Accelerator Development Department

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# ANALYSIS OF THE ENERGY FLOW FROM THE "HOT SPOT" IN A QUENCHING SUPERCONDUCTING MAGNET, DD0017 AND SLN-012

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# Analysis of the Energy Flow From the "Hot Spot" in a Quenching Superconducting Magnet, DD0017 and SLN-012

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Magnet DD0017 was equipped with spot heaters and potential taps arranged so that the details of the physical process associated with a quench can be studied. The experiment consisted of firing the "spot heater" and measuring the electrical potential vs time developed across a short length of the conductor. From this information and the knowledge of temperature vs resistance of the conductor including magnetoresistive effects, the temperature-time function can be computed, see Figure 5. Since the enthalpy vs temperature of the cable is also known, the thermal energy deposited in the observed length of cable can be computed. When this energy is subtracted from the electrical E x I input, quantities of missing energy are observed. These results are shown in Figures 1, 2 and 3 for the various events observed.

For the early part of the quench, only a small part of the electrical input energy is used to raise the conductor temperature. Helium expansion removes the balance of this electrical input energy and results in a lowering of the temperature of the "hot spot".

The piece of cable under observation consists of the following:

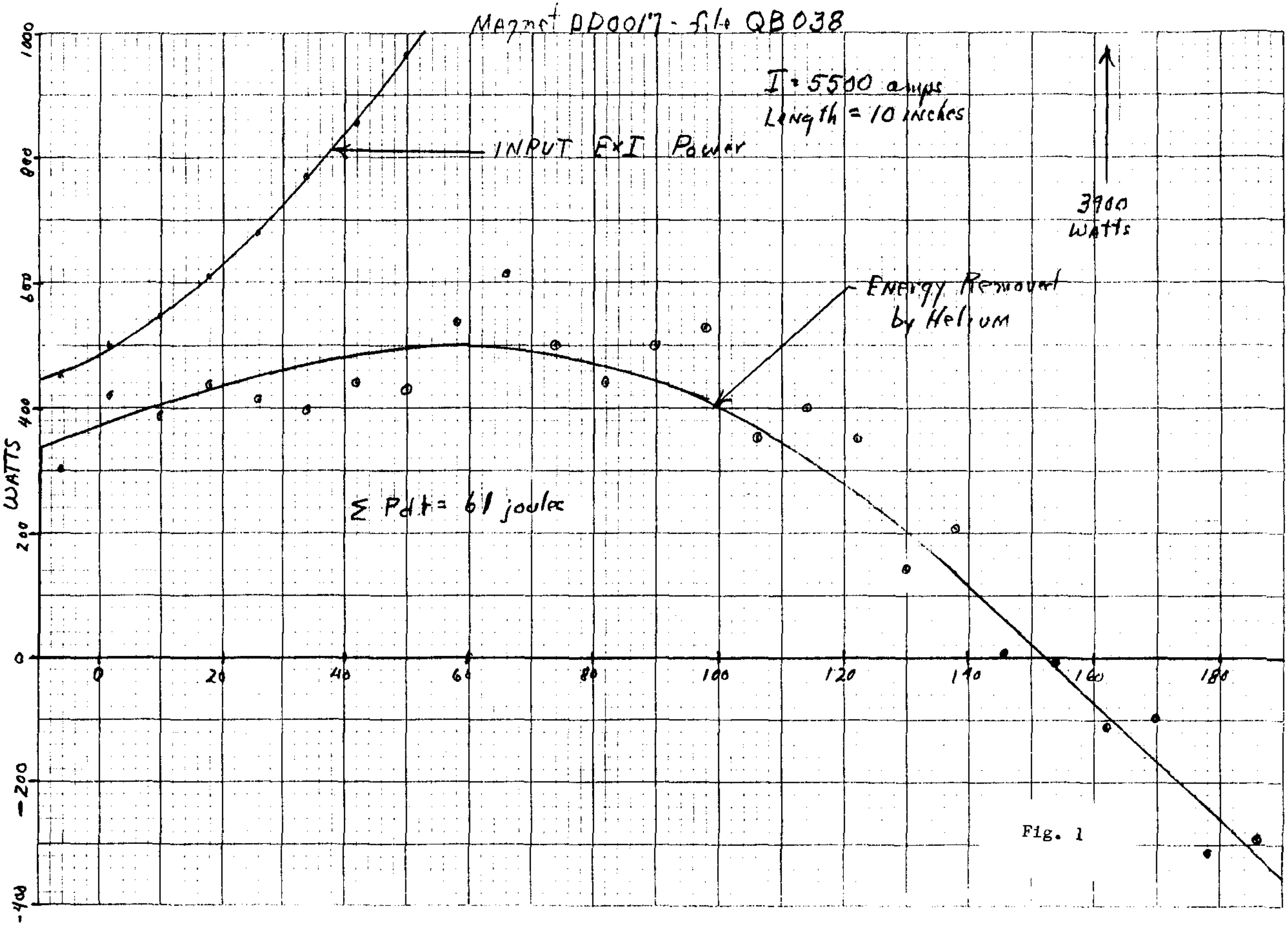
| | |
|---|---|
| Length | 10. inches (4" in SLN-012) |
| Width | 0.366 inches |
| Thickness, avg. | 0.0574 inches |
| No. of wires | 23 |
| Copper/superconductor ratio | 1.6:1 |
| Wire diameter | 0.0318 inches |
| Wire area, total | 0.11785 $cm^2$ |
| Helium volume | 0.4483 $cm^3$ |
| Mass | 0.0624 grams |
| Temperature | 4.3 K |
| Helium pressure | 5.0 atms (1 atm, liquid in SLN-12) |

The integral under the power-time curve for the removed energy is shown on the respective figure. This energy must be carried away by warmed and expanding helium. The T-S diagram for the process described in Figure 1 in shown in Figure 4. A unit mass of helium moves from point A to point B by two imaginary processes. First, a constant volumn (no work) heating to 52.5 K, the time average temperature (see Figure 5), followed by a constant temperature expansion back to the 5 atms. pressure line. The thermal energy required to move from point A to point B along this path is given by $J/M = (H_2 - H_1) + T(S_2 - S_1)$. Using the values shown on Figure 4, J becomes 69.4 joules and is in fair agreement with the measured missing thermal energy of 61 joules.

This expanding gas is working against the vicious friction of other helium which may, through friction, deposit heat ahead of the quench front and be part of the mechanism that accelerates the quench.

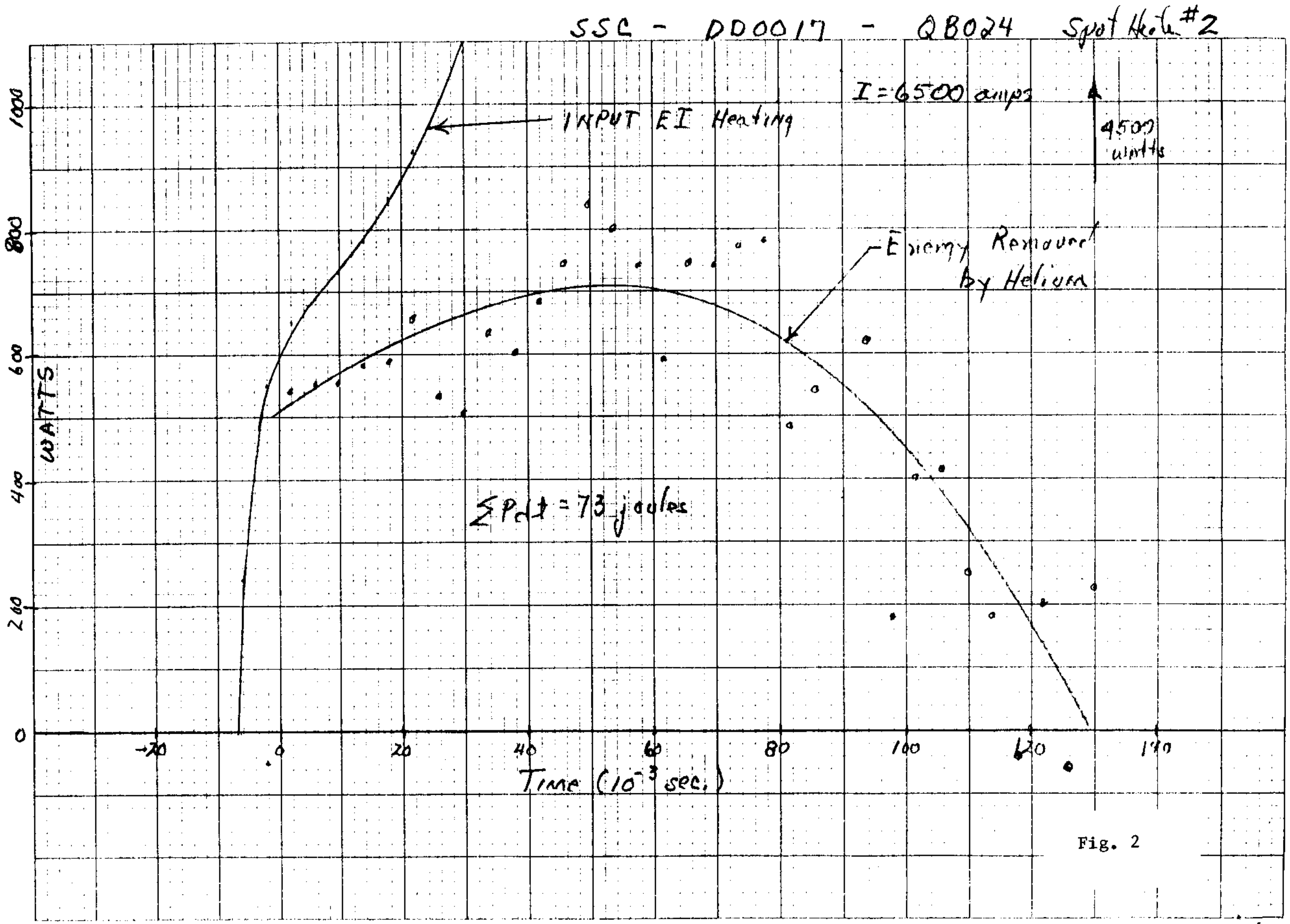
While the mechanism for quench acceleration is speculative, the cooling is clear. Figure 6 shows the adiabatically computed MIITS-temperature relationship and experimental measurements of the same. The measured relationship is clearly shifted toward lower temperatures, similar to that indicated by the cooling calculated above.

The measured results reported for magnet DD0017 represents MIITS vs temperature for the single event indicated. Those reported by Ganetis and Prodell are the peak values observed on different events. This explains the difference in shape of the two curves. If one believes that 800K represents the cable burnout temperature then this cable can go to 14 MIITS.



Magnet DD0017 - file QB038
I = 5500 amps
Length = 10 inches
INPUT E×I Power
3900 watts
Energy Removal by Helium
Σ Pdt = 61 joules
WATTS
1000
800
600
400
200
0
-200
-400
0
20
40
60
80
100
120
140
160
180


Fig. 1



SSC - DD0017 - QB024 Spot Heater #2
I = 6500 amps
4500 watts
INPUT EI Heating
Energy Removed by Helium
$\Sigma P dt$ = 73 joules
WATTS
1000
800
600
400
200
0
-20
0
20
40
60
80
100
120
140
Time ($10^{-3}$ sec.)


Fig. 2

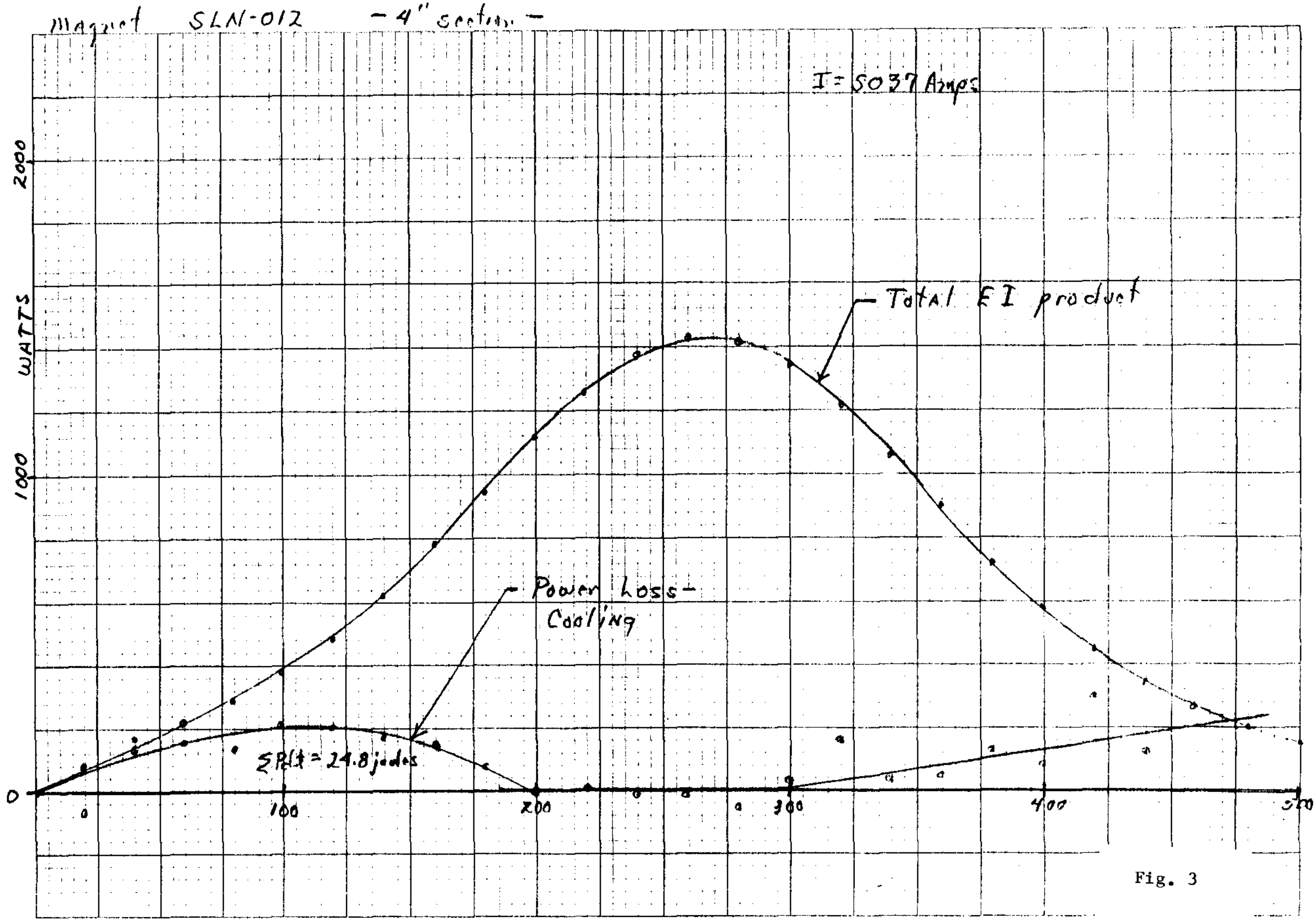
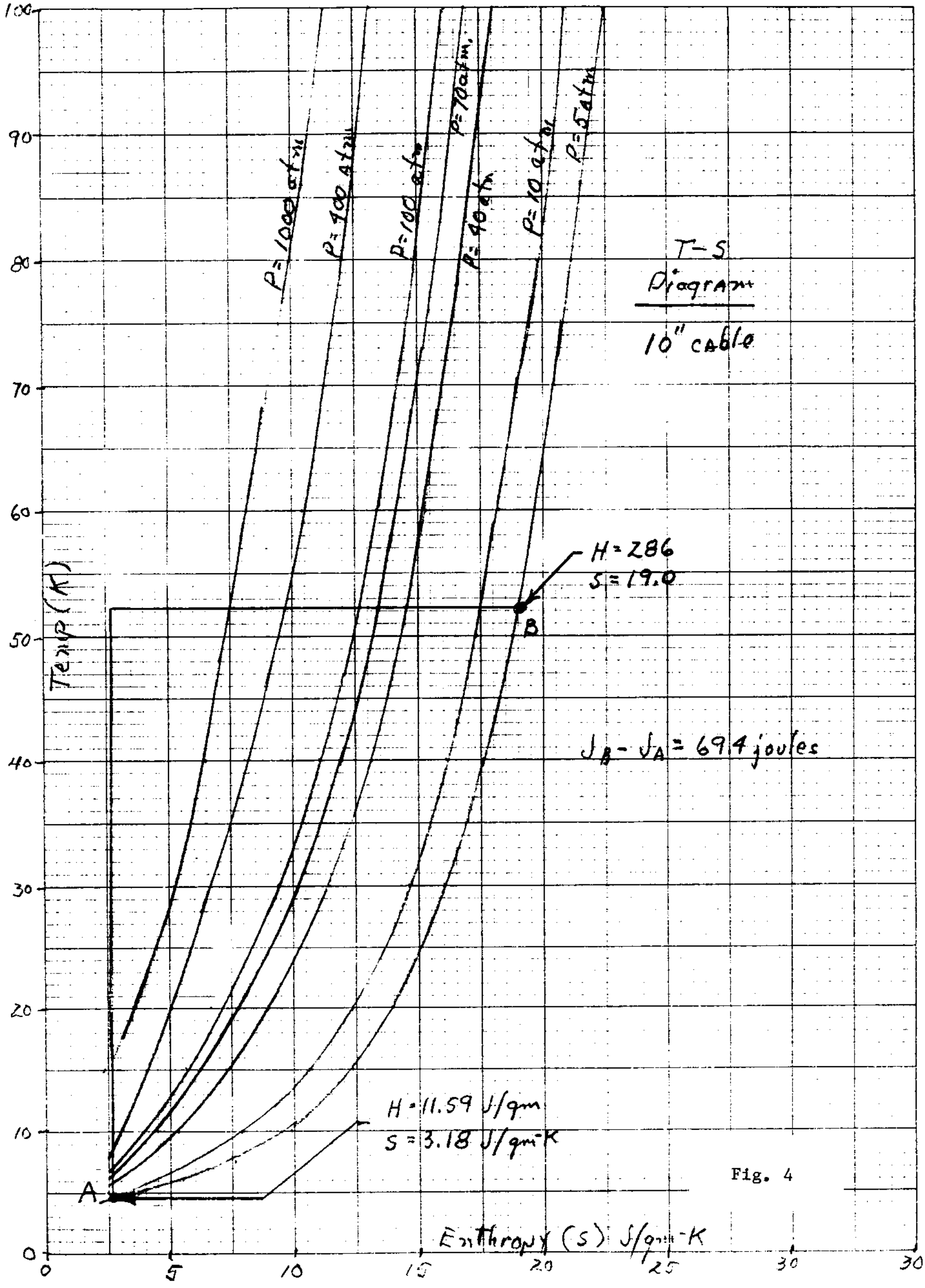

Magnet SLN-012 - 4" section -
I = 5037 Amps
Total EI product
Power Loss - Cooling
ΣPΔt = 24.8 joules
WATTS
0
1000
2000
100
200
300
400
500

Fig. 3



T-S Diagram
10" cable
P=1000 atm
P=400 atm
P=100 atm
P=70 atm
P=40 atm
P=10 atm
P=5 atm
H=286
S=19.0
B
A
$J_B - J_A$ = 69.4 joules
H = 11.59 J/gm
S = 3.18 J/gm-K
Temp (K)
Entropy (S) J/gm-K


Fig. 4

SQUARE 5 X 5 TO THE HALF INCH AS 0811

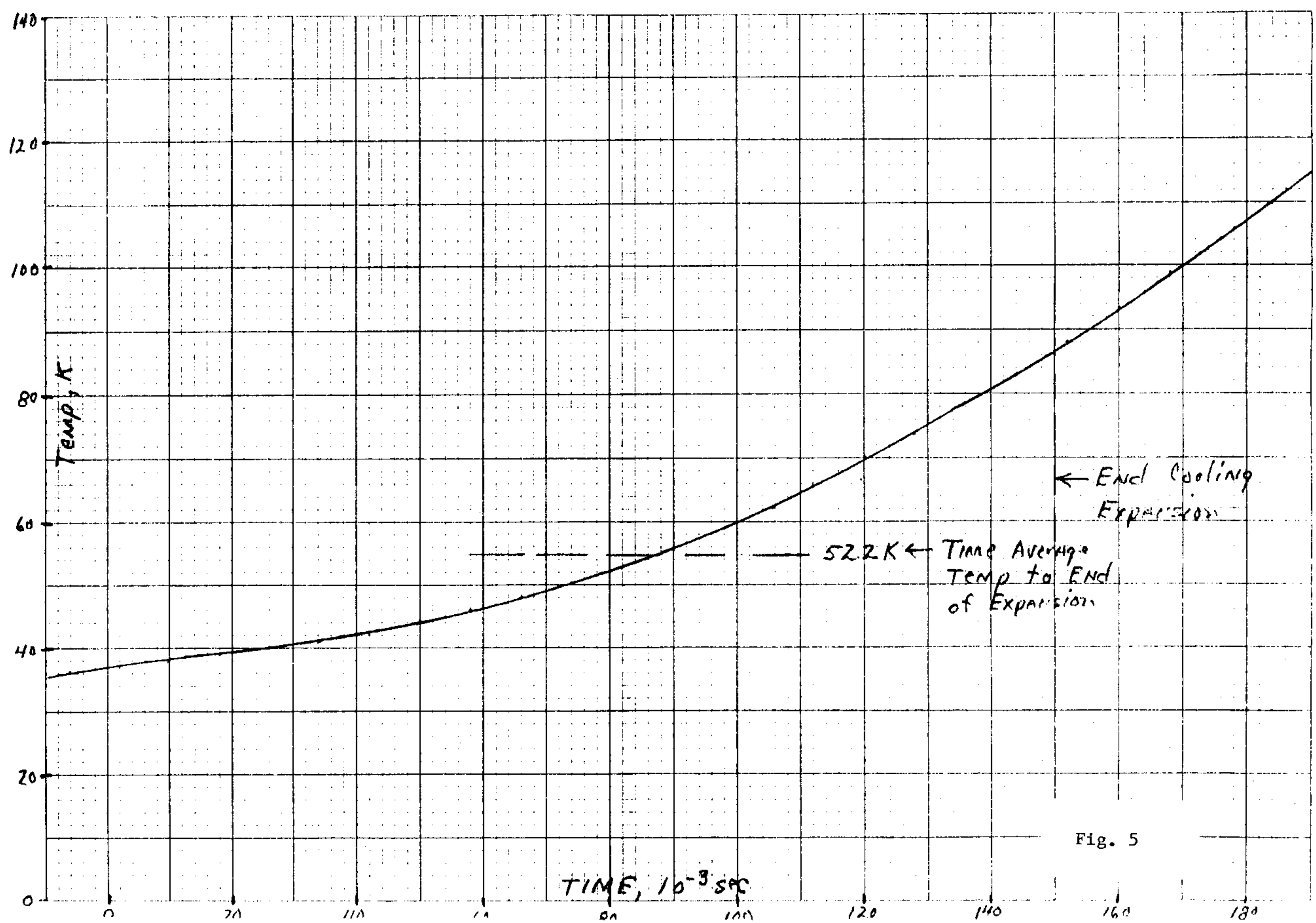



Fig. 5

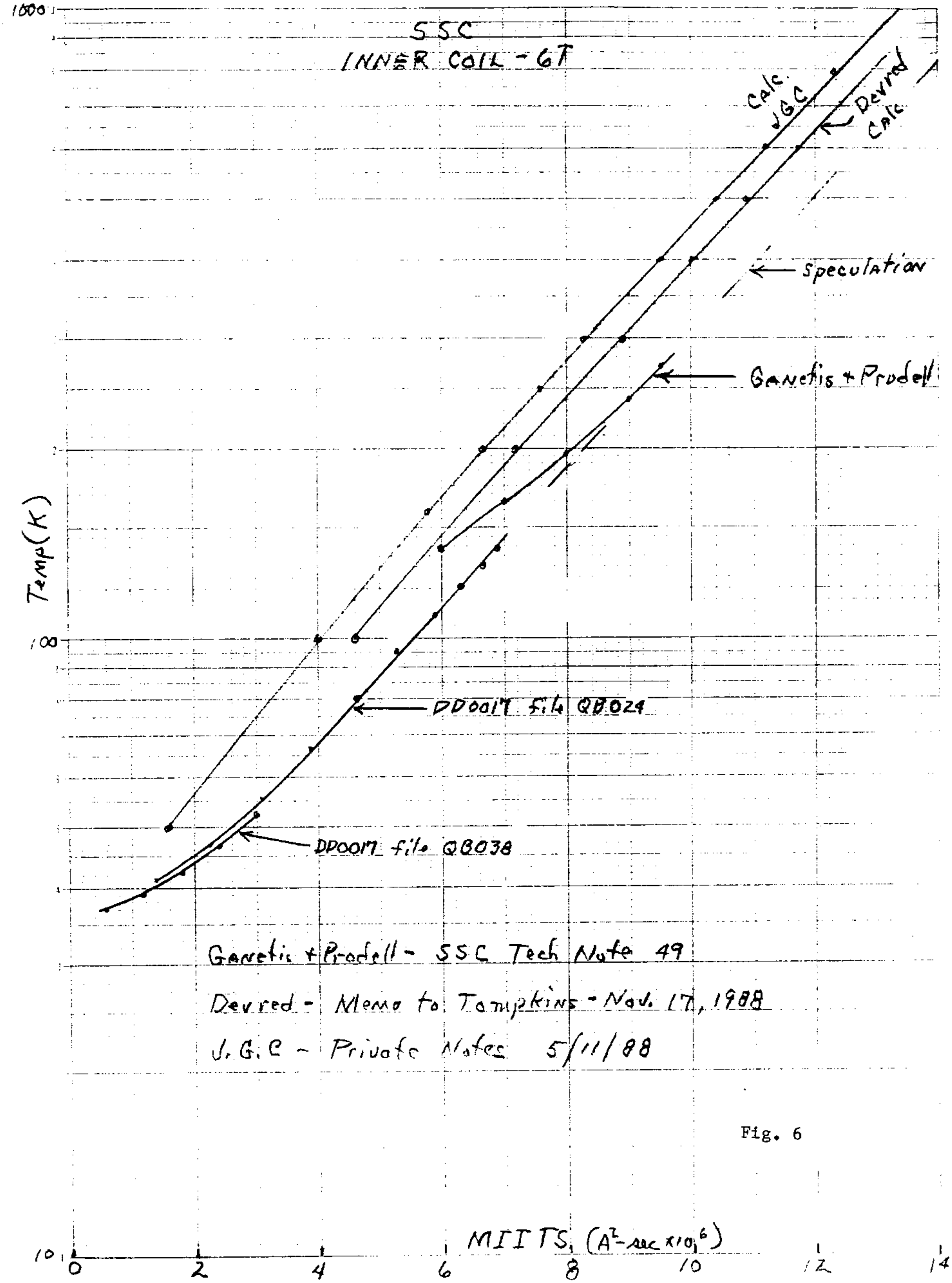

SSC
INNER COIL - 6T
Calc. J.G.C
Devred Calc
Speculation
Ganetis + Prodell
DD0017 file QB024
DD0017 file QB038
Ganetis + Prodell - SSC Tech Note 49
Devred - Memo to Tompkins - Nov. 17, 1988
J.G.C - Private Notes 5/11/88
Temp (K)
MIITS (A²-sec x10⁶)
1000
100
10
0
2
4
6
8
10
12
14

Fig. 6

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