Fermilab

SDC SOLENOID DESIGN NOTE #126

TITLE: CGA Equations for Homogeneous Outer Vacuum Shells; Shell Thickness for Typical Materials

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ABSTRACT: This design note gives the CGA equation for the thickness of a homogeneous vacuum shell as a function of the shell dimensions and the modulus of the material of which it is constructed. It also gives the thickness of one radiation length of several possible shell materials and a figure of merit for each.

EQUATIONS FOR THICKNESS OF A HOMOGENEOUS VACUUM SHELL

The Compressed Gas Association Standard for Insulated Cargo Tank Specification for Cryogenic Liquids (CGA-341-1987) contains the following equation for P_c, the critical collapsing pressure:

$$P_c = 2.6E\ (t/D)^{2.5}/[(L/D) - 0.45(t/D)^{0.5}]. \tag{1}$$

For a given L/D and E (modulus of elasticity), a t may be calculated. The CGA standard requires that $P_c \geq 30$ psi.

I rearranged Eq. 1 to get

$$t(\text{exact}) = \{P_c D^{2.5}[(L/D) - 0.45(t/D)^{0.5}]/2.6E\}^{0.4} \tag{2}$$

and defined t(approx) as

$$t(\text{approx}) = \{P_c D^{2.5}(L/D)/2.6E\}^{0.4}. \tag{3}$$

Obviously t(approx) ≥ t(exact), but since Eq. 3 is so easy to use I put in some typical numbers to see how different t(approx) and t(exact) really are. For L = 315", D = 160.0" and t = 1"

$$t(\text{exact}) = \{P_c D^{2.5}(1.9259)/2.6E\}^{0.4} \tag{4}$$

$$t(\text{approx}) = \{P_c D^{2.5}(1.9614)/2.6E\}^{0.4} \tag{5}$$

and $t(\text{approx}) = 1.0073t(\text{exact})$. (6)

For t = 0.5", $t(\text{approx}) = 1.005t(\text{exact})$. (7)

I concluded from this that the approximate equation for t (Eq. 3) is adequate for the outer vacuum shell of the SDC solenoid.

SHELL THICKNESS FOR TYPICAL MATERIALS

I solved Eq. 3 with P_c = 30 psi, D = 4.08 m = 160.6", L = 8 m = 315":

$t = (7.397 \times 10^6/E)^{0.4}$, where E is in psi and t is in inches. (8)

and calculated t for the various values of E given in the table below. I plotted t vs E in the attached figure.

E (Msi)	$t^{2.5}$	t(in)	Materials with this E	Ref.
8	0.925	0.969	CFRP-cloth	Wake
10	0.739	0.886	Aluminum, CFRP-FW (filament wound)	-- SCI
15	0.493	0.754	Ti alloys (E = 16)	--
20	0.370	0.672	CFRP-FW (?)	SCI
25	0.296	0.614	Aluminum MMC (metal matrix composite)	R&D
30	0.246	0.571	Stainless steel, Inconel 718	-- HA

The thickness of one radiation length (RL) of various materials which could be considered for the outer vacuum shell is given below, along with a figure of merit (FOM) for each. The thickness of the shell in radiation lengths (X_0) is inversely proportional to the FOM,

$t(X_0) \propto 1/(E^{0.4}\ RL) = 1/FOM$ (Units of FOM are $Msi^{0.4}$-mm)

Material	RL (mm)	FOM	Normalized FOM
Copper	14.5	NA	NA
Inconel 718	16.4	64	0.28
Stainless steel	17.3	67	0.30
Titanium alloys	37.2	113	0.5
Aluminum	90.0	226	1
Aluminum MMC	? if 30,	? then 326	? 1.44
GFRP (G-10, E = 3.2)	180.	286	1.27
CFRP (FW, E = 10)	240.	603	2.67
DacronFRP	360.	?	?

REFERENCES

HA "Inconel Alloy 718," Huntington Alloys

SCI "Advanced Composite Structures," Structural Composites Industries

R&D R & D Magazine, Nov. 1990, p. 60

Wake Masayoshi Wake, "CFRP Vacuum Chamber for a Large Superconducting Magnet," KEK