Performance of a Layer-00 Thermal Prototype

Memo

To: Layer00 Colleagues

From: Tim Jones, Dave Muskett

CC:

Date: 28/06/99

Re: Measurements of the performance of a half-length Layer-00 thermal prototype

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Scope

This note summarises the results of experimental measurements made on a half-length thermal model of the CDF laye-r00 vertex detector. The aims of this study were:-

1. Determine the effectiveness of the "SVX-II Inner Screen" in imposing a low temperature outer boundary to the Layer-00 volume thus eliminating the major source of heat in layer-00, namely the influx from SVX-II.

2. Investigate the possibility of removing the heat produced in the silicon detectors of layer-00, in addition to the influx from SVX-II. via heat transfer to the "SVX-II Inner Screen"

Experimental Configuration

Figure 1 shows a cross-section view of then prototype configuration. A 500mm long section of a carbon-fibre (CF) tube (radius 20.25mm, thickness 0.3mm) representing the SVX-II Inner screen was mounted on an insulating support. Cooling channels, formed into a "racetrack" profile (1.5mm x 3.8mm internal cross-section) were clamped on the outside of the CF tube at two opposing positions. The thermal interface between the CF tube and the cooling channels was Dow Corning DC340 thermal grease. A water/glycol (70:30) mixture was circulated in a serial manner through the two channels with the connection between them being made via a short length of plastic tubing. The coolant was supplied via a 3m length of 4mm ID plastic tubing by a re-circulating heater/chiller capable operating over the temperature range ~0C to 50C with a stability of ~ 0.1C regulated by a P.I.D. temperature controller.

The CF tube was enveloped in an outer screen formed from a thick-walled aluminium tube (radius ~ 29mm), mounted co-axially, representing the inner layer of SVX-II. Heater pads were attached to the outer screen so that its temperature could be regulated via a suitable choice of the supply voltage applied to the heaters.

The system was equipped with K-type thermocouples for the measurement of the incoming fluid temperature and the outer screen temperature. An infra-red probe was used to make non-contact measurements of the temperature of the CF tube. All sensors were mounted at the mid-point of the 500mm length to minimise any "end-effects".

The above system was extended to allow further tests to be made into the possibility of cooling layer-00 via the SVX-II inner screen. A thick walled aluminium tube (radius 15mm) was wound uniformly with an insulated heater wire of total resistance 18Ohm. This was inserted co-axially into the CF tube to represent the silicon of layer-00. The heat generated by the silicon of layer00 was simulated over the range 1 W to 6 W (NB. half-length) by suitable choices of the supply voltage and the temperature of the silicon was estimated from the reading on a K-type thermocouple attached to the aluminium tube.

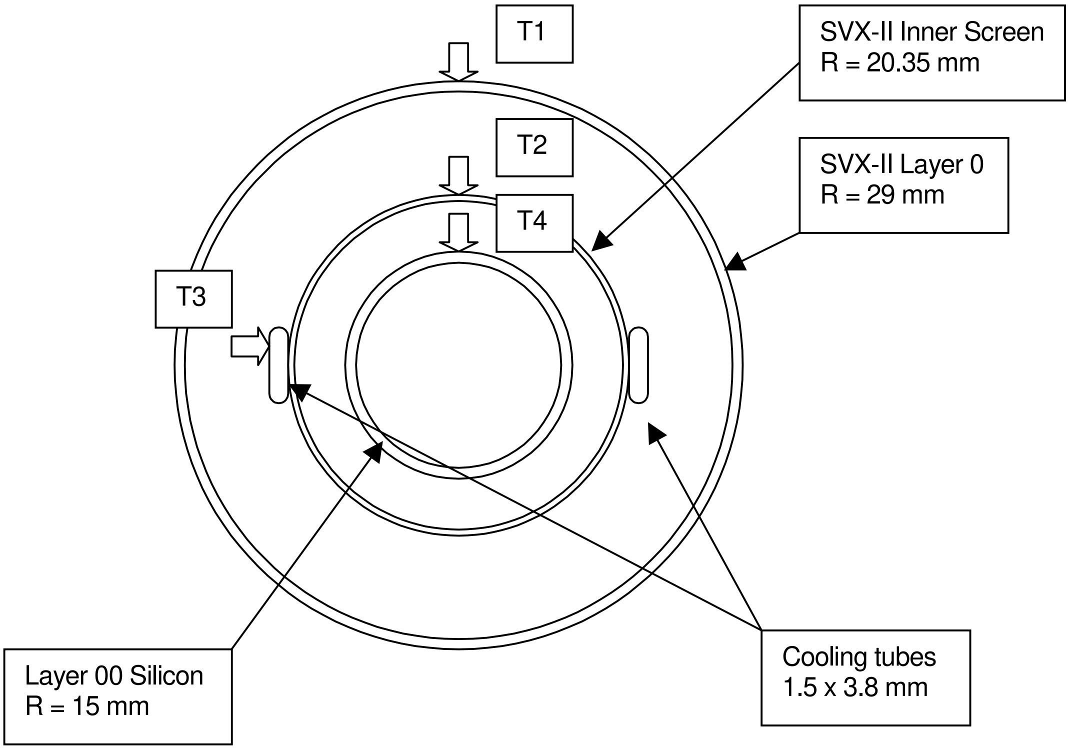


Figure 1: Geometry of thermal prototype

Measurements

1. CF Tube Temperature vs. Input Fluid Temperature

As the temperature of the incoming fluid is varied, heat will be transferred through the gas from the outer screen to the CF tube. This heat will be conducted through the carbon fibre to the cooling channels. The temperature of the CF will be highest at a point on the circumference which is equidistant from the cooling channels (neglecting the temperature rise in the fluid along the pipe length).

Measurements of the temperature of the CF tube and outer aluminium screen were made as the fluid temperature was varied. These measurements were performed with both nitrogen (k=0.026 W/m.K) and Argon (k=0.017 W/m.K) as the gas filling in the void between the CF tube and the outer screen.

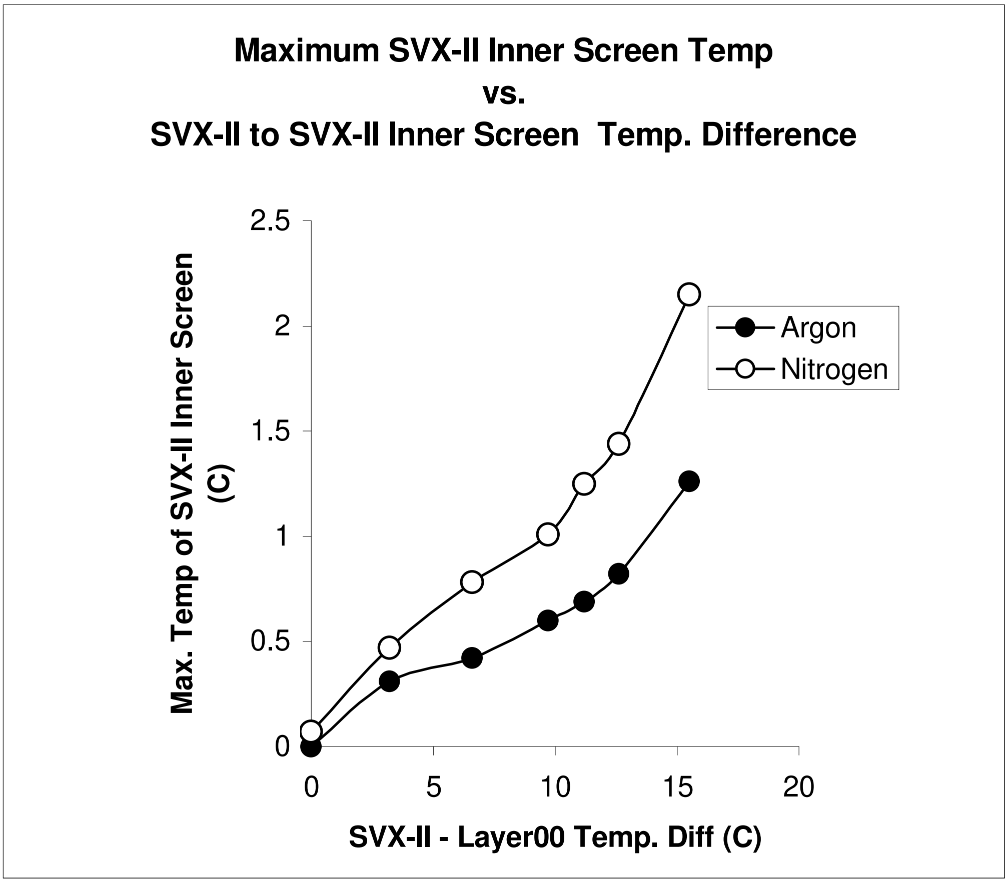
The temperature rise from the cooling channel to the top of the CF cylinder was measured as a function of the temperature difference between the outer aluminium screen and the fluid temperature. The difference ΔT, given by $T_{al} - T_{fluid}$, i.e. T1-T3, is a measure of the heat influx into the CF screen whilst the difference δT, given by T_{CF}-T_{fluid}, i.e. T2-T3, is a measure of the thermal resistance of the CF screen and depends on the thermal conductivity, thickness and arc length.

- Argon

Fluid Temp (C)	ΔT (C)	δT (C)	ΔT/δT
22.3	0	0	0
18.9	3.78	0.37	10.2
14.7	6.77	0.43	15.5
10.4	9.12	0.87	10.5
8.1	10.91	0.67	16.3
6.0	12.59	0.82	15.4
1.7	15.50	1.26	12.3
-2.7	17.13	1.19	14.4

- Nitrogen

Fluid Temp (C)	ΔT (C)	δT (C)	ΔT/δT
22.5	0.22	0.07	0
18.9	3.20	0.47	6.8
14.6	6.57	0.78	8.4
10.2	9.70	1.01	9.6
8.0	11.22	1.25	9.0
5.7	12.75	1.44	8.7
1.4	15.48	2.15	7.2
-3.0	17.03	2.18	7.8



The data show that with an outer screen-to-CF tube temperature difference of ~ 15C, corresponding to the operation of Layer-00 at 0C and SVX-II at 15C, the temperature rise to the hottest point on the CF screen is less than 2.2C.

The temperature rise in the CF tube is reduced for argon when compared to nitrogen. This is due to the poorer thermal conductivity of argon which reduces the heat influx into the CF tube for the same ΔT. The ratio $\Delta T/\delta T$ (argon) / $\Delta T/\delta T$ (nitrogen) ~ 13.2/8.1 ~ 1.63 which is in good agreement with the inverse of the ratio of the thermal conductivities (0.026/0.017 = 1.53).

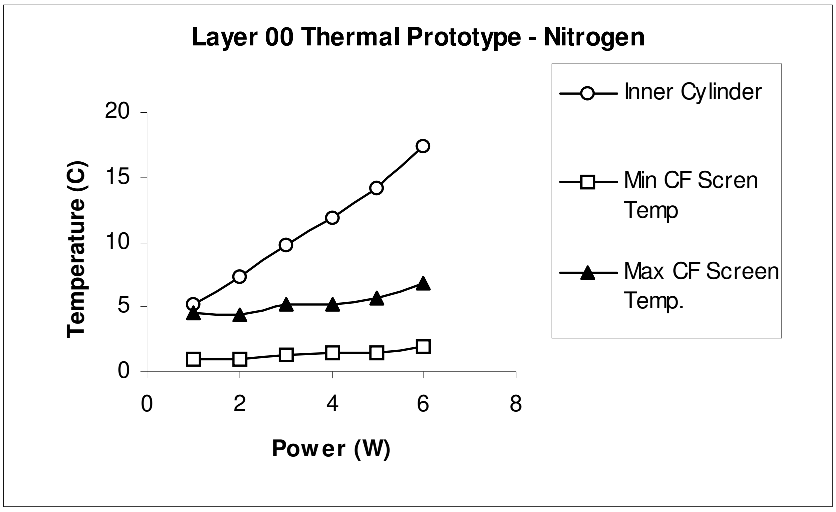
2. Cooling of Layer00 via the SVX-II Inner Screen

The system was operated at a constant input fluid temperature of ~ 0C and power was applied to the heater wire on the 15mm radius aluminium tube representing the silicon of layer-00. The heat generated is transferred to the CF tube via (mainly) conduction through the 5mm thick annulus of gas. The temperature of the thermocouples mounted on the inner aluminium cylinder, the cooling tube and the hottest point of the CF tube were recorded as a function of the power applied.

The measurements were performed for nitrogen and helium gas filling the annulus between the inner aluminium tube and the CF tube. The conductivity of helium is 0.16 W/m.k which is six times that of nitrogen. Initially the system was filled using a high flow rate to disperse any residual contaminant gas and then the flow rates were reduced to the low level required to prevent any ingress of the ambient air.

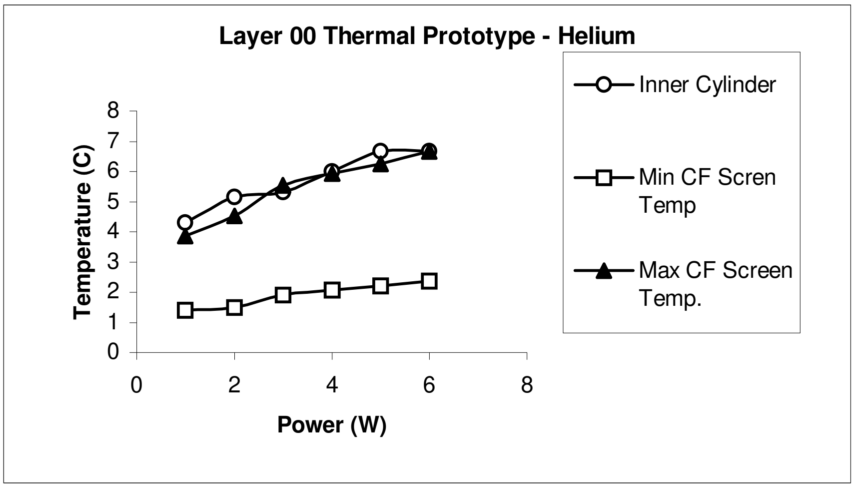
- Nitrogen

Heater Power (W)	Layer-00 temp (C)	Min CF temp (C)	Max CF temp (C)
1	5.2	0.9	4.5
2	7.3	1.0	4.4
3	9.7	1.3	5.3
4	11.9	1.5	5.2
5	14.2	1.5	5.6
6	17.4	1.9	6.8



- Helium

Heater Power (W)	Layer-00 temp (C)	Min CF temp (C)	Max CF temp (C)
1	4.3	1.4	3.9
2	5.2	1.5	4.5
3	5.3	1.9	5.5
4	6.0	2.1	5.9
5	6.7	2.2	6.3
6	6.7	2.4	6.7



Predictions for the bias voltages and strip currents, applicable to the situation following 3 years of operation have been made for a range of temperatures. For a temperature of 10 C the strip current for a 50 μm pitch detector of length 150 mm is ~ 2 μA. The corresponding depletion voltage is ~ 150 V. This results in a power dissipation of 38.4 (76.8) mW per narrow (wide) detector. The total power generated in the silicon of layer00 is then 2 x 3 x 6 x (38.4 + 76.8) mW = 4.15 W. Thus the relevant power for the test performed (1/2 length) is 2.07 W @ 10 C.

The nitrogen data show that at 2 W the temperature of the tube representing the silicon is 7 C rising to 10C for 3 W. The greater thermal conductivity of helium results in a smaller temperature rise. The temperature is always less than 7 C for even the highest powers applied. At the nominal power the silicon temperature would be somewhat below 10 C resulting in a reduced strip current (I ~ 1.2 μA @ 5 C) and hence a reduced power dissipation. This will in turn lead to a reduced temperature. Hence one may expect that the final temperature with a helium filling would be ~ 5C.

Conclusions

A half-length thermal prototype representing the silicon of layer-00, the SVX-II inner screen and the first layer of the SVX-II has been constructed and tested. Providing sufficient cooling power can be integrated into the SVX-II inner screen, then;

1. An SVX-II inner screen, formed from a 20.25 mm radius carbon-fibre tube of thickness 0.3 mm as supplied by FNAL, is capable of acting as an outer thermal boundary to the layer-00 system and is effective in reducing the heat ingress from SVX-II to a low level.

2. The benefit of the screen could be improved if the gas filling the SVX-II volume were argon rather than nitrogen. However, it is acknowledged that this may not be possible due to overriding considerations.

3. The silicon of layer-00 may be kept below 10 C during the whole of a 3 year operating scenario by heat transfer through the nitrogen gas within the layer-00 volume to an SVX-II inner screen cooled to ~ 0 C.

4. The temperature of the silicon can be reduced to ~ 5 C, by heat transfer to an SVX-II Inner screen cooled to ~ 0 C, if the layer-00 volume can be filled with helium with a flow sufficient to prevent the ingress of nitrogen.