SDC SOLENOID DESIGN NOTE #127

TITLE: Feasibility Study of a Titanium Honeycomb Vacuum Shell

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ABSTRACT: This design note contains a feasibility study of a titanium honeycomb vacuum shell. An approximate approach is used to calculate the stiffness of honeycomb vacuum shell and its thickness. It shows that the radiation length of a titanium honeycomb is about twice the aluminum honeycomb even though the skin thickness is less for titanium.

COMPUTATIONAL METHOD:

(1). The Relation Between the Critical Collapsing Pressure Pcr and the Shell Thickness t

The cylindrical shell subjected to an external pressure will fail due to the buckling. The Compressed Gas Association For Cryogenic Liquid Cargo Tank Specification For Cryogenic liquid (CGA-341-1987) recommends a following equation to calculate the critical collapsing pressure Pcr

$$Pcr = \frac{2.6E\left(\frac{t}{D}\right)^{2.5}}{\frac{L}{D} - 0.45\left(\frac{t}{D}\right)^{0.5}} \qquad (1)$$

Fast[1] has modified this equation and give a relation to calculate the minimum thickness t. for a given Pcr :

$$t = \left(Pcr \cdot D^{2.5} \cdot \frac{L}{D} \cdot \frac{1}{2.6E}\right)^{0.4} \qquad (2)$$

The CGA standard requires that Pcr $\geq$ 30 (psi). For a shell made of solid aluminum plate, E=10 msi, D=160.6", L=315", this gives t_{min}=0.866" [1].

The plate stiffness can be calculated as following

$$D_{al} = \frac{E_{al} \cdot t_{al}^{3}}{12 \cdot (1 - \mu^{2})} \tag{3}$$

We know that the characteristic of the vacuum shell is governed by buckling phenomena, which basically is a bending model. If we could find a honeycomb structure offering the same stiffness as a 0.866"aluminum plate, equation-2 should be satisfied.

$$D_{h}(honeycomb) = D_{al}(solid\, plate) = \frac{E^{3} \cdot t_{al}^{3}}{12 \cdot (1 - \mu^{2})} = \frac{E_{al} \cdot 0.886^{3}}{12 \cdot (1 - \mu^{2})} \tag{4}$$

(2) The Calculation of the Stiffness of the Honeycomb Plate D_h

It is assumed that the core material provide no stiffness to the structure[2]. The section stiffness will be

$$D_{h} = \frac{E \cdot h^{3}}{12 \cdot (1 - \mu^{2})} - \frac{E \cdot c^{3}}{12 \cdot (1 - \mu^{2})} \tag{5}$$

where E is the modulus of the skin material, μ its possion ratio, h is the total thickness of the honeycomb and c is the core thickness. By setting D_{al}=D_h and neglecting the difference between μ (Ti) and μ (Al), it gives

$$h^{3} - c^{3} = \frac{Eal}{E} \cdot 0.866^{3} \tag{6}$$

If the skin and the honeycomb are both aluminum, E will be equal to Eal and equation (6) becomes

$$h^{3} - c^{3} = 0.866^{3} \tag{7}$$

We take h=1.5" and calculate the skin thickness t_s(al)

$$t_s(al)=\frac{h-c}{2}=0.055" \qquad (8)$$

which is very close to the data calculated by HEXCEL(h=1.5", t_s=0.0625"). In the case of titanium alloy, E(Ti)=16 msi, the equation (6) gives a skin thickness t_s(Ti)=0.042". The radiation length RL of the two skins is

RL(Ti) = 0.042" x 2 x 25.4/37.5 = 0.063 (Xo)

RL(Al) = 0.0625 x 2 x 25.4 / 90 = 0.035 (Xo)

CONCLUSION: It seems to us that the titanium material gives no advantage when the radiation length RL is to be considered as a major concern. In fact, the equation (6) shows that the skin thickness of shell is inversely proportional to a cubic root of modulus for a given material. Titanium has a modulus only 1.6 times the aluminum, but its radiation length per unit thickness is about 2.5 times the aluminum. It indicates that the thickness reduction is trade off by radiation length and give an even worth result for this particular case.

REFERENCES:

1. Ron Fast , "CGA Equation for Homogeneous Outer Vacuum Shells; Shell Thickness For Typical Material", SDC DN-126, Dec. 20, 1990
2. J.H. Fanpel, F.E.Fisher , " Engineering Design", Wiley-Interscience, 1981, pp 320-325