Fermilab

Particle Physics Division 12-01-01

Mechanical Department Engineering Note

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Project: CDF_run_2b Silicon Detector Upgrade

Project Internal Reference:

Title: Space tube Design

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Abstract/Summary:

1. Introduction

The lower spacetube for CDF run2b has inner radius of 177mm and outer radius of 185mm. The overall length is 1946mm. It consists of one honeycomb and two carbon fiber composite skins. HexWeb HRH-36-1/8-3.0 from HEXCEL COMPOSITES will be used as the core material. The 12" wide Unidirectional Carbon Fiber Prepregs K1392U2K/BRYTE EX1515 from MITSUBISHI will be used as the skin material. Each skin has 0.384 mm in thickness. The skin lay-up is at (0,90,45,-45,-45,45,90,0). The fiber area weight of this prepreg is rated at 55 G.SM. The resin content of this prepreg is rated at 32%. Please note the "X" direction of the laminate and the "L" direction of the honeycomb are defined as the longitudinal direction of the tube. There are two u-channels made of the same carbon fiber composite to cover the rims of the spacetube. Two barrels, each barrel weighs 20 kg, are supported at four points on the rim of the tube. The cable load of 10 kg on each end of the tube is distributed evenly on the surface.

The spacetube is supported by ISL at three locations of

- One end at the 6 o'clock position referred to as the bottom support, all three DOF are fixed (Ball joint)
- The other end at the 3 o'clock position referred to as left side support, fixed in x and y (V-groove)
- The other end at the 9 o'clock position referred to as right side support, fixed in y only (plane)

Detail design should be referenced to the following drawings. They are:

1. Spacetube lower half assembly 2563.530-ME-405550
2. Spacetube cylinder lower half detail 2563.530-ME-405551
3. Spacetube right side support assembly 2563.530-ME-405552
4. Spacetube left side support assembly 2563.530-ME-405553
5. Spacetube lower support pad assembly 2563.530-ME-405554
6. Spacetube right support detail 2563.530-ME-405555
7. Spacetube left support detail 2563.530-ME-405556
8. Spacetube bottom support pad detail 2563.530-ME-405557
9. Spacetube support ball insert 2563.530-ME-405558

The carbon fiber composite skin material properties were calculated in CompsitePro. This software is a practical design and analysis tool, which has been accepted broadly in the composite industry. The skin lay-up of (0,90,45, -45, -45,45,90,0) is a quasi-isotropic lay-up, which exhibits the same properties in all directions. O degrees will address the minimum vibration frequency. +/- 45 degrees will handle the torsional stresses. 90 degrees will prevent torsional buckling. The results of these composite material properties can be found in the cdf_run2b folder under the name of "cf_material".

The HexWeb HRH-36 is manufactured using KEVLAR paper. The standard resin system is phenolic. It is a high performance non-metallic core. It can be readily heat formed to help produce complex components and offers similar mechanical properties to KOREX core as well as comparable moisture pickup. In addition, HexWeb HRH-36 offers a weight reduction over higher density Nomex honeycomb cores. This core supports the barrel loads in the t-direction in tension and compression, and in the L-t and W-t planes in shear. The t-direction refers to the thickness of a slice of honeycomb. The L-direction is parallel to the continuous sheet used to form the honeycomb, and the W-direction is perpendicular to the L-direction. The stiffness and strength of honeycomb in the L and W direction is very low, as are the L-W shear properties. The estimated engineering constants are obtained based on experimental data from HEXCEL. The detailed properties of this core can be found in the cdf_run2b folder under the name of "hexweb_HRH36".

2. Engineering Design and Verifications

The spacetube FEA study was performed in I-ideas. The combined shell and solid mesh was applied in the model to achieve the accuracy of the solution. The displacement of the spacetube under the design load must be less than 4mm due to its geometry constrains. 25 FEA models were built to optimize this displacement requirement, which included optimum composite material design through carbon fiber and core material selection and the lamina orientations and laminate lay-up design. The various reinforcing ring options were also investigated inside the tube. The detailed design results can be found in the cdf_run2b folder under the following names:

1. meeting 2-25-03.doc
2. meeting 2-28-03.doc
3. meeting 3-11-03.doc
4. meeting 3-25-03.doc
5. meeting 4-8-03.doc
6. meeting 4-15-03.doc
7. meeting 5-5-03.doc
8. meeting 5-12-03.doc
9. XN-A fiber data sheet folder
10. Fiber_volume.xls
11. barrel_angles.xls
12. Total of 22 FEA plots in PDF format

The maximum deflection of the spacetube in gravity direction is 0.76mm. The maximum deflection of the spacetube in X direction is 1.68mm. Please note the z direction refers to the longitudinal direction of the tube. The weight of the carbon fiber is 7.04 pounds. The weight of the core is 1.70 pounds. Thus, the total weight of the tube without the three supports is 9.1 pounds. The maximum displacement angle at barrel supports ranges from 255 to 466 microRad in gravity direction and from 177 to 1040 microRad in X direction.

To evaluate the accuracy of this design, four physical displacement measurement tests were conducted on the CMM at Lab C. The existing cdf_run2a spacetube was utilized to simulate the barrel loads on its rims. Later, a reinforcement ring was added to the center of the tube to repeat the tests. Two FEA models were built based on the true geometry and its composite material. The carbon fiber is GRANDCXN50/YLARS3 with fiber content of 60%. The core material is Dupont Korex 1/8" -3.0. Each skin thickness is 0.46 mm. The inner skin has a lay-up at (0, 60,-60) while the outer skin has a lay-up at (-60,60,0). Four test weights were fabricated to conduct these tests. The test procedure can be found in the cdf_run2b folder under the name of "test_procedure". The test set up pictures can be found in the cdf_run2b folder. A total of 12 photos are in the "CMM_photo" subfolder. The CMM measurements and FEA results on deflections are consistent. This comparison study can be found in the cdf_run2b folder under the name of "results_comparison". The detail calculation can be found in the cdf_run2b folder under the name of "old_cmm".

3. Fabrications and Procurement

Nine leading composite manufacturers were contacted to bid on this project. Six out of nine companies responded to this inquiry. Three fabrication options were considered in order to satisfy the tight tolerance of the spacetube. However, option 1 would yield the highest quality compared with options 2 and 3.
Option 1

> Fabricate each skin separately (i.e. lay-up and cure each skin on a separate tool). Next, secondarily bond the skins to the honeycomb using one or both of the skin fabrication tools as a bonding jig.

Advantages:

This approach provides optimal compaction, flatness and surface finish of both skins. There is no possibility of the honeycomb cell edges telegraphing through the skins. The highest quality, strongest and stiffest structure will be achieved as well as optimal dimensional control.

Issues:

Duplicate tooling will be required for inner and outer skins. A separate film adhesive is needed to bond the skins to the core. A slight increase in weight will be seen due to the additional adhesive. It may not be possible to use both tools as a bonding jig due to stack-up clearance. This is the highest cost option.

- Option 2

Pre-cure the critical skin separately on its own tool. Next, secondarily bond the skin to the honeycomb while co-curing the bag side skin to the honeycomb using the original tool as a bonding jig.

Advantages:

This approach provides optimal compaction, flatness and surface finish of the pre-cured skin. There is no possibility of the honeycomb cell edges telegraphing through the pre-cured skin. Good dimensional control of the pre-cured skin will be achieved. Only one tool is required. This will be a lower cost option than option 1.

Issues:

A separate film adhesive is needed to bond the pre-cured skin to the core. A slight increase in weight will be seen due to the additional adhesive. The bag side (non-tool) skin will be less well compacted, less flat and will exhibit a typical bag side surface finish. There is a possibility of honeycomb cell edge telegraphing on the bag side. The bag side skin will possess less dimensional control than option 1. This option provides less structural strength and stiffness overall.

- Option 3

Fabricate and co-cure both skins to honeycomb in one step using a single tool on the critical side.

Advantages:

Good flatness and surface finish of the tool side skin can be achieved as well as good dimensional control of the tool side skin. Only one tool is required. This is the lowest cost option.

Issues:

Tool side skin will be less well compacted. The bag side of skin will be less compacted, less flat and will exhibit a typical bag side surface finish. There is a possibility of the honeycomb cell edges telegraphing through both skins. The bag side skin will possess less dimensional control. This option provides less structural strength and stiffness than options 1 and 2.

The tooling material options were also investigated to minimize thermal distortion of the tool during heat up and cure. The carbon composite tool has the most significant advantage to dimensional stability. The other advantage of this type of tooling is lower weight than metal tool.

The fabrication cost of the spacetube was summarized under various options. The detailed study can be found in the cdf_run2b folder under the name of “bids_summary”. It is my assessment that Chattahoochee Specialty could be the most reliable vendor for this project.