High Energy Facilities

Accelerator Development Branch

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Results Using the Active Quench Protection Strip Heaters Installed on SNL008

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Measurements were made on the SSC reference design D dipole magnet SNL008 to study quench behavior of the magnet when active quench protection strip heaters were used to initiate quenches. The strip heaters, their arrangement and installation were essentially as described in Magnet Division Note 107-9 (SSC-MD-82) by J.G. Cottingham with the exception that the distances between the heaters on the 12 heater array proposed for the SSC long magnets had been shortened so that 12 heaters per strip were also employed for the 4.5 m long magnet tested.

Only three of the strip heaters and combinations of these heaters were used during the tests. In the first series of tests, the magnet current was set at 4.5 kA, the current at which previous studies had indicated the quantity $\int I^2 dt$ was a maximum. A capacitor bank with a capacitance of 0.0465 farads was charged and then discharged through a strip heater with the charging voltage being increased progressively until a magnet quench was initiated. The time interval between when the voltage was applied to the strip heater and when the magnet quench was initiated was measured as was the time interval between when the voltage was applied to the strip heater and when the voltage across the magnet coil that had quenched reached 3 volts. After the lowest charging voltage at which a quench could be initiated was determined, the "threshold voltage", the voltage was increased in a number of steps until no substantial change in the times being measured was observed.

Figures 1, 2, and 3 show plots of the times measured as a function of the voltage applied to the strip heater when heaters #1, 2, and 3 were fired singly. The quantity $\int I^2 dt$ is also plotted as a function of the applied voltage. It is apparent that the times measured decrease rapidly at first as the voltage is increased from the threshold voltage to values in the range of 250 to 300 volts beyond which range the rate of decrease is much smaller and approaches a con-

stant value. A similar statement may be made about the $\int I^2 dt$ vs Heater Voltage curves.

Curves for the time interval between heater voltage applied and quench initiated are shown in Fig. 4 and 5 for heater combinations (1+2), and (2+3) which were pulsed together in pairs. Since the voltages across the magnet coils which were being quenched were bucking, it was not possible to obtain accurately the times at which 3 volt quench signals developed.

Figure 6 shows the plots for the heater combination (1+3) where the quench voltages were not bucking. Although the curve for the times between heater voltage applied and quench initiated is similar to those for the single strip heaters, the times between quench initiated and a quench voltage of 3 volts were smaller than those for the single heater tests as expected.

Figure 7 shows the curves for the heater combination (1+2+3) where two voltages were additive and one was bucking.

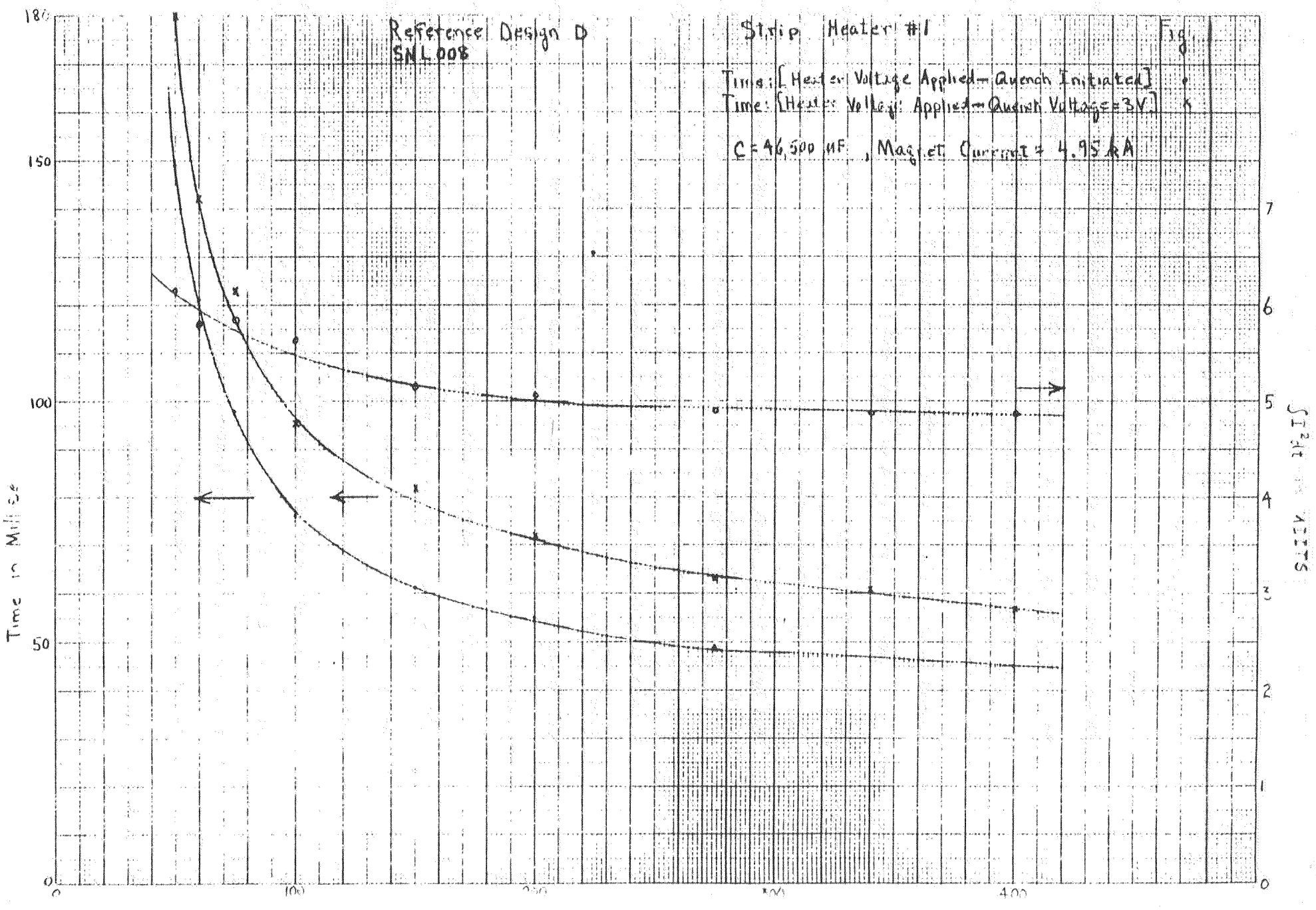
The curves shown in Fig. 8 are from measurements made by varying the capacitance while setting the charging voltage each time at 275 volts. The magnet current for each of these quenches was 4.95 kA. As can be seen from this figure the times become dependent on the capacitance, and therefore the energy discharged in the heater, only at low values of the capacitance.

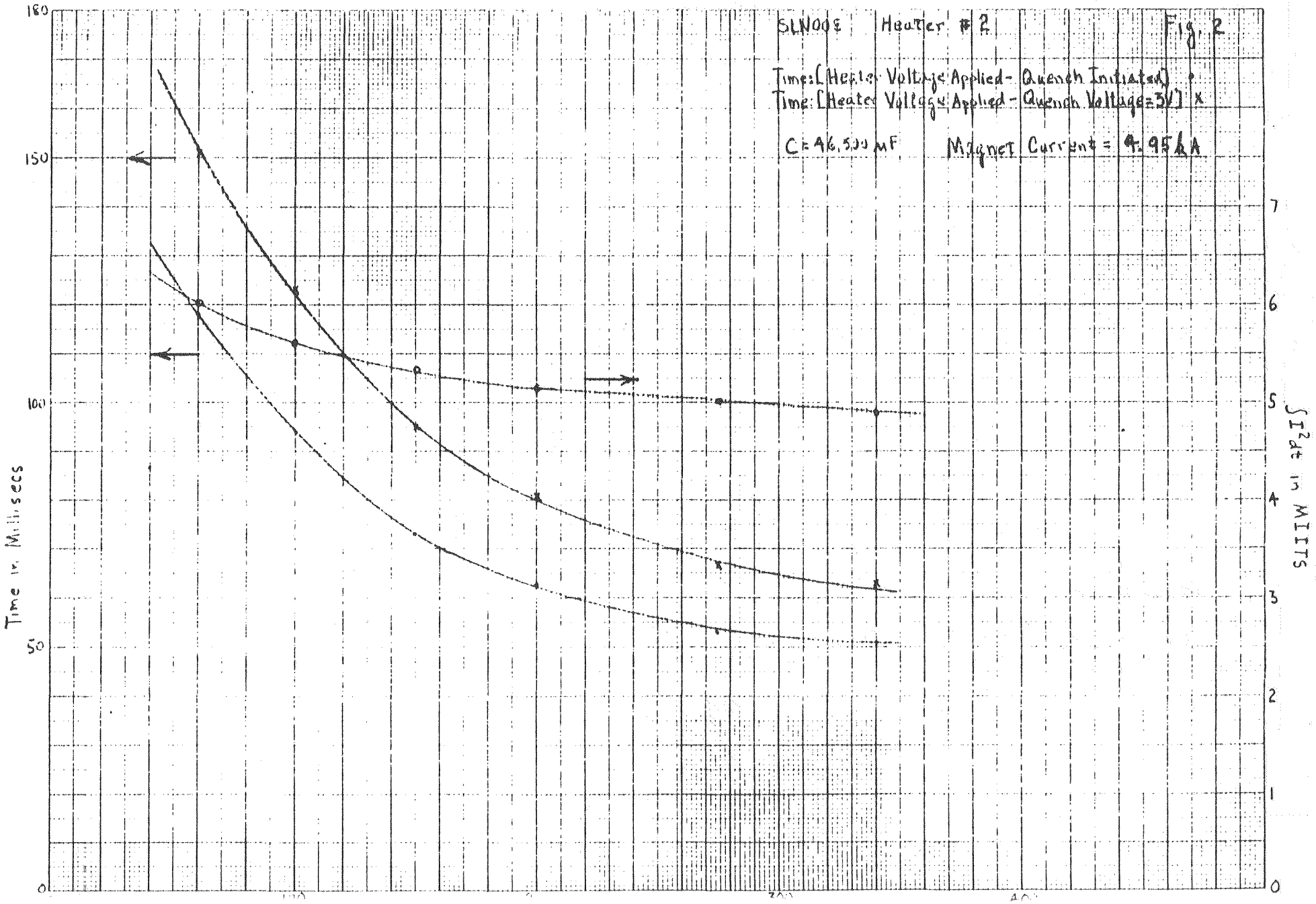
Figure 8 and the previous figures indicate that the times to initiate a quench and to achieve a quench voltage of 3 volts are strongly dependent on the voltage applied to the strip heater for the lower values of the applied voltage with this dependence weakening as the value of the voltage is increased. Presumably this dependence is related to the power level applied to or the initial "kick" given to the heater. The heater acts like a fuse but once a quench has been initiated the heating effects are rapidly dominated by the magnet discharging through the increasingly resistive conductor.

These figures also show that the time interval between the initiation of a quench and the quench voltage reaching 3 volts approaches a constant limiting value as the strip heater voltage is increased which value probably depends primarily on the quench front velocities which in turn are dependent on the magnet current. The increase in this time as the strip heater voltage is decreased probably relates to the initial conditions of temperature and length of the conductor that is first driven normal by the heater.

Figure 9 shows plots of times and $\int I^2 dt$ as a function of magnet current with a capacitance of 0.046 and 275 volts being used to activate strip heater #1 for each of several magnet currents. The time interval between the heater voltage applied and quench initiated decreases as the magnet current is increased because the thermal margin of the conductor decreases as the magnet current approaches the "natural" quench current. The interval between the two time curves also decreases with increasing magnet current, an indication that the time between the initiation of a quench and a measured quench voltage of 3V is dependent on the quench front velocities which are increasing as the magnet current increases.

Curves of magnet current versus time and $\int I^2 dt$ versus time are plotted in Fig. 10 for the three cases where one, two, and three strip heaters are powered using a capacitance of 0.0465 and a voltage of 275 volts. As expected, the time constant of the current decay decreases as the number of heaters used increases, indicating that more of the magnet conductor becomes resistive as more heaters are brought into play. The effect of the shorter time constant on $\int I^2 dt$ is noticeable, the use of 3 heaters reducing the value of $\int I^2 dt$ by about 14 percent below that measured when one heater was used.


Reference Design D
SNL 008
Strip Heater #1
Fig.
Time: [Heater Voltage Applied – Quench Initiated] •
Time: [Heater Voltage Applied – Quench Voltage = 3V] x
C = 46,500 μF , Magnet Current = 4.95 kA
Time in Milli se
∫I²dt
0
50
100
150
180
0
1
2
3
4
5
6
7
0
100
200
300
400


SLN008 Heater #2
Fig. 2
Time: [Heater Voltage Applied - Quench Initiated] •
Time: [Heater Voltage Applied - Quench Voltage=3V] x
C=46,500 μF
Magnet Current = 9.95 kA
Time in Milliseccs
∫I²dt in MIITS
180
150
100
50
0
7
6
5
4
3
2
1
0

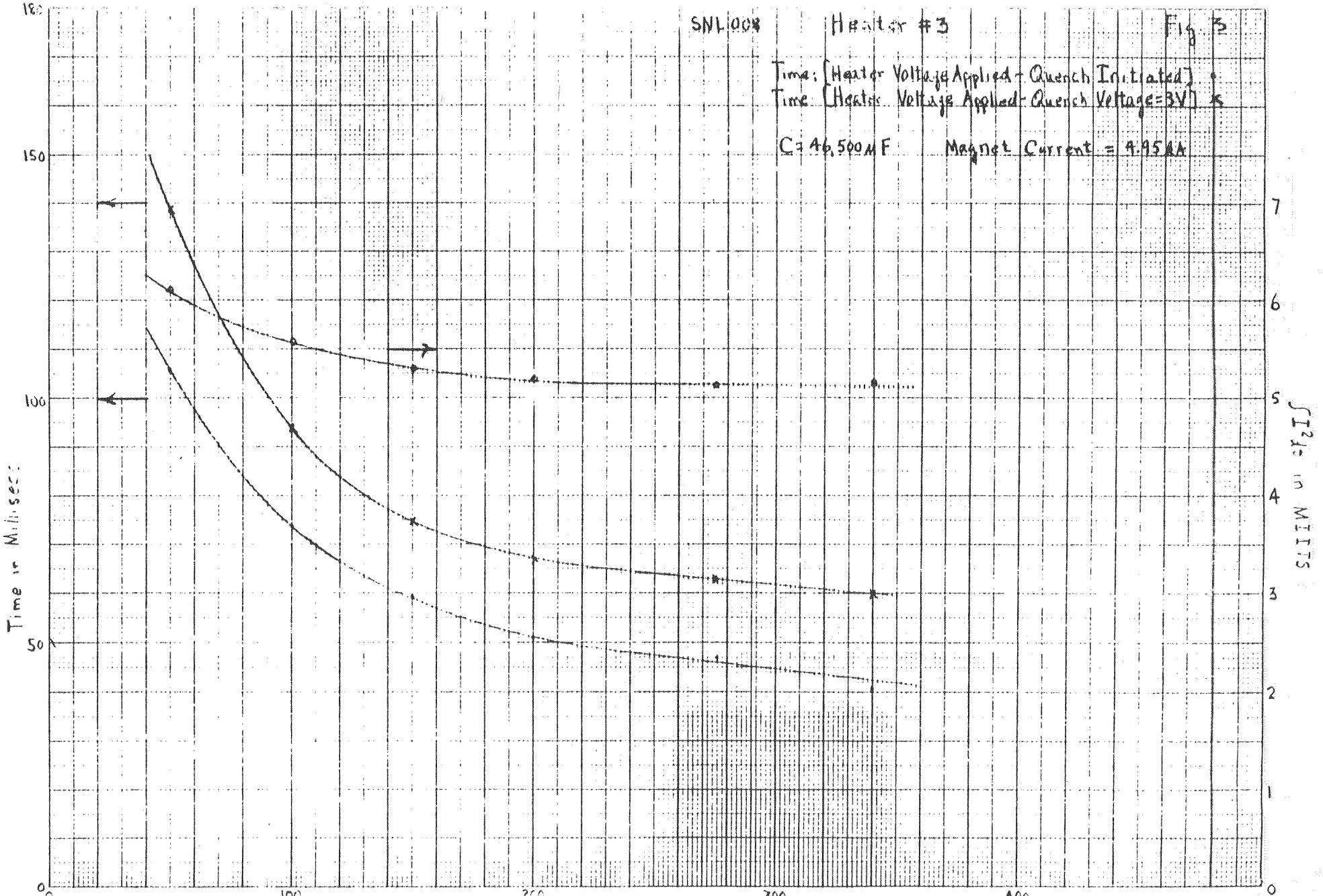

SNL008
Heater #3
Fig. 3
Time: [Heater Voltage Applied - Quench Initiated]
Time [Heater Voltage Applied - Quench Voltage=3V]
C=46,500 μF
Magnet Current = 4.954 kA
Time in Milliseconds
∫I²dt in MIITS
0
50
100
150
180
0
1
2
3
4
5
6
7
100
200
300
400

Fig. 4

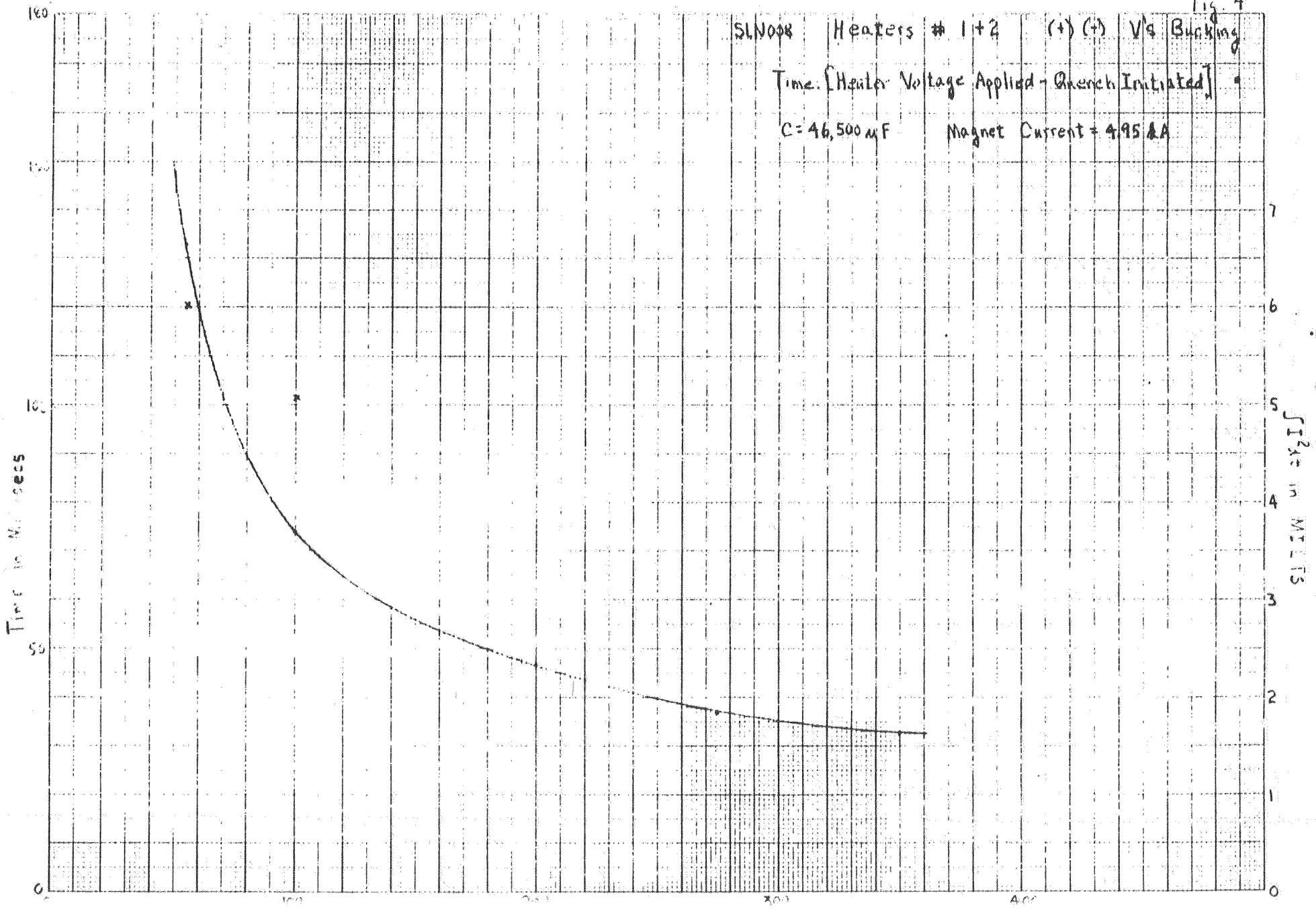
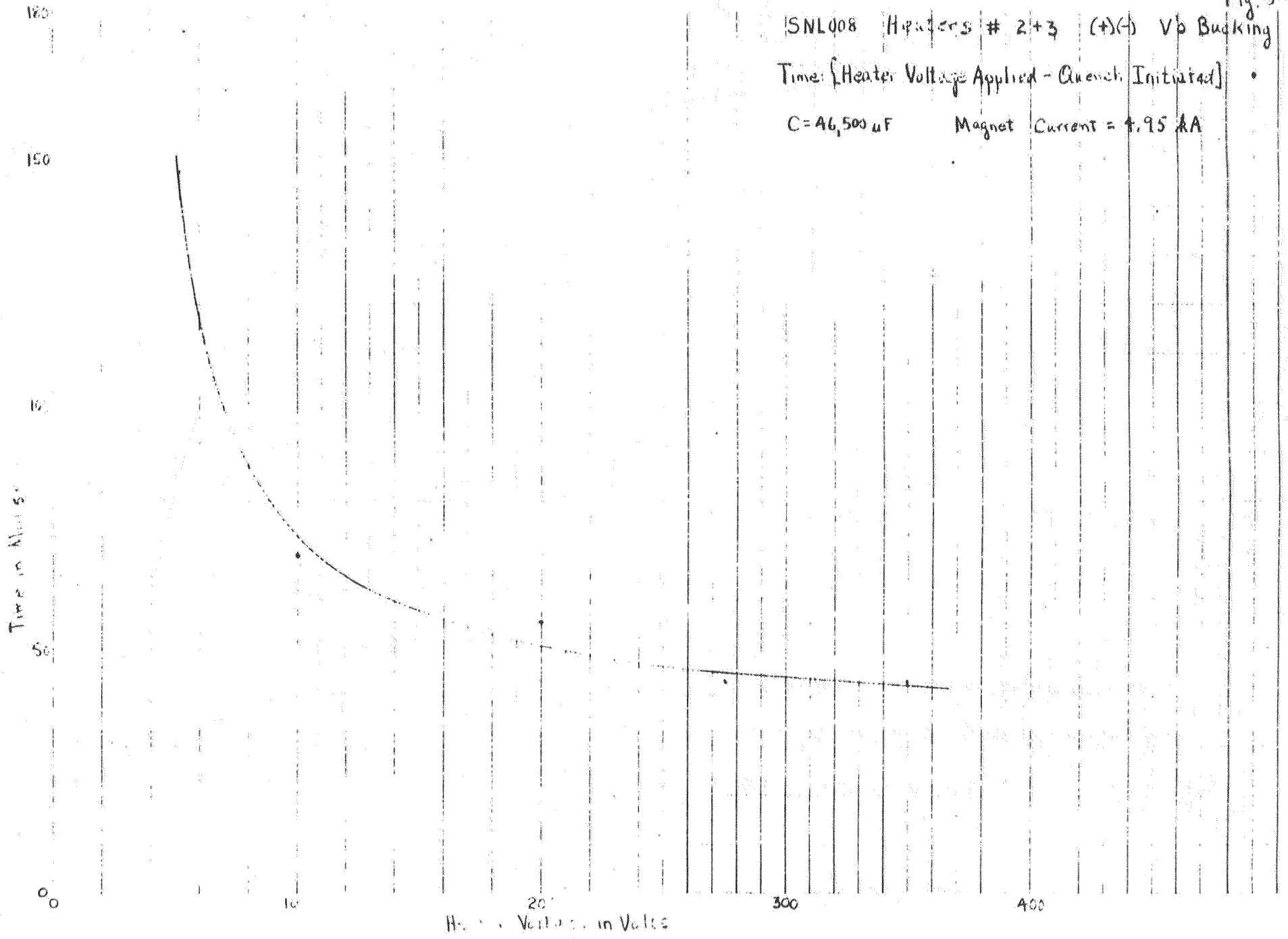

SLN008 Heaters # 1+2 (+) (-) V's Bucking
Time. [Heater Voltage Applied - Quench Initiated]
C = 46,500 μF Magnet Current = 4.95 kA
Time in Milliseconds
$\int I^2 dt$ in MILLIS
0
50
100
150
200
300
400
1
2
3
4
5
6
7

Fig. 5


SNL008 Heaters # 2+3 (+)(-) Vb Bucking
Time: [Heater Voltage Applied - Quench Initiated]
C = 46,500 uF
Magnet Current = 4.95 kA
Time in Mins
Heater Voltage in Volts
0
50
100
150
180
0
10
20
300
400

461510

Fig. 8

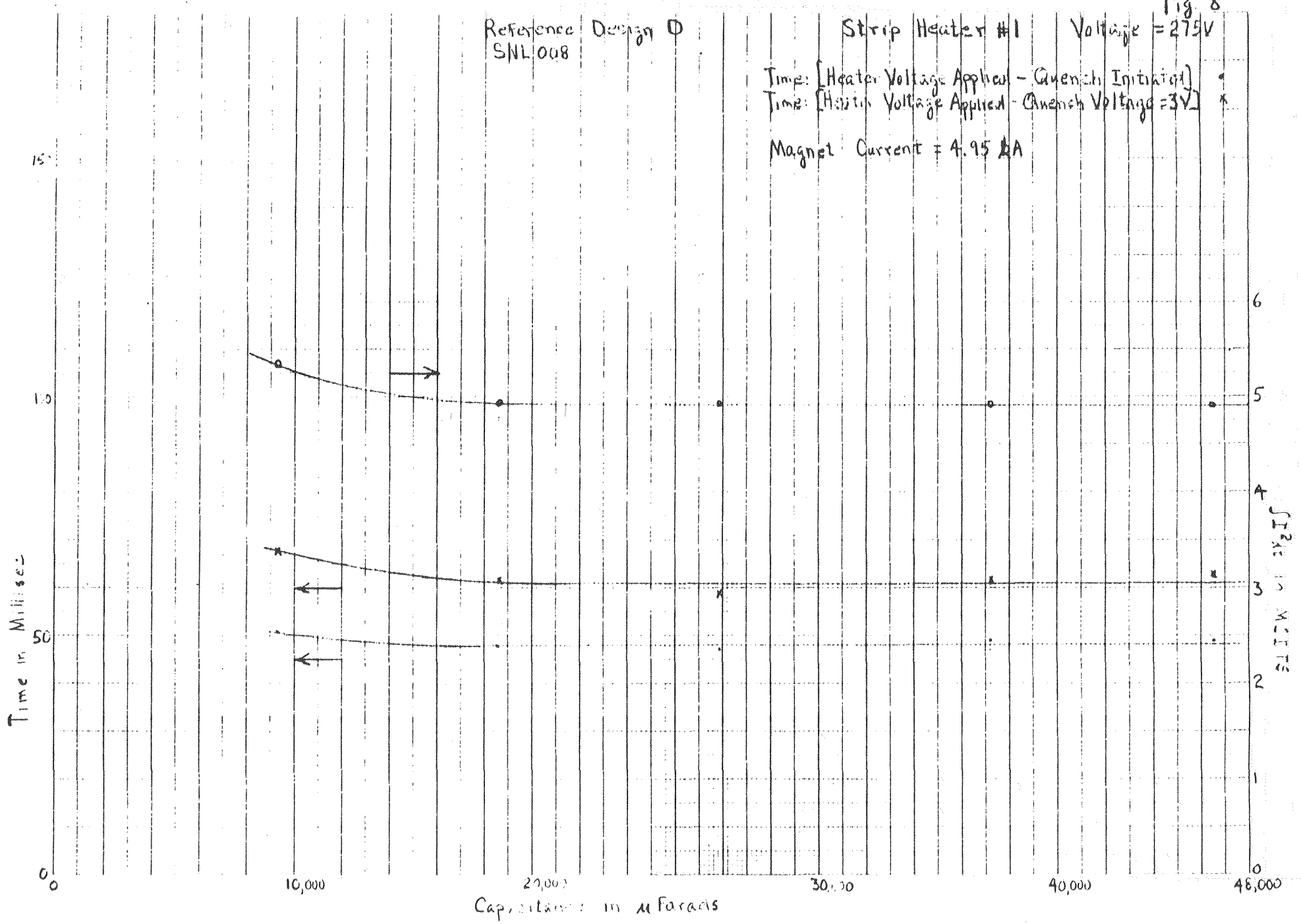
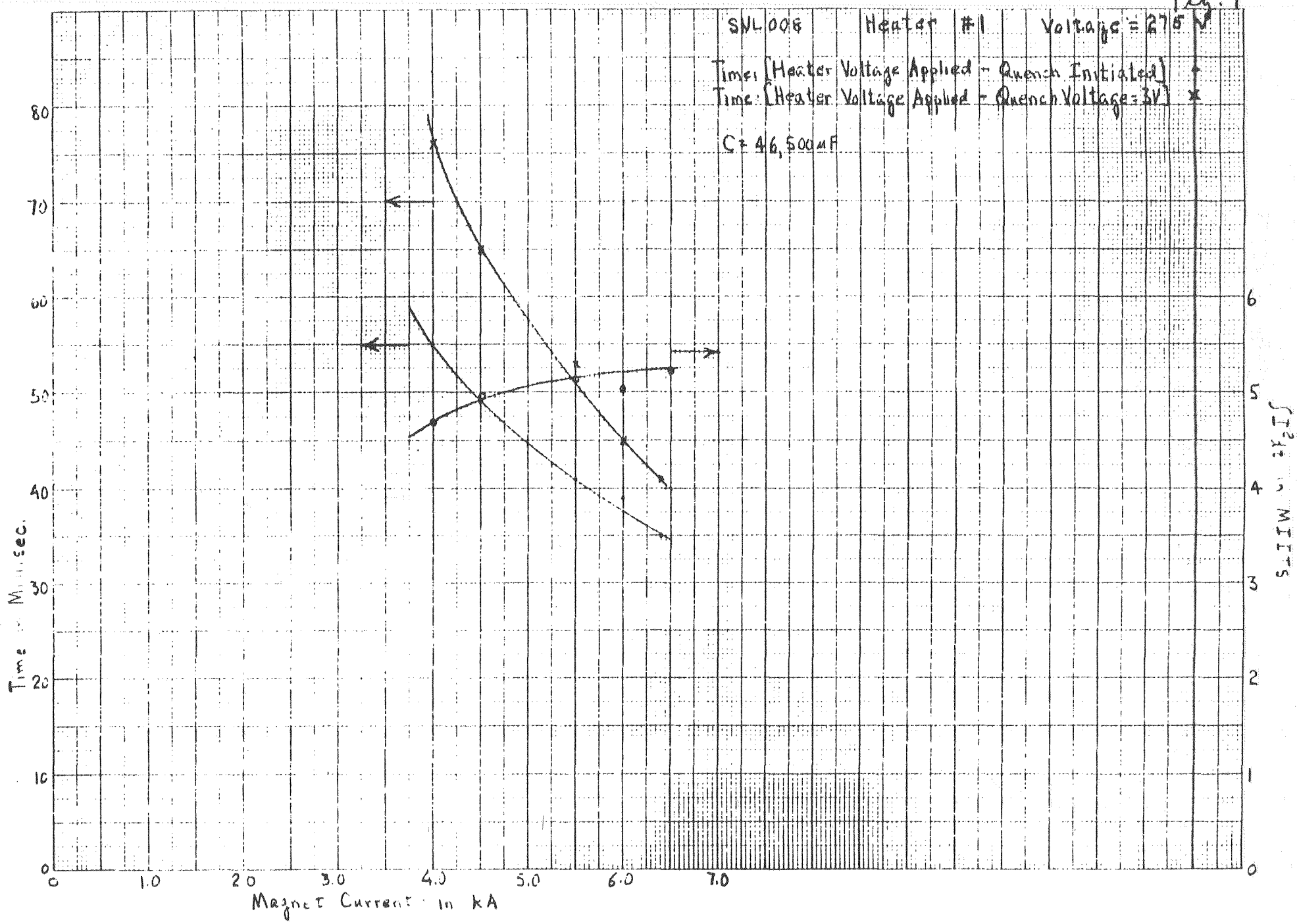
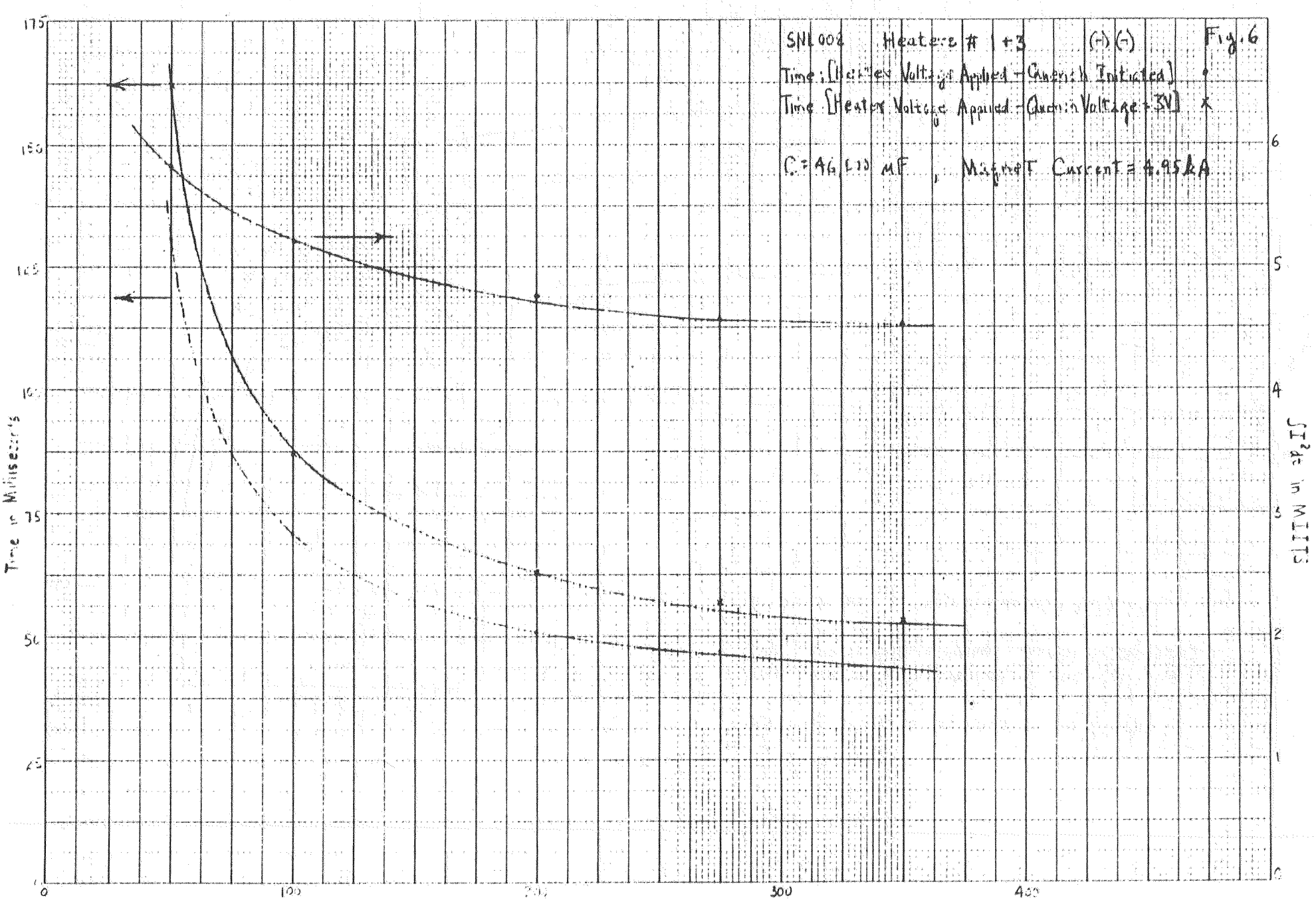
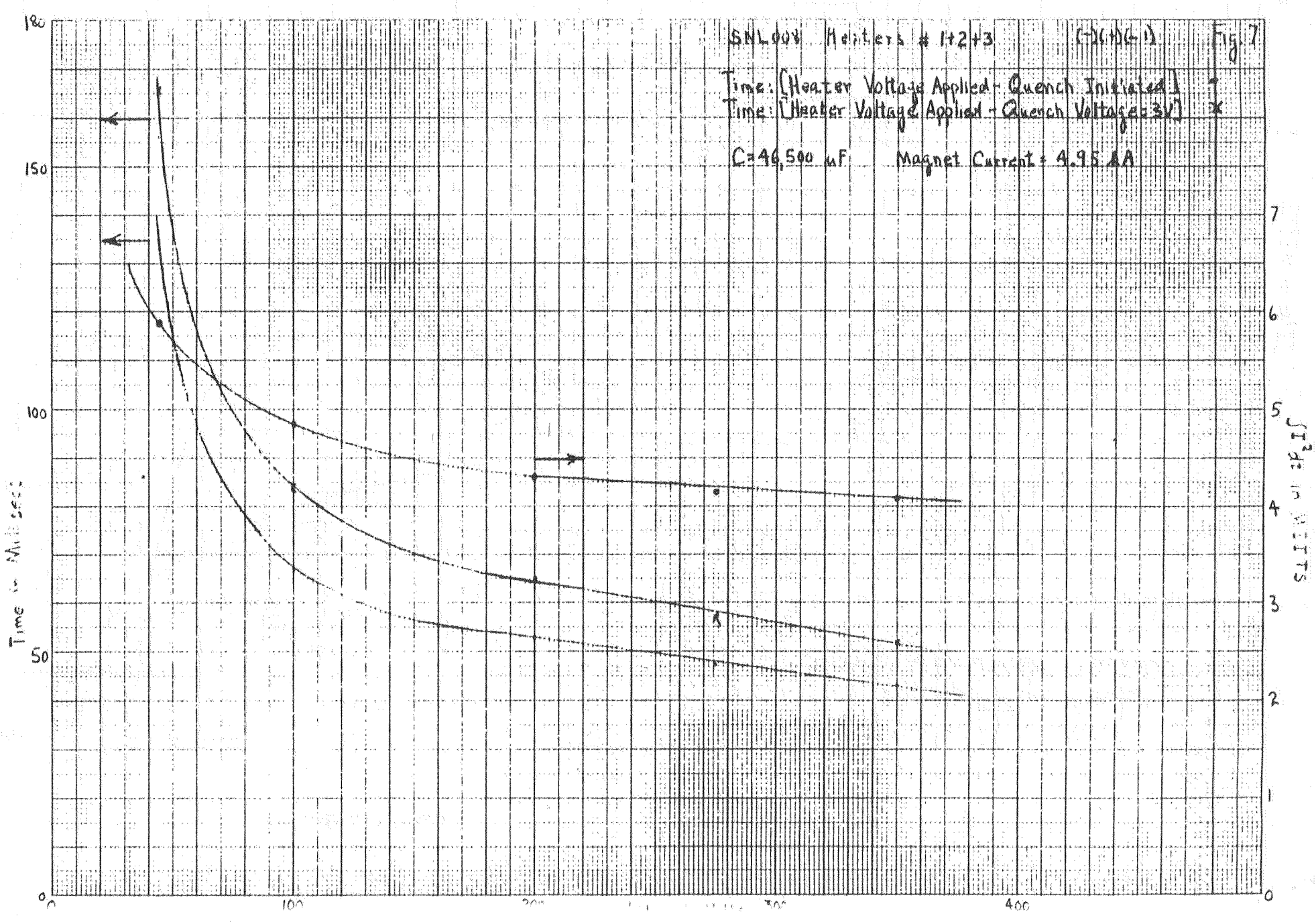

Reference Design D
SNL 008
Strip Heater #1
Voltage = 275V
Time: [Heater Voltage Applied - Quench Initiation]
Time: [Heater Voltage Applied - Quench Voltage = 3V]
Magnet Current = 4.95 kA
Time in Milliseconds
15
10
50
0
0
10,000
20,000
30,000
40,000
48,000
Capacitance in μ Farads
∫I²dt in MJ/m³
6
5
4
3
2
1
0

Fig. 9


SVL 008 Heater #1 Voltage = 275 V
Time: [Heater Voltage Applied - Quench Initiated]
Time: [Heater Voltage Applied - Quench Voltage = 3V]
C = 46,500 μF
Time in Milli-sec.
Magnet Current in kA
$\int I^2 dt$ in MIITs
0
10
20
30
40
50
60
70
80
1.0
2.0
3.0
4.0
5.0
6.0
7.0
1
2
3
4
5
6

K+E 10 X 10 TO ½ INCH 359-10 KEUFFEL & ESSER CO. MADE IN U.S.A.

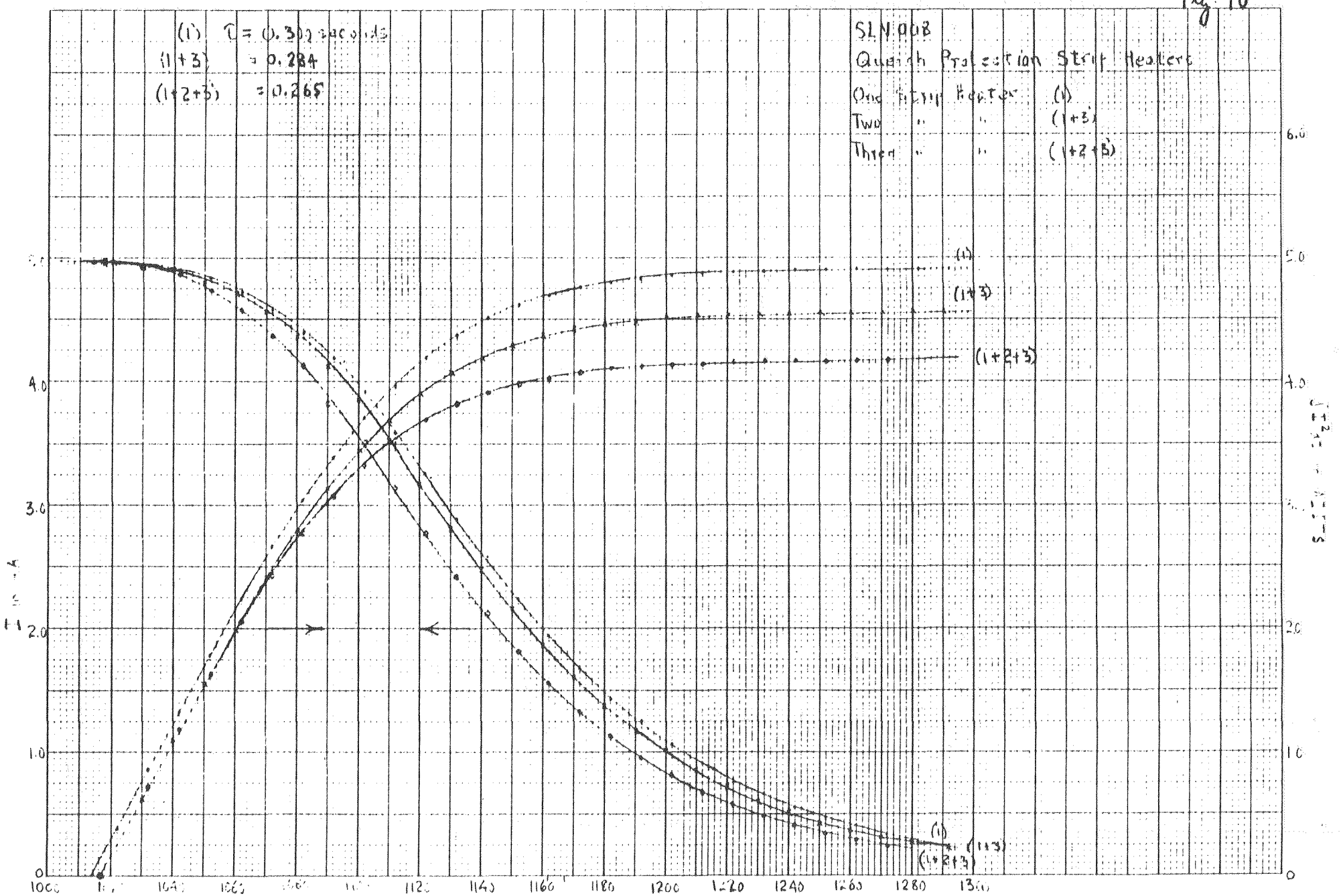



SNL008 Heaters # 1+2+3 (-)(+)(-1)
Fig. 7
Time: [Heater Voltage Applied - Quench Initiated]
Time: [Heater Voltage Applied - Quench Voltage = 3V]
C = 46,500 uF
Magnet Current = 4.95 kA
Time in Milliseconds
$\int I^2 dt$ in MIITS
180
150
100
50
0
100
400
7
6
5
4
3
2
1
0

K+E 10 X 10 TO 5 INCH KEUFFEL & ESSER CO. MADE IN U.S.A.

46 1320

Fig. 10



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