SSC DETECTOR SOLENOID DESIGN NOTE #32

TITLE: Indirectly Cooled Coil: Preliminary Conductor Design from Quenching Considerations

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SUMMARY:

At the very beginning of our study we concluded that since the coil could be thick it would be pool boiling and cryostable. Bob Kephart has pointed out that we should consider an indirectly cooled coil, at least to the point of showing whether or not it could be considered for the SSC detector magnet. I have begun this by looking at what a conductor might look like for an indirectly cooled coil that has the same maximum hot spot temperature as the conductor we have been using for the pool boiling design. My conclusion from some simple-minded calculations and from looking at other indirectly cooled solenoids is that the 1 GJ SSC solenoid could be made quench-safe by using a sufficiently low current density, as we did for the pool boiling case, and that the conductor to do this is reasonable.

I don't think we can eliminate an indirectly cooled coil design on the basis of quench safety. I will look into the operating stability margin next.

APPROACH:

In this note I will determine a conductor current density from a first-guess quench analysis. Such an analysis assumes that the quench is adiabatic, that the dump resistor is much larger than the resistance of the normal zone, $\tau = L/R_D$, and that the conductor is all aluminum. Starting from a maximum hot spot temperature I worked backward to a maximum current density in the aluminum and then to conductor/aluminum dimensions.

ASSUMPTIONS: $B_0 = 1.7$ T, $I_0 = 5000$ A,
Same electrical circuit as PB coil: L = 100 H, $R_D = 0.1\ \Omega$
Same 2-m modular design as PB coil

EXCITATION: NI(1.85 T) = 3.043 MA-turns per 2-m module
Estimate NI(1.7 T) = 2.8 MA-turns per 2-m module
NI/z(1.7 T) = 2.8 MA/1.812 m = 1.55 MA/m = 1.55 kA/mm

QUENCH SAFETY CRITERIA: Same maximum hot spot temperature as PB coil, $\theta_m = 100$ K. For an all aluminum conductor (ignoring copper and Nb-Ti) with RRR = 1500, this means a maximum $U(\theta_m) = 6 \times 10^{16}\ A^2\text{-s-m}^{-4}$. (See Fig. 1 in Design Note 29.)

FIRST GUESS CURRENT DENSITY: $J_0^2 L/2R_D = U(\theta_m)$, where J_0 = maximum allowable current density in the aluminum stabilizer.

$$J_0 = [2U(\theta_m)/L/R_D]^{1/2} = [12 \times 10^{16}/10^3]^{1/2}$$
$$= 1.095 \times 10^7 \ A/m^2 = 11 \ A/mm^2$$

Note that for a copper conductor with RRR = 100, $U(\theta_m) = 7 \times 10^{16}$ for θ_m = 100 K and J_0 = 11.8 A/mm^2; the current density for an indirectly cooled coil is about the same as for a pool-boiling one.

CONDUCTOR DIMENSIONS: If ΔR = radial dimension (width), Δz = axial dimension (thickness), and n = number of layers,

$$\Delta z \Delta R J_0 = I \text{ and } \Delta z = I/(1/n)(NI/z); \text{ therefore } \Delta R = I/J_0 \Delta z = (NI/z)/(1/n)$$

For I = 5 kA, NI/z = 1.55 kA/mm and J_0 = 11 A/mm^2,

$$\Delta z = 3.22n \text{ mm}, \ \Delta R = 141/n \text{ mm and } \Delta z \Delta R = 454 \text{ mm}^2.$$

The dimensions of a conductor for a indirectly cooled 1 GJ solenoid of 1 - 4 layers are given in Table 1 and compared with those of other aluminum stabilized detector magnets in Table 2. I believe that the conductor for a 3-layer design is quite feasible even though aluminum cross-sectional area is larger by a factor of 3.6 than the largest conductor used heretofore (Aleph).

SUMMARY: In Table 4 I give some numbers that I took from papers written about recent thin, aluminum stabilized solenoid coils. In Fig. 1 and 2 I have plotted J_0 and θ_m as a function of stored energy. My choices of 11 A/mm^2 and 100 K for a 1000 GJ magnet seem consistent with these other magnets, even though I am extrapolating by a factor of 7.3 in stored energy. My conclusion from this is that if a 9.67 x 47 mm conductor is in fact feasible (I have not checked with possible vendors about this) then an indirectly cooled 3-layer solenoid will be safe against damage during a quench.

I have thought a little bit about the coil design. I would stick to 2 m coil modules. I would wind each layer on the inside of an outer support cylinder which had circumferential thermosiphon cooling channels extruded or welded in it. The three coil assemblies would then be nested and attached together at the ends to form a monolith with respect to the forces. As with the pool boiling design, the 2-m modules would be bolted together into an 8-m cold assembly, which would be attached to the vacuum vessel with an appropriate support system.

Table 1. Dimensions of Aluminum Conductor for θ_m = 100 K

n	Δz (mm)	ΔR (mm)	$\Delta R/\Delta z$
1	3.22	141.	43.79
2	6.44	70.5	10.95
3	9.67	47.	4.86
4	12.89	35.25	2.73

Table 2. Aluminum Conductors for Large Solenoids

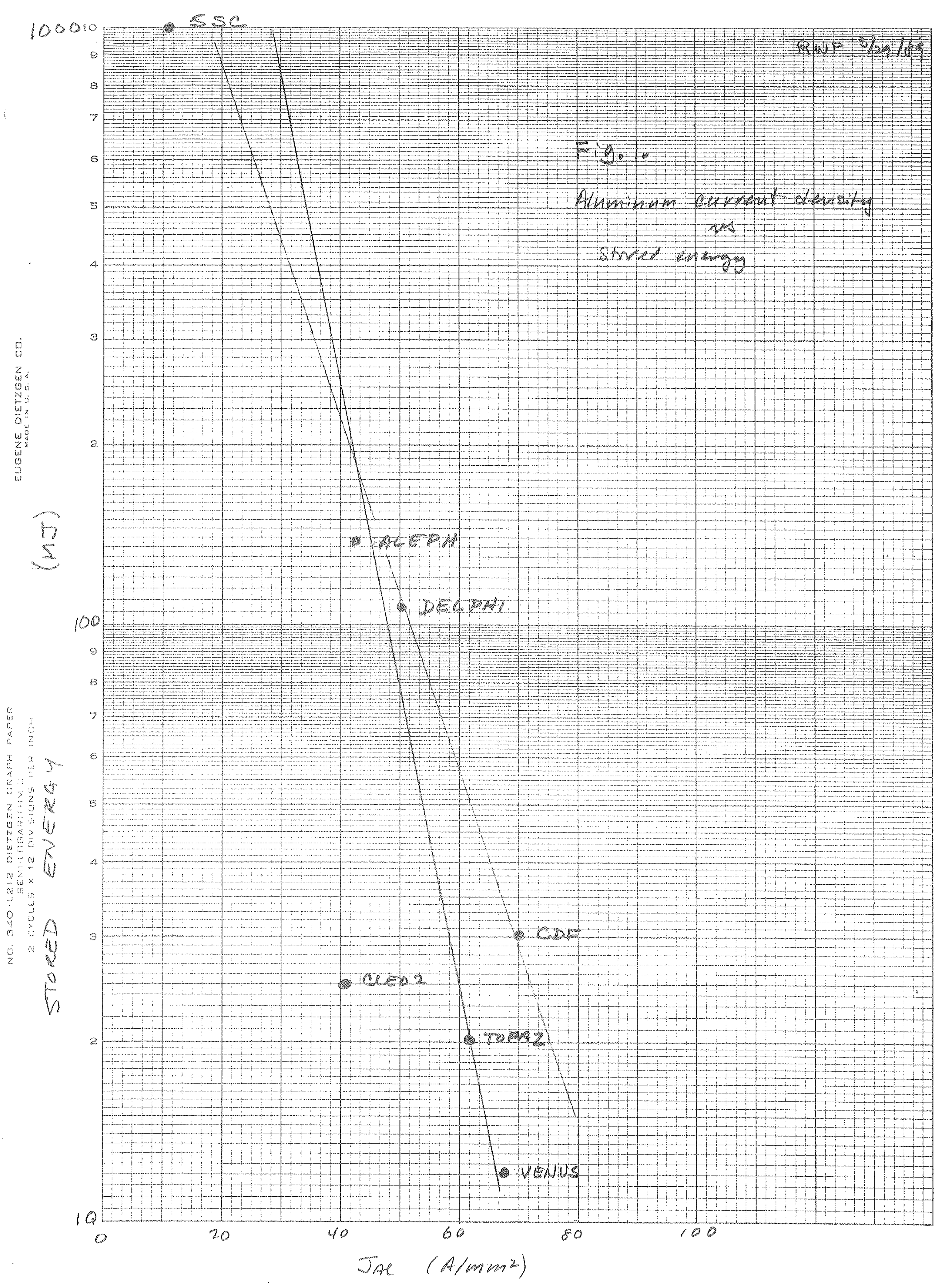
Magnet	Energy (MJ)	I_0 (kA)	Cond. Dim. (mm x mm)	Cond. Area (mm^2)	$\Delta R/\Delta z$
Venus	12	4.0	6.6 x 10	66.0	1.5
Topaz	20	5.0	3.6 x 18	64.8	3.65
Cleo 2	25	3.3	5.0 x 16	80.0	3.2
CDF	30	5.0	3.89 x 20	77.8	5.14
Delphi	108	5.0	4.5 x 24	108.	5.33
Aleph	137	5.0	3.6 x 35	126.	9.72
SSC-IC 3-layer	1000	5.0	9.67 x 47	454	4.86
SSC-PB 1.85 T	1000	5.0	18 x 26	468	1.44

Table 3. θ_m for Large Solenoids

Magnet	L/R_D (H/Ω)	τ* (s)	J_0(Al) (A/mm^2)	$U(\theta_m)$** (A^2-s-m^{-4}) x10^{16}	RRR	θ_m (K)
Venus	1.3/0.1	13	67.2	2.94	1000-1500	~37
Topaz	3.0/0.147	20.4	62.0	3.92	1500	50
CDF	2.4/0.076	31.5	70.4	7.8	1500	195
Delphi	?	60	49.7	7.42	1500	170
Aleph	?	90	42.8	8.25	2000	195
SSC	100/0.1	1000	11.0	6.05	1500	100

* Calculated from L and R_D, not observed value.

** $U(\theta_m) = 0.5 J_0^2 \tau$


RWF 5/29/89
Fig. 1
Aluminum current density vs Stored energy
SSC
ALEPH
DELPHI
CDF
CLEO 2
TOPAZ
VENUS
STORED ENERGY (MJ)
JAl (A/mm²)
1000
100
10
0
20
40
60
80
100
EUGENE DIETZGEN CO. MADE IN U.S.A.
NO. 340-L212 DIETZGEN GRAPH PAPER SEMI-LOGARITHMIC
2 CYCLES X 12 DIVISIONS PER INCH

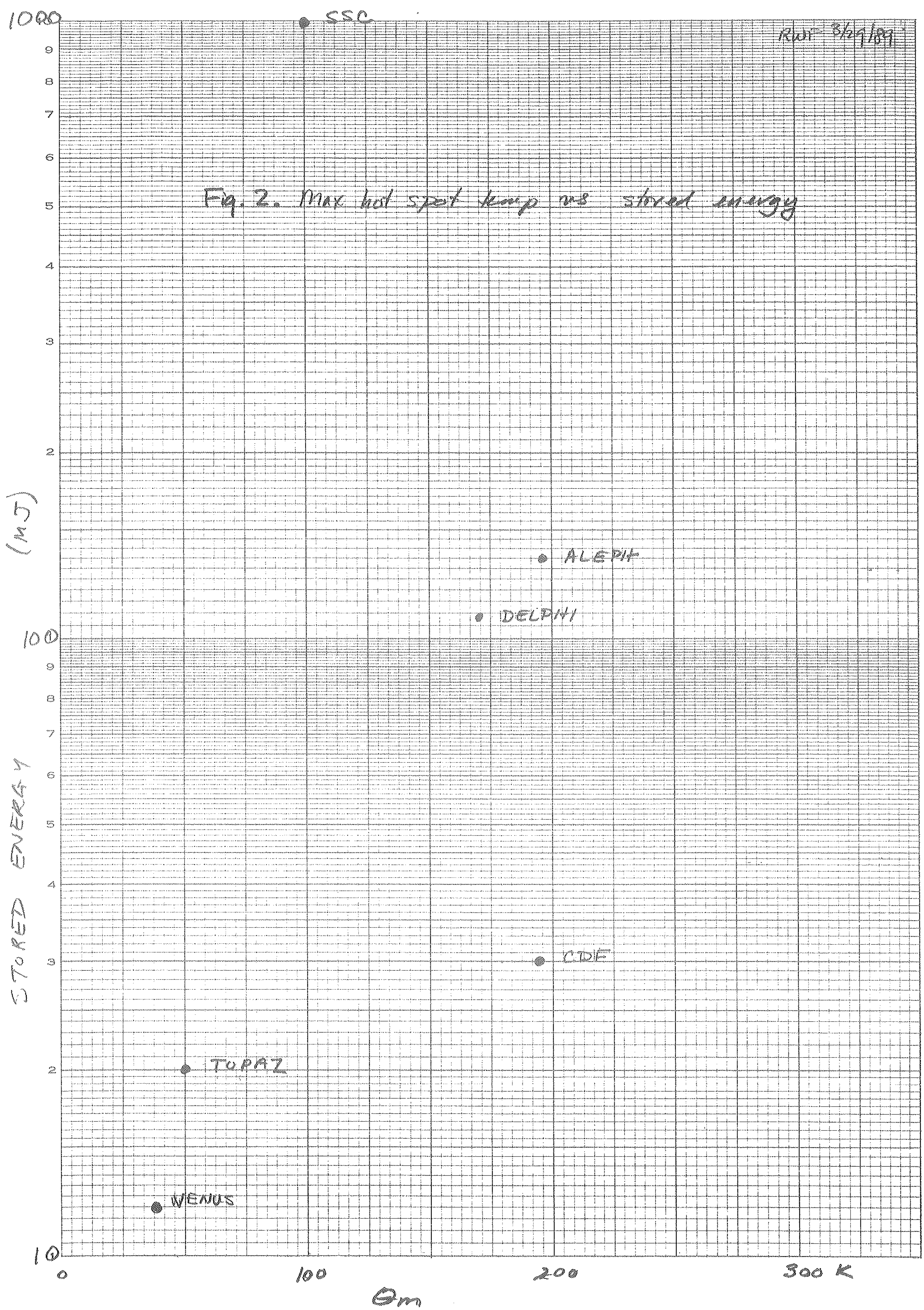


Fig. 2. Max hot spot temp vs stored energy