SSC DETECTOR SOLENOID DESIGN NOTE #20

TITLE: Charge/Discharge Times, Eddy Current Power and Energy

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SUMMARY: A charge voltage of ~30 V will permit the magnet to be charged in about 3 hours with an eddy current power of a few watts in each 2-m coil/LHe vessel module. The eddy current heat load during a fast dump (R_{FD} = 0.1 Ω, τ = 600 s) is 645 W per 2-m coil module, which would probably quench the module. I propose that the coil be discharged through R_{FD} only if a quench is detected; otherwise it would be discharged through a slow dump resistor (R_{SD} = 0.01 Ω, τ = 6000 s, P_E'(max) = 6.5 W).

I. Charge time

During a charge

$$V_L = \text{voltage across coil}$$
$$= L \, dI_L(t)/dt$$

Assuming a constant voltage charge from $I_L(t) = 0$ to 5 kA and L the inductance of an 8-m assembly (four, 2-m coils in series electrically),

$$t_{chg} = L\, I_L(t_{chg})/V_L = (60\,H)(5000\,A)/V_L$$
$$= 30 \times 10^4\, s \cdot V / V_L$$

$P_{PS}(t)$ = power drawn from power supply

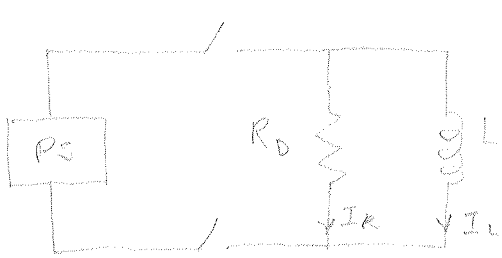
$$= V_L \left[I_L(t) + I_R(t) \right]$$

At $t = 0$: $I_L(0) = 0$, $I_R(0) = V_L/R_D$

$t = t_{chg}$: $I_L(t_{chg}) = 5\,kA$, $I_R(t_{chg}) \sim 0$

$$P_{PS}(max) = V_L\, I_L(t_{chg})$$

Circuit



$L = 60\,H$ (8-m unit)

V_L (V)	P_{PS} (max) (kW)	dI_L/dt (A/s)	t_{chg} (s)	(h)
15	75	0.25	20×10^3	5.6
20	100	0.33	15×10^3	4.2
30	150	0.50	10×10^3	2.8
60	300	1.0	5×10^3	1.4

II. Discharge time – fast dump

$R_{FD} = 0.1\,\Omega$ to limit discharge to 500 V across terminals

$$I_L(t) = I_L(0)\, e^{-\frac{R_{FD}}{L} t}$$

$$= (5000\,A)\, e^{-t/600}$$

$$V_L = I_L(t)\, R_{FD}$$ (No quench, or for $R_{FD} > R_Q$)

$$= (500\,V)\, e^{-t/600}$$

III. Eddy current heating in helium vessel during charge

The changing current in the coil induces a voltage $V_E = M\, dI_L/dt$ in the helium vessel and hence an eddy current $I_E = V_E/R_E$.

The power dissipated in the vessel due to this eddy current

$$P_E(t) = V_i^2/R_E = \left(M\, dI_L/dt\right)^2/R_E$$

where

M = the mutual inductance between the coil and the helium vessel

R_E = circumferential resistance of the helium vessel

To estimate R_E of 2 m module

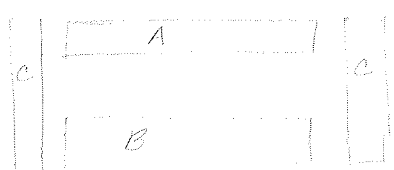


Plate A : $1880 \times 35\ mm^2$

B : $1880 \times 50\ mm^2$

C : $244 \times 35\ mm^2$

A_E = cross section of helium vessel

$= (1880 \times 35) + (1880 \times 50) + 2(244 \times 35) \times 10^{-6}\ m^2$

$= 0.1769\ m^2$

$$R_E = \frac{(\rho_{SS} @ 4.5K)(\text{vessel circumference})}{A_E}$$

$$= \frac{(50 \times 10^{-10}\ \Omega\text{-}m)^* (9.5\pi\ m)}{0.1769\ m^2}$$

$$= 84.4\ \mu\Omega$$

* From S.C. Machinery Handbook for 304L at 4.5 K

To estimate M

$M =$ flux linked by the vessel per unit coil current

$$= \frac{\Phi(I_{L\,max})\ (1\ \text{turn})}{I_{L\,max}}$$

$$\sim \frac{(2T)(\frac{1}{4}\pi\ 9.5^2)(1)}{5000}$$

$$= 0.028\ H$$

To estimate P_E during charge (2-m module)

$$P_E(t) = (0.028)^2 (dI_L/dt)^2 / 84.4\times10^{-6}$$

$$= 9.3\,(dI_L/dt)^2\ \text{W}$$

		For 2-m module	
V_L (V)	dI_L/dt (A/s)	P_E (W)	E_E (kJ)
15	0.25	0.58	11.6
20	0.33	1.01	15.2
30	0.50	2.33	23.3
60	1.0	9.3	46.5

Where E_E = energy absorbed by helium vessel during charge

$= P_E\, t_{chg}$

IV. Eddy current heating during fast discharge

$P_E'(t)$ = power dissipated during fast discharge - 2-m module

$$= (M\, dI_L/dt)^2 / R_E$$

$$\frac{dI_L}{dt} = \frac{d}{dt}\left(I_0\, e^{-t/600}\right)$$

$$= -\frac{I_0}{600}\, e^{-t/600}$$

$$\therefore \quad P_E'(t) = \frac{M^2 I_0^2}{600^2 R_E}\, e^{-2t/600}$$

$$P_E'(max) = \left[\frac{(0.028)(5000)}{600}\right]^2 / R_E$$

$$= 645 \text{ W per 2-m module}$$

$$E_E'(t) = \left(\frac{MI}{600}\right)^2 \frac{1}{R_E} \int_0^\infty e^{-2t/600}\, dt$$

$$= \left(\frac{MI}{600}\right)^2 \frac{1}{R_E}\,(300) = 300\, P_E'(max)$$

$$= 194 \text{ kJ per 2-m module}$$

This heat load appears to be unacceptably large for a routine discharge, i.e. it may cause the coil to quench. Therefore the coil will be discharged through the $0.1\,\Omega$ resistor only if a quench is detected. A "slow" discharge resistor, $R_D' = 0.01\,\Omega$, could be used to reduce the eddy current heat load to 6.5W during discharge. The energy deposited in the vessel during a slow dump is 19.4 kJ.