realisable and better. This is beyond the scope of this paper. **PIPPA**

Summary:

- It is important to keep the design of the detector as simple as possible and to give prominence to engineering considerations.
- Great care is needed in designing a robust cooling system; failure to do so can lead to a significant loss of usable modules.
- Where possible, delicate services should be avoided; if they are unavoidable, straightforward replacement strategies should be envisaged.

- Testing should be anticipated at the time of design.
- Sealing strategies require careful consideration and prototyping.

SH2: I discussed producing tables of yields of components with MT. This would be really difficult. To find the info would be hard and it is often not simple: failed components are sometimes reworked, there are many stages where components may be rejected.

In a few cases, the original specifications or requirements were not met. It'd be useful to expand a bit on what drove the specs in the first place and why it was later on decided that the specs could be relaxed or changed.

SH: I was wondering whether we might get this comment.
May be difficult - may require some archeology and original specs may not have been well motivated. Does Referee have specfic issues in mind? I have looked through paper and identified several examples where we might provide more details. **PIPPA**

See Specs - below

Another point is the mass estimates. On pg 63, it was said that the differences between the two SCT end-caps greatly exceeded the known differences but there was no explanation given.

SH: We don't know - probably something was missed. (We had not wanted to go into too many details about this.) We could state that we do not know why the measured masses differ. Explain complicated measurement and something may have been added and not accounted for. Do not believe that the actual differeces betwen the EC's are great. **PIPPA**

Detailed comments

1. The acronyms should be explained at the first time it was used. Eg. CFRP was used on pg8 but was introduced as carbon-fiber reinforced plastic only on pg 10. Concentricity was used in Table 3 (pg 10) and explanation given only for Table 5 (pg 12).

SH1: Did try.

Revisted and will change.

2. Pg 8 on Radiation: silver (local concentration) should be kept below 1g. Is this total or per unit area or end cap?

SH1: I believe this is per "blob", ie a "local" concentration of a few cm3. **IAN DAWSON**

ID1: We'd estimated 178mg Silver per module, so "locally" means per module. Also, most of the silver is apparently in conductive glue between ASICs and hybrid, so I suppose you could define "local" on a smaller scale if necessary.

SH2: So should be less than 1 gramme in an volume occupied by a module. Actually only very small amounts of silver were used and these were dominated by that already in the Modules.

3. There are various epoxies being used and I wondered whether some explanation should be given about the choice of the epoxies.

SH1: Araldite 2011 used because it is rad hard. I thought use of Cyanate-Ester & FM73U and Techsil and Tempflex was made clear. Will check. **JASON**

- Araldite 2011 - general puprose expoxy; rad-hard Cyanate Esther - low CME, suitable for stable structures but sensitive to moisture
- FM73U - also suitable for CFRP structures, but less sensitive to moisture
- Techsil - soft adhesive, easily cut or peeled for holding soft services and sealing; doesn't set so well
- Templflex - to replace
- Techsil; does set ... albeit rather too well

JT1: Araldite 2011 2 part epoxy adhesive - General purpose for small area bonds between various materials. Also used for large area bonds where cold curing required. Used for bonding parts to the Support Structure, bonding the aluminium skins & polyimide heaters to the thermal enclosure and sealing the friable surface of the polyetherimide foam.
YLA's RS4 cyanate ester film adhesive - An areal adhesive, suitable for bonding of stable composite structures due to its low CTE & CME. Sensitive to moisture during curing. Used for co-curing of the YSH50A/RS3 facesheets to the KOREX core of the Support Cylinder.
FM73U unsupported epoxy film adhesive - A less moisture sensitive composite areal adhesive. Has higher CTE & CME properties. Used for bonding pre-cured YSH50A/RS3 facesheets to the KOREX core of the Front & Rear Support Panels.
Techsil 2 part silicone sealant - A soft weak sealant with very little adhesive strength. Low viscosity so best used for leak sealing small gaps in inaccessible areas. Initially used for sealing in services but was replaced by Tempflex.
Tempflex single part silicone sealant - Tougher sealant than Techsil that sets to a rubbery state. Strongly adhesive in comparison to Techsil and used to bond parts with a sealed but flexible connection. Used for sealing and bonding between outer thermal shield components.
I took out the radiation hard as of course it should all really be radiation hard.

4. Cu-Ni: there is at least one other experiment which is planning to use Cu-Ni tubes. It'd be useful if the authors could comment on the manufacturing process, possible leaks.

SH1: Could add some more details and explain where leaks can occur. **JASON & IAN**

5. Pg 16: last paragraph: . Accepted on the basis of 10 of them passing. Section 2.2.1.3 said 10

SH1: Does this refer to 10 Seals vs 10% of Cooling Blocks? I don't understand the problem. (If this was written in Tex, I suspect there was a problem with "%".) **EDITOR & REFEREE**

6. It was said that an irradiated module was tested on a proto block design and was stable against thermal runaway. What would happen if theres a small leak developed? It'd be interesting if the authors include some risk analysis in the paper.

SH1: How general do they want us to be? Should we consider all risks or just thermal ones or leaks (loss of coolant; cost, environment, TRT)? Could list possible causes of failures and consequences. **PIPPA**

7. Test of the Cu-Nu tubes: the circuits were tested to 25bar. What is the maximum expected operating pressure? Was there any thermal cycling test?

SH1: Will clarify. **IAN**

8. pg 18: use sticky polyimide tape; is this robust enough over time?

SH1: Not critical - mainly needed during assembly. **IAN**

9. Is the FSI insensitive to temperature effects?

SH1: No - text says "monitor temp of ambient gas" ... may need to add that it affects refractive index.

10. DCS: what system is used to read out the thermistors and the humidity sensors?

SH1: Will ask Richard Brenner. **RICHARD**

The ATLAS DCS is read out by a standard Controller Area Network (CAN) fieldbus and a custom-developed OPC CANopen server (REF The Detector Control System of the ATLAS SemiConductor Tracker during Marco-Assembly and Integration, submitted to JINST).

11. Fig 18: why are there discrete steps?

SH1: Record at discrete times, and then interpolate. Does it really need an explanation?

12. Testing: were all modules turned on simultaneously during the testing?

SH1: Clarify with Tim Jones. **PAUL**

Due to limitations of the test system, the maximum number of modules which could be readout simulataneously corresponded to one quadrant of a disk.

13. tab 6: for comparison, should include results from modules before placing on ECs.

SH1: Paul is obtaining this info. **PAUL**

14. Was a FEA done for the support cylinder? And did the FEA results agree with the load testing results?

CN1: The predicted maximum deflection of the modelled structure at room temperature with mass budget loads was 0.63mm and is in good agreement with the experimental load test values of 0.74mm and 0.87mm from the two cylinder load tests.

15. Section 4.1.5 (FEA): was the analysis being done under normal heat load and operating temperature condition including effects of irradiation?

CN1: Load cases were run at room temperature and at operating temperature. There was not found to be a large difference due to the high performance low CTE materials used. The effect of irradiation was not analysed, but proven radiation hard materials were used, and a large x2 factor of safety was used to allow for any degradation in the structural properties of the material.

16. LMT: what is the resistivity of 36um Cu and the expected IR drop?

TW1:

The conductivity of annealed copper is 5.8 10^-7 S/m. The longest length of EC LMT is 2.991 m. Therefore the worst case (ie allowing for the maximum current of 1.3A for VDD or VCC) round trip voltage drop is 83 mV.

17. Leak rate exceeded the specs: isnt this worrying since it can only get worse over time and after connections are made in the pit. Is there any particular spot or the leak is rather uniform?

SH1: I guess they must not exceed the 750 l/h N2 flow, else we cannot maintain an over-pressure. Nigel indicated that there may be an attempt to increase the flow, although I believe this is temporary to dry the SCT. **NIGEL & PATRICK**

NH1: The leak rate was measured with the access-holes for cooling pipes sealed off with tempflex and dummy *covers. If the seals in the pit are made equally well, there is no reason for the leak to increase. However, I would expect leaks to increase with time as joints flex and things shrink with drying out. At least, I don't expect any leaks to fix themselves. The leaks seemed to be very uniform for Endcap-A. I would even like to measure the leak-rate through a panel of CFRP to see - maybe it just isn't gas-tight. But I think for C there were specific places where they were higher and difficult to fix. In any case, the nitrogen leaks are dominated by the Barrel SCT which has a much higher leak- rate than the two Endcaps combined.*

PW1: For the thermal enclosure leak rate we have measured the following:
EC-A:
In SR1 with the temporary feed through boxes 85 l/h at 1mbar
In the pit with the final feed through boxes 45 l/h at 1mbar
EC-C:
In SR1 with the temporary feed through boxes 350 l/h at 1mbar
In the pit with the final feed through boxes 390 l/h at 1mbar
To be able to reach a good seal within the EC the sealing has to be done right the first time. For EC-C Richard believes that too early (before the Tempflex was cured) pressure was put on EC-C causing leaks. I also believe that the Invar temporary front wing, which was not very flat (~4mm) caused so much stress that leaks were made in the parts already sealed. Even more when the Front Support was mounted, which was flat more leaks appeared, but by that time the SCT was already inside the TRT. After the EC seals there was a whole of labyrinths for the leaks to find its way out. When sealing a leak on one side, the leak found its way through another path. The only sensible way to get a better leak rate at some point would have been to move the SCT out of the TRT again and redo all sealing completely, but who knows what damage this would have caused.
The leak rate in the barrel is much worse: > 2000 l/h and not reaching any overpressure. So for us it is not very useful to try and be much better than the 390 l/h, looking at the TRT. As soon as the EC is dry we will go to a lower overpressure and lower flow rate. An overpressure of 0.4mbar should approximately half the leak rate. A lower pressure will also reduce the possibility for the leak rate to increase over time. We will have to find the proper relation at some point between flow rate and overpressure without increasing the moisture content inside the SCT.
FYI the problem with the Barrel has consequences for the Barrel SCT and TRT. I think the current plan is to flush the ID volume with Dry air and not CO2 anymore. Also the leaks at the ID end plate are believed to be so big that we will not be able to fill the complete volume with CO2.

(Suggested by HN) Before "Further electrical tests..."
For EC-A no significant localised leaks were found by flushing with argon and using a gas sniffer; for EC-C, some regions of higher leak rate were but were not accessible for repair. Despite the leaks, the supply rate of 750 l/hr is sufficient to develop enough over-pressure to prevent moisture diffusing in, and so these leaks are not a problem for the SCT. However, any nitrogen which leaks out to the inner detector volume may be a problem for the TRT, which is very sensitive to this gas. Therefore, it may be necessary to clean the recirculated Xenon-based active gas more carefully. *(Added after PW comments)* Once the end-caps are dry, the flow rate will be reduced, corresponding to an overpressure of 0.4 mbar. This should halve the leak rate and reduce the likelihood of the leak rate increasing with time.

SH2: Do we say anything about the current situation in situ and anything about the Barrel ?

18. Survey and dry-out: what is the expected effect due to temperature and when the B field is turned on?

SH1: By design, Cyanate-esther construction should have low CTE (and CME). CTE/CME are given in Sect 4.1.5. Don't expect significant effect from B-field, because little use of magnetic materials. **JASON**

NH1: For Q18, we expect very little effect from the magnetic field because we have almost no magnetic materials, and because the magnetic field ramps up and decays very slowly (minutes) (even in a fault condition) so eddy currents are very small.

JT1: Where we do have conductive materials that may be susceptible forces during field movements during quench we have split them in phi and added capacitors where necessary.

19. Grounding: are all exposed metal grounded, including the metallic cooling heat sinks?

SH1: Not sure what is refered to here. In principle, all metalic conductors (other than those intended to carry currents) have been grounded (stated at start of Sect 11.1). This includes foils (eg on TE's), Disk Fixations, etc - could state more explicitly. The Metalic Cooling Heat Sinks are on the Hybrid - assume grounded. **TIM**

TJ1: There seems to be some confusion - no one knows what the Metallic Heat Sinks are

PB1: I think it's the cooling block. The term "heat sink" is introduced in last line on page 59 when talking about the module. In this paragraph (first line, page 60) is stated that the cooling block is insulated (from the module). Probably it would help to explain that the cooling block is part of the cooling pipe and then grounded in the same way (same paragraph and next one).

Add some more statements about what is grounded.
Replace "Metallic Cooling Heat Sink" with "cooling circuits". Make it clear Block is attached to Pipe.

20. measurements (11.2): are the real cables (length, type) used for the measurements? And was the readout clocked at 40 MHz and the trigger rate was close to what was expected?

SH1: Don't understand. These are measurements of the G&S system - to make sure items are either connected or insulated. Maybe the Referee is really thinking of the noise measurements. These were made were made with the actual LMT's, but dummy Type II Cables. **PIPPA**

PB1: Yes, as stated in the first line of 11.2 "to check the correct implementation of the grounding scheme...". Regarding the noise measurements we are just testing EndcapA after installation, maybe the paper can say something like that the endcap has not any noise increase or degradation (if this is confirmed) after installation and tested with final cables and electronics readout. Of course, this is much more general than the Grounding and Shielding (section 11).

SH2: I would not add further comments about the in-situ measurements since this is new and post-submission of the paper ... and we have to draw a line somewhere.

Changes to Paper

We need to say that we now have serious leaks of the Cooling System (not the TE) in EC-C. Footnote to last para of Sect 11.1? **PIPPA**

Specs

Specs which would benefit from a bit more explanation:

4 layers

- Robust standalone tracking.

Shield apertures less than a few cm2:

MW1: Our electronics is most sensitive to pick-up at frequencies between 1-10 MHz (due to the preamplifier characteristics). A typical engineering guideline is to avoid openings (linear slots) of length/dimension larger than 1/20 of the critical wavelength. This ensures x100 attenuation of the entering fields already. If there are multiple apertures, effectiveness is roughly reduced in proportion to the square root of the number of aperatures. Note that not the area, but the max. linear dimension matters. This gives 300m/20 = 15 m for 1 MHz and 1.5 m for 10 MHz. Note also that we could act both as a noise source and recipient.

Disk Specs (Sect 2.1):

PATRICK

- Were the max displacement and electrical resistance of the Disk met (p9) ?
- Were the tolerances of Tab 4 for the machined Disks met ?

PW1: The Disk requirements were written for the manufacturing of the Disks after some prototype disks had been manufactured and tested. The tolerances on the disk were discussed what was reasonably possible to manufacture and to maintain maximum stiffness without increasing material.
The module sizes were fixed and the maximum height needed for the services was known, leaving a total of 9.4mm for the thickness envelope of the disk. We had agreed with PCI that for the flatness 0.5mm and for the thickness +/- 0.2mm were reasonable specifications, leaving 8.7mm for the thickness. The disk should be as stiff as possible. The only possibility to add extra stiffness was to have thicker facesheets, but this would have increased the material. Under the circumstances we were happy with the result.
There was not a lot of space between the support cylinder and ITE. The tolerances on the ID and OD of the Disk could be easily met, leaving more than enough clearances for disk and ITE insertion.

PW2: For the statically loaded displacements FE calculations were made. These calculations showed that a stiffness requirement of at least 30 N/mm out of plane would satisfy our static stiffness requirements. The worse disk was D9, since we have cooling circuits only on one side. The results of the Static Stiffness tests are in Table 5. So I guess you have to add the requirement of 30 N/mm somewhere.
I have attached a file with the final measurement results of the completed disks. This file contains the Flatness Inserts Front, Rear and the Envelope of the Inserts. Most of the envelope dimensions are just a bit outside there tolerance. Since the whole procedure for making the disks flat was complex, time consuming and with relatively high risk to make mistakes we accepted these small violations. The flatness of the inserts were all very good and inspected during the measurement. These numbers were not stored. We still have the files, but it would be a lot of work to work out all these numbers. The same is for the slope of the inserts.

NH1: Re stability: was probably physics based, tailored with some reality. Under normal operation power levels change (hit rate during a spill for example) causing temperature changes. We decided (no idea where it came from) that these could be about 2 deg C. So we wanted structures that do not move under 2 deg C changes by more than a harmful amount. This should probably have been about 4 micron in x and y, which is about 20 % of the resolution, which is tolerable in tracking because it does not affect the track-probability too badly. (So no attempt to do W mass here.) But I guess it was increased to 10 micron because of what can be reasonably achievable, and given that we do have an FSI which can follow these at some level.
The 100 micron in z reflects the lesser importance of this parameter in tracking, and the reality that discs are not very stiff in z and get high forces from the cooling pipes - despite the wiggles - and tend to make a conical deformation quite easily.

NH2: Re Statically loaded Disks: I think this came from Corijn, and is not motivated by physics. These displacements are permanent and so do not badly affect tracking. They do however affect initial alignment: you would not want to put in a whole load of effort positioning modules accurately on a disc only to have them move a lot when you put the disc into use. So they should be smaller than positioning accuracy.

PW3: The FE calculations showed much better results than the 10 micron in-plane displacement: only a couple of microns. We could have made this tolerance smaller, but did not do that for some reason. Any way we had no possibility to measure these kind of displacements and probably just put in a "measurable" number that was smaller than the positioning accuracy.

☑ Disk positions in x-y (p39):

- 100 um (one is 400 u m out (p40))
    - Systematic twists of the Disks are more difficult to remove with tracks, so reduce by construction
    - Not strong constraint, since can obtain alignment from tracks
    - Sufficient overlap exists anyway to allow for beam-spot envelope
    - Tolerance gives good starting point for alignment

☑ Disk positions in z (p39):

- 500 um (ATL-IS-ER-0027 suggests 1000 um)
    - z-position has a smaller effect on momentum determination
    - Not strong constraint, since can obtain alignment from tracks
    - Sufficient overlap exists anyway to allow for beam-spot envelope
    - Tolerance gives good starting point for alignment

☑ TE (Sect 8.1):

- Leak rate less than 25 l/h.
    - Avoid poisoning TRT
    - Maintain overpressure to ensure no ingress of moisture.

See Nigel's comments for Q17.

☑ ITE Gas Flow (Sect 8.4.3):

- Flow rate 1700 l/h.
    - Dry SCT
    - Maintain overpressure to ensure no ingress of moisture.

See Nigel's comments for Q17.

G&S Resistances (Sect 11.2)

PB1: Maybe 3rd paragraph in section 11.2 is not strictly correct. As mentioned, there were two techniques (hand multi-meter and current source plus voltage measure).
The 0.2 Ohm comes from the precision of the hand multimeter, which was used either in sensitive devices or in "not very important" connections.
For important joints (soldered Cu-Cu joints or Al-Al joints with fingerstock for example), we tried to use the second technique. These joints we expected from design (solder or fingerstock) to have very low resistance (below 1 mOhm). In that case we were happy if we measured values below 1 mOhm (tenths of mOhm). In fact, as checked this value came from the contact resistance of the leads, the actual joint value was quite smaller.

SH2: So I conclude that the values were either "common sense" or what was measureable rather than any profound electrical requirement; therefore don't comment.

-- StephenHaywood - 08 Jan 2008

This topic: Sandbox > SCTECEngComments
Topic revision: r13 - 2008-01-25 - StephenHaywood