ATLAS Internal Note
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MEASUREMENTS OF PIXEL DISK SECTOR PROTOTYPES

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ABSTRACT

Measurements of the thermal performance of two different pixel disk sector prototypes are presented. One prototype was fabricated from machined carbon-carbon(C-C) plates, sealed to contain coolant. The other prototype was fabricated using carbon-carbon plates, carbon tubes and high thermal conductivity fibers to provide a rigid, low density structure. Electronic Speckle Interferometry(ESPI) has been used to monitor the deflection of latter sector prototype under changing temperature and operational conditions. No significant distortions were observed.

I. INTRODUCTION

The ATLAS pixel detector is comprised of barrel and disk elements. The barrel is composed of staves(or ladders) on which the pixel modules are mounted. The disks are composed of sectors and disk pixel modules are mounted on both sides of a sector that provides mechanical support and cooling. This concept is illustrated in Fig. 1. In this paper, we present measurements of the thermal properties of two types of prototype sectors. The deflection under operating conditions of one of these sectors has also been evaluated using Electronic Speckle Interfermotetry(ESPI).

II. MACHINED SECTOR

A sector prototype was constructed by machining two plates of carbon-carbon material.[1] The dimensions of the machined structure are given in Fig. 2. The carbon-carbon plates are 0.7 mm thick. The cooling channel is 3.0 mm internal diameter and has a "W" shape. Carbon-carbon material is porous and must be sealed to prevent leaks.[2] We sealed this sector with thermally conducting epoxy.

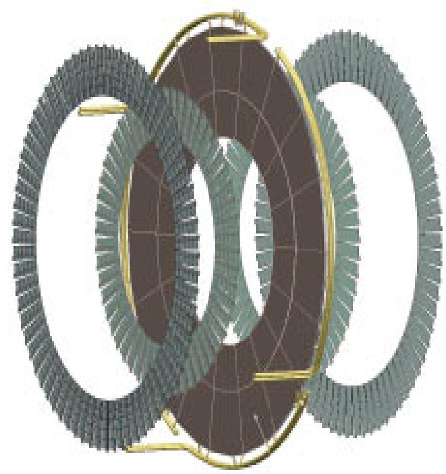

Fig. 1 Pixel disk structure showing sectors held by a support ring with disk modules attached to both sides of a sector.

A. METHANOL-WATER RESULTS

Measurements of the thermal performance of the prototype were made with a 30-70% methanol-water mix at Lawrence Berkeley National Laboratory(LBNL). The prototype was mounted in a cold box cooled by liquid nitrogen boil off. The ambient temperature in the cold box was maintained at about - 7.7°C. The methanol-water

[1] The carbon-carbon material was supplied by BF Goodrich.

[2] We have explored a number of techniques to attempt to seal carbon-carbon and these will be described in a another paper.

mixture was circulated by a pump and the flow measured. The pressure drop across the sector was also measured. The inlet and outlet fluid temperatures were measured in small "mixing stations" to obtain a precise measurement of the bulk fluid temperatures.

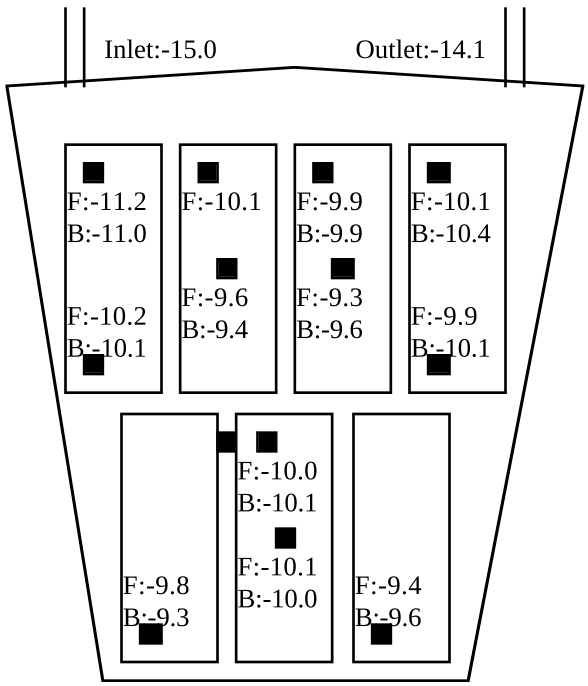

Fig. 2 The temperature distribution in the machined prototype sector with 30% methanol in water coolant. The black squares indicate RTD positions. The front(F) and back(B) temperatures are shown. Not to scale.

Dummy silicon modules were glued to the sector with thermally conducting epoxy. Kapton heaters were glued to the silicon and powered to simulate the power density of 0.6 W/cm^2 expected from the pixel electronics, detector leakage currents and other sources. The temperature distribution in the sector was measured with RTDs mounted on the silicon and on the carbon-carbon plates. The inlet fluid temperature for these measurements was about -15°C although there was some small variation in this number.

The temperature distribution in the sector prototype is shown in Fig 2. The flow rate was 8.7 cm^3/sec and the pressure drop was 209 mbar. This prototype easily meets the criterion to keep the silicon temperature below -5 °C even with methanol-water coolant.

B. BINARY ICE RESULTS

The prototype was transported to Rutherford Appleton Laboratory for measurements with binary ice, small ice crystals in a methanol-water mixture. The sector was mounted in a temperature controlled box and the ambient temperature was maintained at about -0.3 °C.

The temperature distribution in the prototype was measured with binary ice with an ice concentration of ≥1%. The ice concentration was not easily controlled or measured during our measurements. The inlet temperature was about -13 °C. We have scaled the measurements to an inlet temperature of -15°C to compare to measurements with methanol-water at this temperature. The results are given in Fig. 3 for a flow rate of 13 cm^3/sec and a pressure drop of 230 mbar.

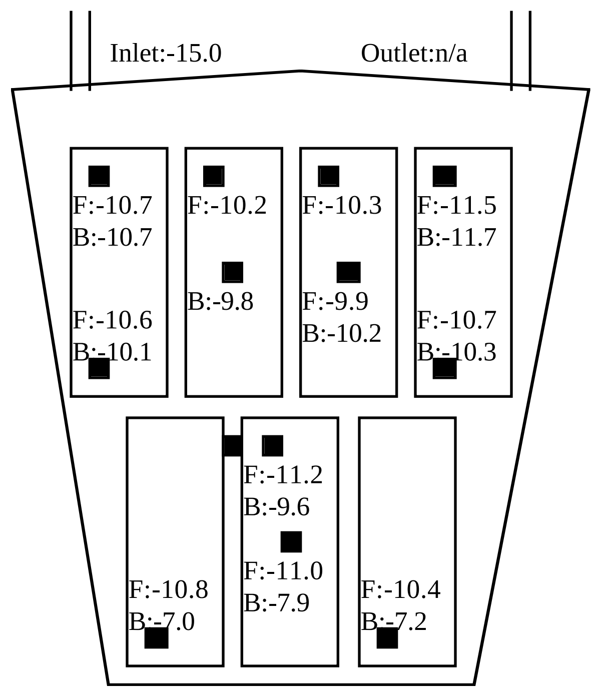

Fig. 3 The temperature distribution in the machined prototype sector with binary ice coolant. The black squares indicate RTD positions. The front(F) and back(B) temperatures are shown. Not to scale.

The binary ice is seen to provide a slightly lower operating temperature over most of the sector, although the flow rate was also slightly higher. The higher temperatures on the back near the bottom are believed to be the result of a poor glue joint that developed during the tests. More work is needed to find a reliable method for sealing carbon-carbon without introducing substantial additional material.

III. CARBON TUBE-FIBER SECTOR

A second prototype sector was constructed by Energy Sciences Laboratory, Inc.(ESLI)[3] A photograph of this prototype is shown in Fig. 4.

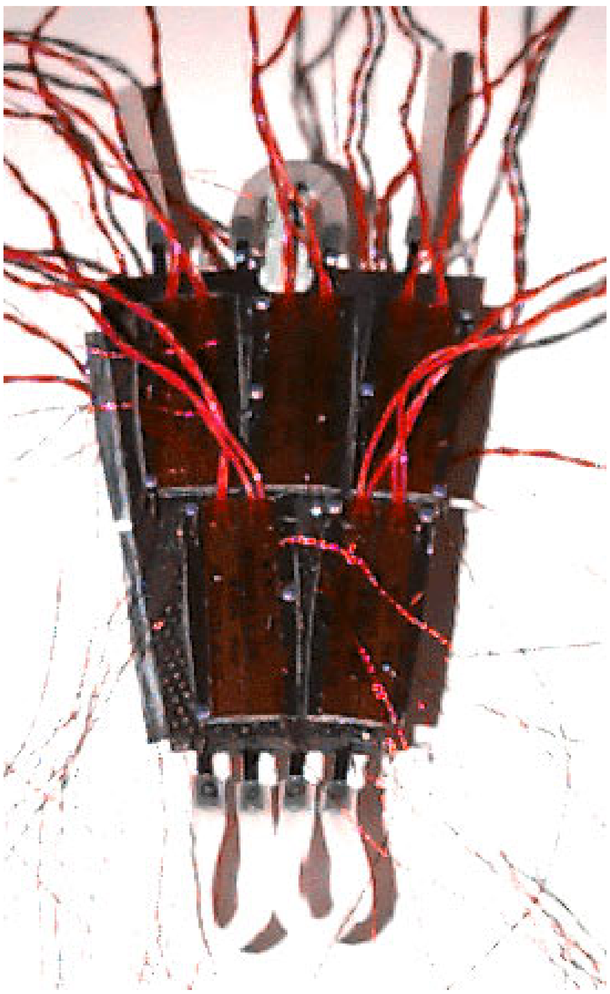

Fig. 4 A prototype sector fabricated by ESLI and described in the text.

A more complete description of the construction technique is in preparation.[4] In brief, the prototype sector is constructed from plates of carbon-carbon material(0.7 mm thick for this prototype). Leakless carbon tubes(in this case 2.5 mm internal diameter) carry coolant. Heat is conducted from the carbon tubes to the carbon-carbon plates by high thermal conductivity fibers that are bonded to the tubes and plates. The resulting structure is very rigid and is expected to have good thermal properties. Silicon modules were glued to both sides of the thermostructure using Masterbond adhesive.

A. METHANOL-WATER RESULTS

The thermal performance of this prototype was measured with 30% methanol in water at LBNL. The flow rate was 6.3 cm^3/sec, the inlet temperature was -15.6 ^{o}C and the total heat load was 36 Watts. The temperature distribution is shown in Fig. 5. The analysis of these data is presented in the next section.

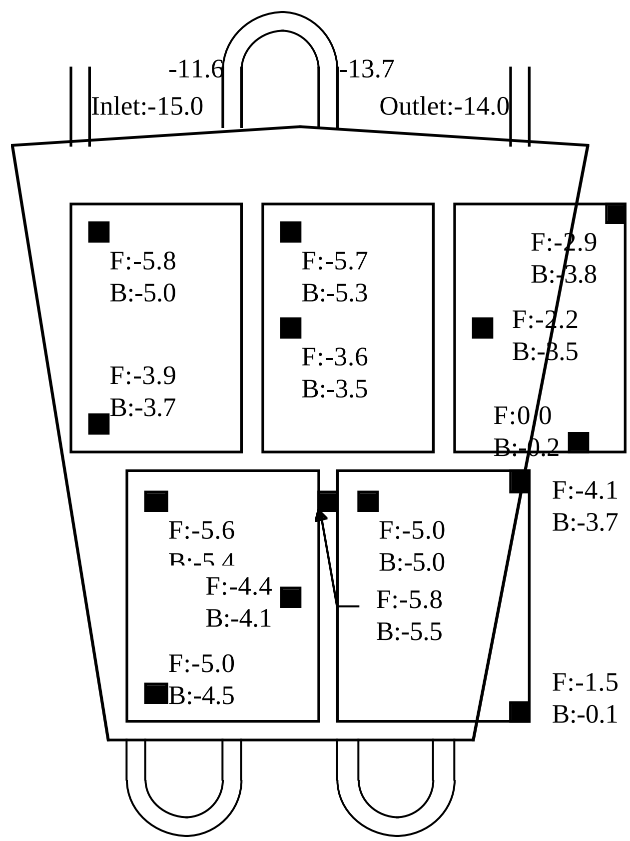

Fig. 5 Temperature distribution of the ESLI prototype sector under the conditions described in the text.

B. ANALYSIS OF RESULTS

[3] Energy Sciences Laboratory, Inc, San Diego, California, USA.

[4] "A New Technique for Construction of Rigid, Low-Mass Structures for Pixel Detectors", in preparation.

A two-dimensional (2D) finite element analysis of these data was made. The 2D FEA was formulated by taking a section through the upper part of the sector. This section (see Fig. 6) permitted an assessment of largely all thermal effects, e.g., properties associated with the fiber core, carbon tube, C-C facings, adhesives joining the modules, and the convective heat transport in the tubes. Properties are reasonably known for the C-C facings, carbon tube, silicon, and adhesives. Convective film coefficients estimated for this model were based on our experience gained with the a prototype barrel stave.[5] Film coefficients for the four individual tubes were estimated by accounting for thermal boundary layer entrance effects, where flow path lengths were adjusted for the tube re-entrant effect.

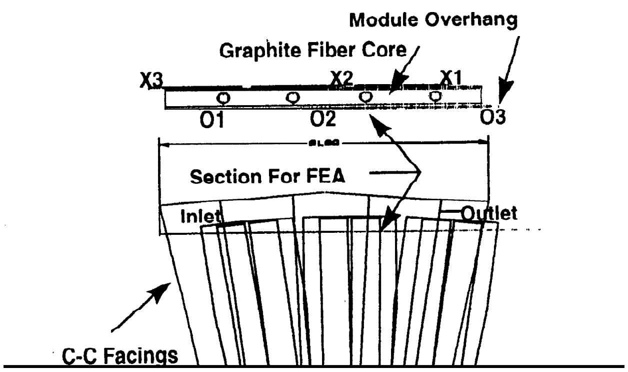

Fig. 6 Outline of the prototype sector showing the section used for the finite element analysis described in the text.

The thermal conductivity of the carbon tube was taken as 4 W/(m-K) (nominal glassy carbon properties), and the conductivity of the carbon-carbon facing was taken as 180 W/(m-K) in the plane and 40 W/(m-K) through the thickness. The conductivity of the fiber core was adjusted to fit the data and was found to be about 6 W/(m-K). A comparison of the temperature measurements and the predictions is given in Table 1. The agreement is excellent.

Measured(°C)		Predicted(°C)
O1	-6.4	-6.5
O2	-5.8	-5.8
O3	-3.3	-3.2
X1	-5.4	-5.1
X2	-5.8	-5.5
X3	-4.2	-4.5

Table 1. Comparison of the temperature measurements of the ESLI sector with predictions from a finite-element analysis under the conditions described in the text.

The good agreement with the FEA results allows one to infer the temperature differentials at each boundary. These are summarized in Table 2, for a region where the carbon cooling tube is in close proximity to the module heater. One's attention may be drawn to the comparatively high ΔT (6.6 °C) through the fluid film in this location. It is important to realize that this ΔT is influenced by heat flux into the coolant, i.e., heat flow well distributed around the tube perimeter results in a lower ΔT (about a 4 °C drop for the machined sector). A more even distribution around the channel perimeter was attained in the C-C machined sector, where more mass was built into the channel wall. In this sector we are trying to achieve this even distribution through the high conductivity fiber core. We have not entirely achieved this condition, although the coolant film ΔT is not that much higher. Another factor contributing to the lower coolant film temperature drop is likely attributed to the more abrupt passage geometry in the fully machined sector. The sharp turns in this sector contribute to mixing or re-energizing of the thermal boundary layer.

The silicon temperature in the prototype was larger than desired. This can be attributed to two primary factors. First, the tube inner diameter was smaller than the 3-3.5 mm ID desired for the final system. Second, the conductivity of the fiber core was lower than expected. In addition, there is the thermal gradient through the carbon tube. The tube wall was 250 microns, thicker than originally anticipated by over a factor of 2. However, in

[5] This procedure is described in more detail in "Thermal Measurements of a Pixel Barrel Stave Prototype", in a forthcoming ATLAS INDET Note.