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The Intermediate Silicon Layers Space Frame

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Summary. — The Intermediate Silicon Layers (ISL) detector is being built as part of the Collider Detector at Fermilab (CDF) upgrades for the run II operation of Tevatron. The ISL Space Frame (SF) is a structure that defines the location of the ISL detectors, supports the micro-vertex silicon trackers (SVXII, L00) as well as the beryllium beam pipe. The SF design, project and construction is challenging due to the precision and mechanical stability requirements that must be achieved using a minimum amount of material. The SF is a high precision light structure made in carbon fiber designed and built at the INFN Pisa and shipped at Fermilab in summer 1999. In this contribution we describe in detail the SF construction phase and the accuracy obtained.

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1. – Introduction

The location of ISL inside CDF is shown in [1]. With a total active length of $\simeq 1.9$ m, it extends the tracking capabilities of CDF in the region up to $|\eta| \simeq 2$. The ISL will improve the momentum resolution and is designed to form, together with the 5 layers of SVXII micro-vertex detector a complete stand alone tri-dimensional tracking [2]. The ISL consists of two symmetric silicon layers in the forward and backward region ($|\eta| \geq 1.1$) located at radii of $R \simeq 20$ cm and $R \simeq 29$ cm respectively (layers 7f, 6f and 6b, 7b) and one in the central region ($|\eta| < 1.1$) at $R \simeq 23$ cm (layer 6c). A description of ISL silicon sensors is reported in [1].

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2. – Space Frame requirements

The main goals of the SF project are to design a medium-term (operation time is $\simeq 3$ years) stable and stiff supporting structure with high precision features that position the ISL detectors within $\Delta R/R \leq 2.5 \cdot 10^{-4}$ [3]. A mechanical stability of few microns must be assured over the period of one Tevatron fill under working conditions and the mass budget must be as low as possible. The total load to support is $\simeq$460 N due to the mass of the ISL itself ($\simeq$16 kg), SVXII ($\simeq$25 kg), L00 ($\simeq$1 kg) and beryllium beam pipe ($\simeq$5 kg). In addition, thermal gradients of 25 K between ledges and SF structure must not influence the geometry of the ISL silicon detectors and the SF must operate in a magnetic field of 1.4 Tesla and in a (relatively low) radioactive environment. The housing space for cooling services, electronics, cabling and alignment devices for the ISL detectors must be provided without compromising easy access and maintenance. The SF must also allow the alignment of the SVXII and beam pipe.

3. – General description

Given the ISL geometry, a supporting structure made out of indipendent barrels is difficult to obtain because of lack of space. On the other hand a monolithic structure that minimizes the material doesn't allow easy access for mounting and maintenance. A good compromise is a support structure formed by three indipendent parts. Figure 1 shows the SF layout where we can distinguish two half SF (each made of four flanges) connected by a central part (spool piece). We refer to the two central flanges as double flanges because two different layers (6c and 6f/b) anchor to them, while the others flanges take their names from the layer they support (*i.e.* see table I). All flanges are connected together by struts and the junction of each strut has been optmized using special carbon fiber (CF) joints. The SF is externally enclosed by two cylindrical CF shells (1 mm thickness) fastened to the flanges to increase the bending and torsional stiffness of the whole structure.

The flanges are hollow CF ring structures carrying high precision parts that define the ISL layers geometry (ledges) and reference the flanges to the rest of the detector (bushings). The sensors geometry implies that, in each flange, the ledges sit at two different radii (external and internal). The ledges are rectangular thin beryllium plates (14.5 mm high, 50 mm large and 1 mm thick) with a slot (7.5 mm high and 2 mm large) in the middle. Their machining accuracy is guaranteed to be within 10 μm of the nominal value. Aluminum pipes are glued to ledges (see figure 3 for a detail of a cooling channel routing in a flange) to provide the necessary cooling system. In this way ledges act as a cold heat sink. The ledges are not directly glued on flanges structure but to a CF strip (ribbon), see figure 3.

To allow mounting and alignment of the Central Outer Tracker (COT) and provide the necessary housing space for ISL electronics, two extensions (see figure 1) are connected to the SF ends.

4. – Choice of materials

We use composite CF material for construction of SF parts. Advantages of using composites arise from their radiation resistance [4], from the very low coefficient of thermal expansion (CTE $\simeq 2.8\ 10^{-6}$ 1/K for 46% fiber content [5]), from the wide possibility to tailor the material's properties to the load requirements and from their high Young modulus. Another advantage is that composites are light so they have quite high radiation length (typical values is $X_0 \simeq 25$ cm). We use the M40J CF, that is a medium-high modulus (300 GPa $<$ E$_{M40J}$ $<$ 500 GPa, dry range values) to perform three differents laminations (60% fiber content) of $\simeq$ 0.475 mm thickness each. The double flanges cylinders are made of 4 plies (orientation $0^o/90^o/90^o/0^o$) of unidirectional CF. Ribbons are made using 4 plies ($0^o/90^o/90^o/0^o$) of unidirectional CF and flanges are built using 2 plies in CF fabric prepreg with orientation ($+45^o$,-45^o). The molds were designed at INFN Pisa while laminations were made by Plyform S.r.L.. Connecting struts and CF joints were made by Reglass S.p.A. To ensure good uniformity all the used struts come from the same lamination batch.

We use epoxy AW106/HV935 (kit name 2011) produced by Ciba Geigy for flanges assembly and SF connecting struts gluing. To maximize stability of the ledge to ribbon gluing (see figure 3), we use the high modulus and high stability bi-component epoxy Master Bond EP30R, reinforced with glass fibers. The thermal conducting Master Bond EP21TDCANHT, filled with aluminum nitrate, was used in the ledges to glue the cooling pipe (see figure 3). This is a low modulus bi-component epoxy that absorbs the possible presence of thermal stress between cooling pipes and ledges.

5. – Mechanical stiffness studies

The most important constrain is the stability and stiffness of the SF. A Finite Elements Model (FEM) analysis of the SF displacements under 1.5 times the estimated loads conditions indicates a 30 μm maximum deflection in the middle of the structure.

6. – Cooling

The cooling system must remove $\simeq$ 1.5 KW generated by the front end electronics, maintaining silicon sensors temperature below 20^oC and the ISL front-end electronics below 30^oC. The cooling fluid is a mixture of water and 30% of ethylene glycol and the pipe outer diameter is 4.5 mm. The fluid flow is 0.6 l/min at -5^oC and the whole system is designed to operate below atmospheric pressure [6]. The difference inlet-outlet is $\simeq 1^o$C even in the case of the maximum number of ledges (nine) glued to one cooling channel. Inner and outer ledges have slightly different equilibrium temperatures because of their different thermal contact gluing length, respectively 35 mm and 50 mm [7]. In order to keep the pressure and temperature drop along the pipes within specs, the design foresees dividing each of the three (two) layers 6f/b/c (7f/b) into three (four) identical sectors and to have an indipendent cooling circuit for each sector.

7. – Flange construction

The construction of precision parts was done using precise gluing masks. This technique was tested for the first time on such large dimensions. The biggest gluing mask used is shown in figure 2. Its outer diameter is $\simeq$ 90 cm. The three necessary gluing masks were designed at Pisa INFN and manufactured, using stress-released stainless steel, by Vega 2000. Each mask has a ground master plane with a flatness ≤ 20 μm and a second plane for mask ledges (two of this planes are present in the double flange gluing mask). In figure 2 we see the 4 screws and 2 precision pins of each mask ledge. Each mask ledge has a 2 mm large slot in the middle. The quality of the three gluing masks

SF part	quantity	CF %	Al %	Be %	glue %	mass (Kg)
Flange 7	4	82.2	9.7	6.8	0.3	3.120
Flange 6	2	83.2	6.8	8.4	0.6	0.858
Double Flange	2	84.4	3.4	9.9	0.3	1.576
Spool Piece	1	92.5	7.3	-	0.2	0.752
Struts	-	100.	-	-	-	1.010
total SF	-	-	-	-	-	7.316

TABLE I. – *Mass inventory of the SF parts and relative content of carbon fiber, aluminum, beryllium and glue. From this table and section 2 we see that the SF supports* $\simeq 6.4$ *times his weight.*

was controlled and the maximum (measured) radial deviation from nominal value was 60 μm, while the maximum φ deviation was 2 mrad.

Flanges construction involves many steps. Once the basic hollow ring structure (with T shaped section) is built, special aluminum ledges are used to glue the CF ribbon. In this way a clearance of $\simeq 200$ μm between ribbon and beryllium ledges final position is provided and this avoid stress during the beryllium ledges gluing. The radial positioning of a beryllium ledge is obtained using the ground surface and the ground step of the gluing mask ledge that hold it (see figure 2). The φ positioning is obtained using a 2 mm precision pin (see figure 2) that fits through the slots of the mask and beryllium ledge.

To evaluate the reliability of the construction procedure, we compare gluing masks and flanges surveys. Taking in account known eccentricity, a maximum radial difference of $\simeq 30$ μm between gluing mask and beryllium ledge positions was measured.

We monitor the total flanges weight (m_i) after the curing of the glue, measuring negligible $\Delta m_i/m_i \simeq 10^{-3}$ effects. The final mass inventory for flanges and spool piece is reported in table I.

8. – Alignment procedure

At INFN Pisa we used a Coordinates Measuring Machine (CMM) DEA Brown and Sharpe that has an accuracy of (4.5 $\pm$ 5 L/1000) μm (where L is maximum dimension in mm of the measured object). All the surveys and alignments were done under the control of this CMM. Four supports, designed by INFN Bologna, were used to align the two half SF and then to build the spool piece. Each support is made of a ground stainless steel base and a vertical aluminum hollow plate with three bumps used to hold a flange. The three contact areas of the bumps are themself ground and define a plane with a flatness ≤ 20 μm similar to the flatness of the gluing masks master planes. The very good perpedicularity (maximum deviation from 90^o was 0.05 mrad) between the plane defined with bumps and the support base defines the parallelism of the flanges during alignment on the CMM plane.

Before alignment and construction of each half SF, each flange was surveyed with respect to a local coordinate system to record eccentricity and orientation of the mean axis of the two cylinders defined by internal and external ledges. After alignment of the supports, fine adjustment of flanges (once supported) was done. In this step of construction we take into account the previous measured characteristics to get the same average longitudinal axis for the four flanges. After alignment, the flange connecting struts were glued in a free state to avoid introducing stress.

The spool piece construction involves the two half SF relative alignment and was done using a similar procedure.

9. – Conclusions

The conceptual design and construction of the high dimensional stability carbon fiber support for the ISL and the CDF silicon trackers was reported. The strategies developed to monitor and control stress during assembly were illustrated as well as the challenge to equip the SF with an adequate cooling system. The achieved precision (ΔR/R$\leq 2.5{\cdot}10^{-4}$) for the beryllium ledges positioning confirm that the gluing mask technique could be used up to R$\simeq$1 m.

The SF was shipped and full assembled at Fermilab in summer 1999.

REFERENCES

[1] Toni Munar for the CDF-ISL collaboration, *The Intermediate Silicon Layers Detector*, These Proceedings.

[2] Valls J. for the CDF-SVX collaboration, *The CDF Silicon Vertex Detector*, to appear in *Proceedings of the Conference Vertex 98*, Santorini (Greece), September 1998, to be published on NIM A.

[3] CDFII Collaboration, *Technical Design Report*, FERMILAB-Pub-96/390-E, 1996.

[4] Robitaille S. Patz G. Johnson S., *Advanced Composite Stable Structures, Appropiate Materials for High Precision Detectors*, in *Proceedings of International Workshop on Advanced Materials for High Precision Detectors*, pp. 118, 1994

[5] Kuno K.U. Stellbrink, in *Micromechanics of Composites - Composites Properties of Fiber and Matrix Constituents*, edited by Carl Hanser Verlag, 1996, pp. 79

[6] Demina R. Kendziora C. Herren M., in *ISL Cooling System Test*, CDF internal note 4650, 1990

[7] Basti A. Mancini C. Gaggelli A. Moggi A. Palmonari F. Raffaelli F., in *The Intermediate Silicon Layers Cooling System*, CDF internal note 5034, 1999

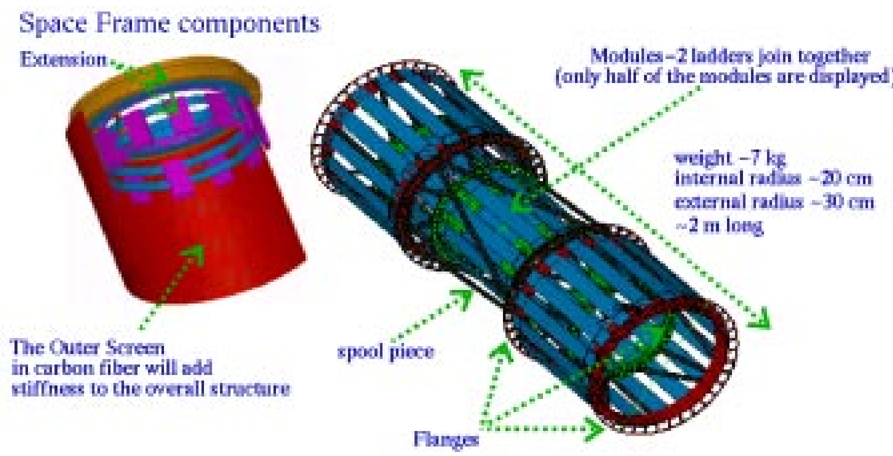

Figure 1: Project layout of the Space Frame (on the right) and of the extension (on the left). In the final assembly of the ISL detector, two extensions are connected at the space frame ends and a carbon fiber shell (outer screen) enclose the overall structure increasing its bending and torsional stiffness.

Figure 2: The biggest precision gluing mask (on the right) used for flange construction. On the left a detail of a smaller gluing mask during the beryllium ledges gluing. We distinguish the two precision pins that locate the mask ledges, the precision pins that gives the φ positioning to the beryllium ledges and the specials springs that hold them during the gluing operation.

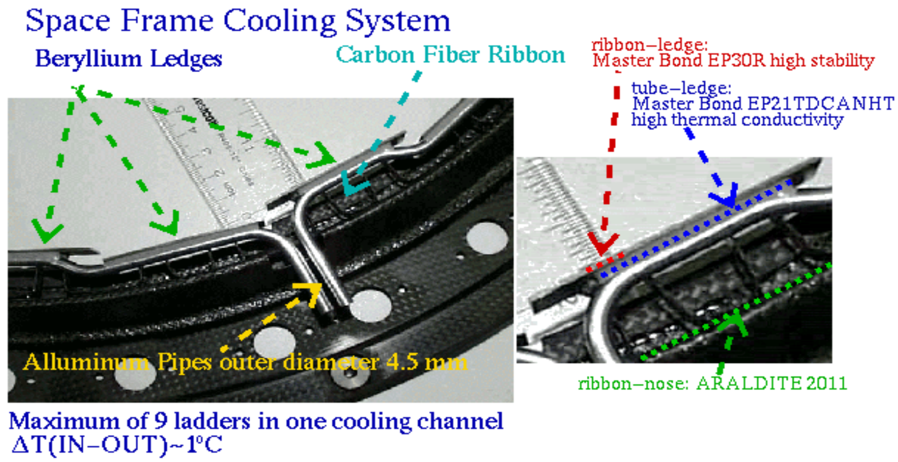

Figure 3: On the right, a detail of the thermal contact gluing of a beryllium ledge. The routing of the cooling pipes and their inlet and outlet ends (on the left).