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1974 Summer Program - Magentic Measurement Group

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December 1974

Collider Accelerator Department

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EP&S DIVISION TECHNICAL NOTE

No. 73

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1974 SUMMER PROGRAM - MAGNETIC MEASUREMENT GROUP

The program of study designed and developed by the Magnetic Measurement Group has the following two goals:

1. The experiments should be relatively simple and require minimum construction work so that the experimental setup, measurement, data analysis, and write ups can be accomplished within ten weeks.
2. The experiment should serve the purpose of education, in order that the student can learn something from it, and at the same time the result of these experiments should benefit this group's future R&D work.

The principles, the experimental background, and the basic techniques were explained to the students first. They then chose the experiments they would like to work on and were left alone to begin, in their own way, the design and setup of these experiments. This kind of arrangement will let the students develop their own skills, and I feel that the students will learn more in this way than by just following orders. However, their work was supported by the entire technical staff members of this group. I, myself, would only make suggestions and provide necessary help whenever there was such a need.

The power lead test, the Hall probe calibration, and Model No. 3 superconducting magnet study did not require much design and construction work since the equipment was there and only assembly was required. The quench propagation test required some work on the Model No. 2 superconducting magnet. This included voltage tap insertion, wiring, and making low temperature heaters. Karen Rutherford worked on this project and took preliminary data during the last few days of this program. The thermal-conductivity measurements on pure aluminum required some design and construction work. Lynne Talley worked on this project and she was able to take the data on all four samples and analyzed this data on the computer just before she left. Therefore, I took the responsibility to complete the written part of these two experiments. Aside from these two, the following articles were written by Karen Rutherford and Lynne Talley, with myself assisting them only in editing and arranging the articles.

Distr. B1

Hall Probe Calibration

Karen Rutherford

Introduction

The three Hall probes were calibrated and found to be linear and well behaved in the region of interest ($-100mA \leq I_{hall} \leq 100mA$, $0 < I_{mag} < 1000A$). These Hall probes will be employed in the study of energy losses of the superconducting 1D7 Model #3 magnet.

Experimental Setup and Results

The circuit used to calibrate the Hall probes is shown in Fig. 1, a standard Hall wattmeter circuit. Two of the Hall probes (#1 and 3) were located inside the air core H coil, and the third (#5) was in the AGS dipole magnet (C-26). A dc power supply connected in series to a 1 ohm precision (0.1%) resistor was used to furnish I (Hall), which was monitored by a DVM across the 1 ohm resistor. The induced voltage was then read directly by another DVM. Magnet current was supplied by the 600V power supply and was monitored across the 40 μΩ shunt resistor.

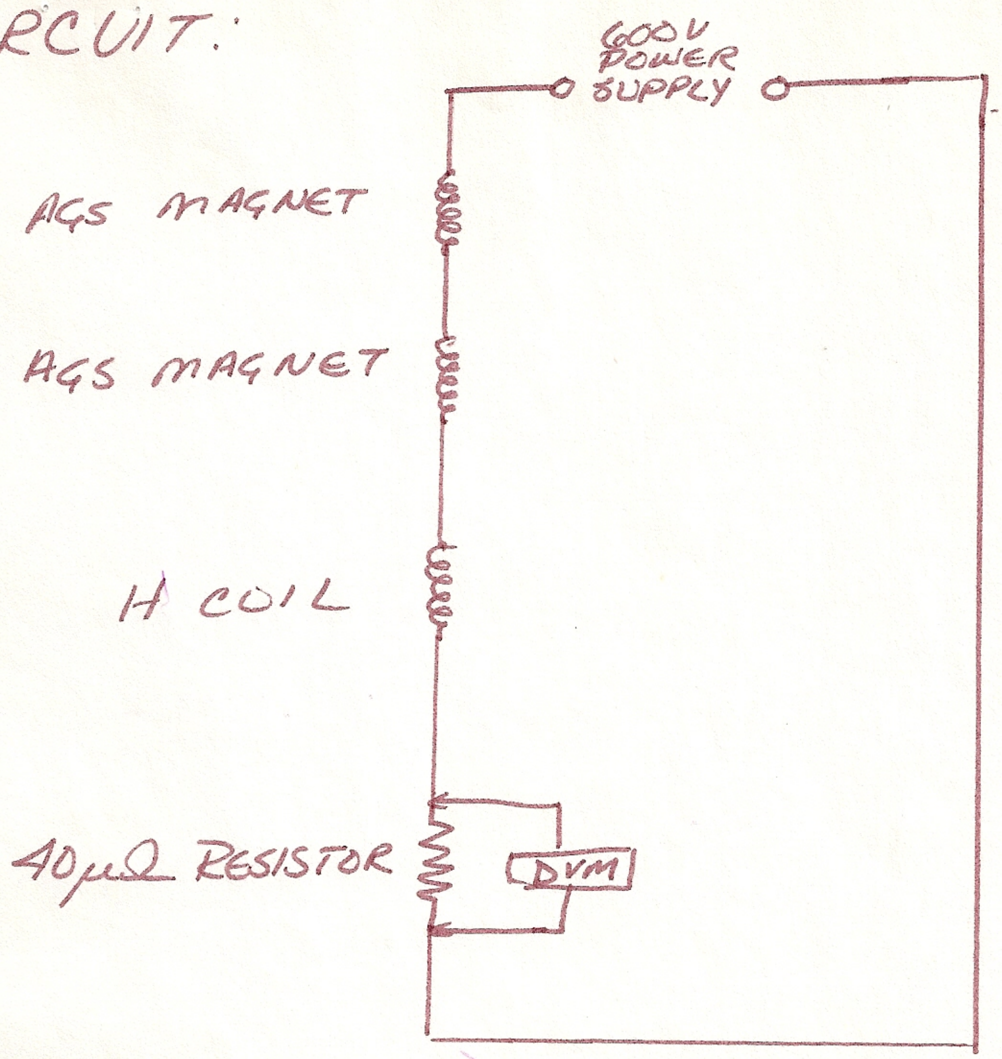
The current in the Hall probe was increased in 20mA steps from -100mA to +100mA. Magnet current was also increased in steps of 200A from 0 to 1000A.

Results are shown in Figs. 2, 3, and 4.

The two AGS magnets were used as chokes to cut down background noise, and also for calibration of probe #5.

CALIBRATION CIRCUIT:

label C-26



HALL PROBE CIRCUIT:

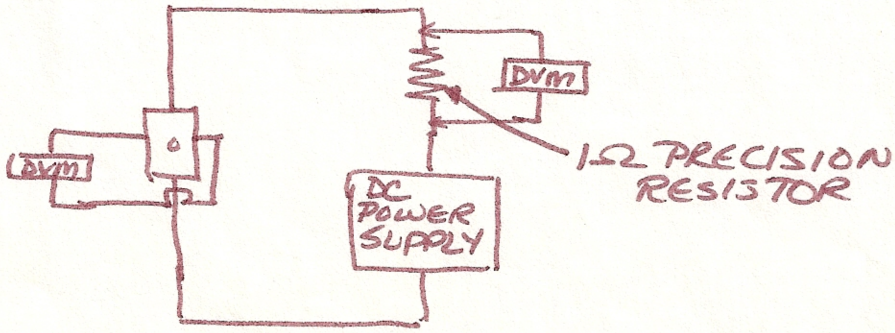
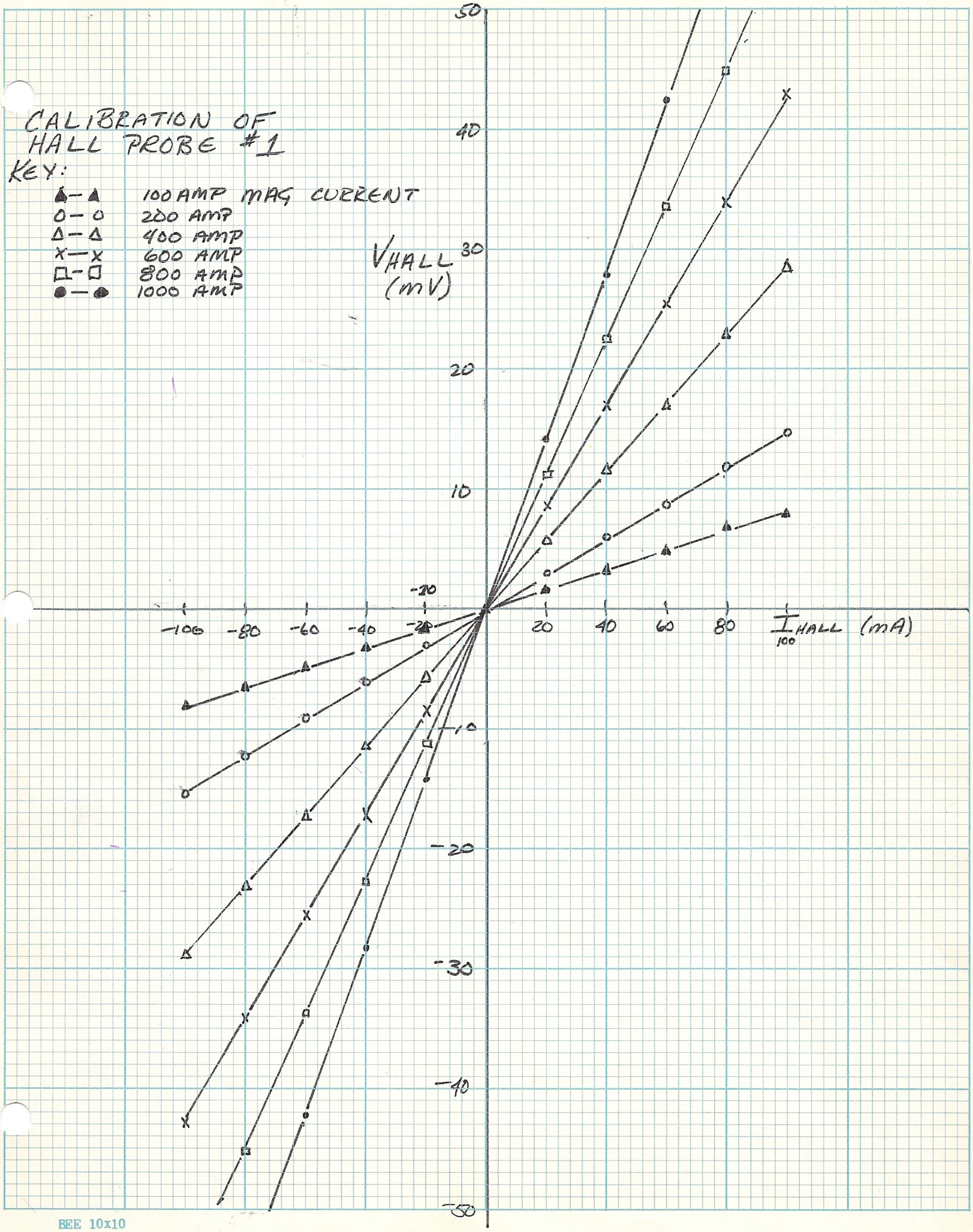


FIGURE 1



CALIBRATION OF
HALL PROBE #1
KEY:
▲—▲ 100 AMP MAG CURRENT
o—o 200 AMP
Δ—Δ 400 AMP
x—x 600 AMP
□—□ 800 AMP
●—● 1000 AMP
V HALL (mV)
I HALL (mA)
50
40
30
20
10
-10
-20
-30
-40
-50
-100
-80
-60
-40
-20
20
40
60
80
100
BEE 10x10

FIGURE 2

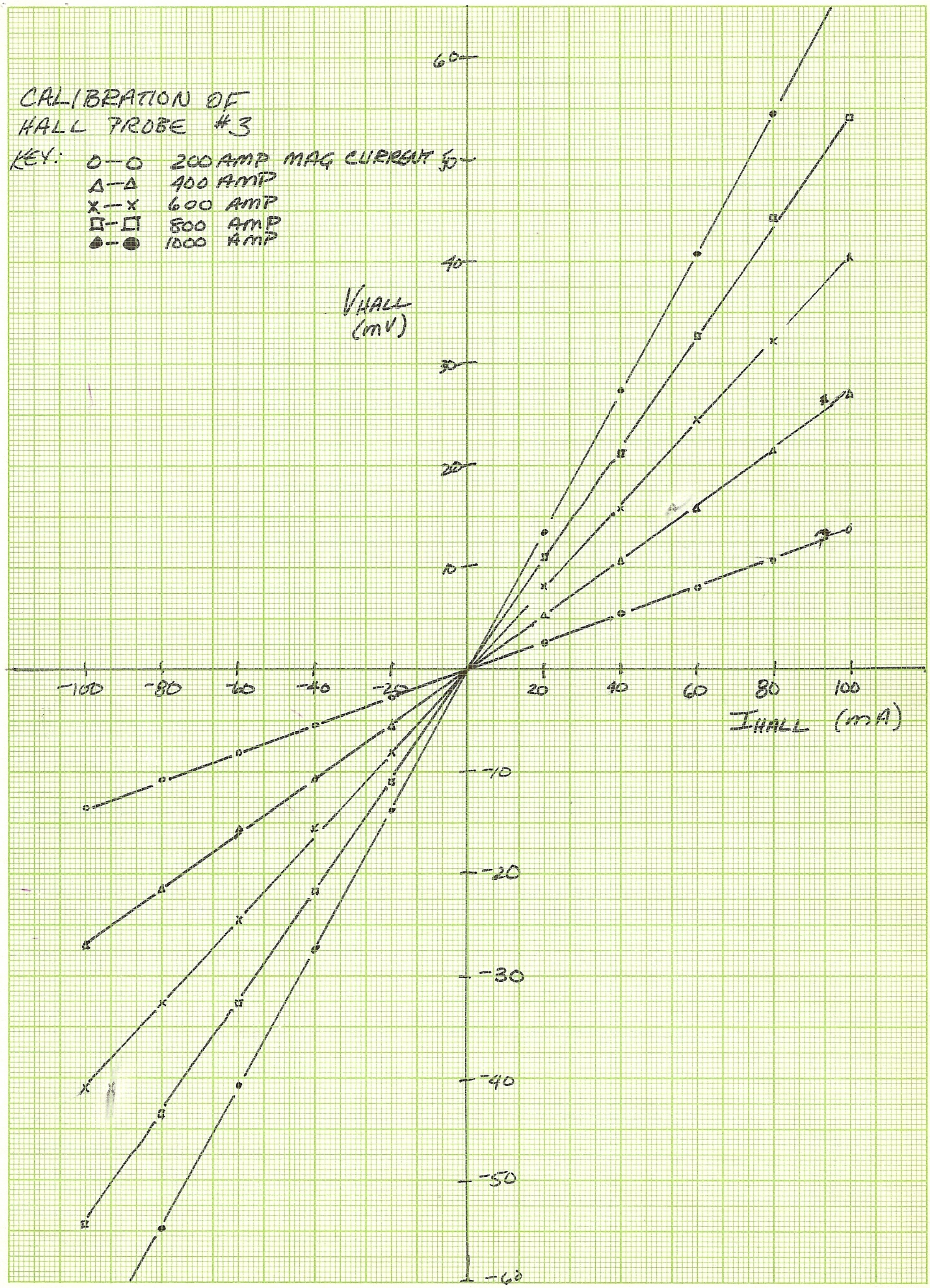
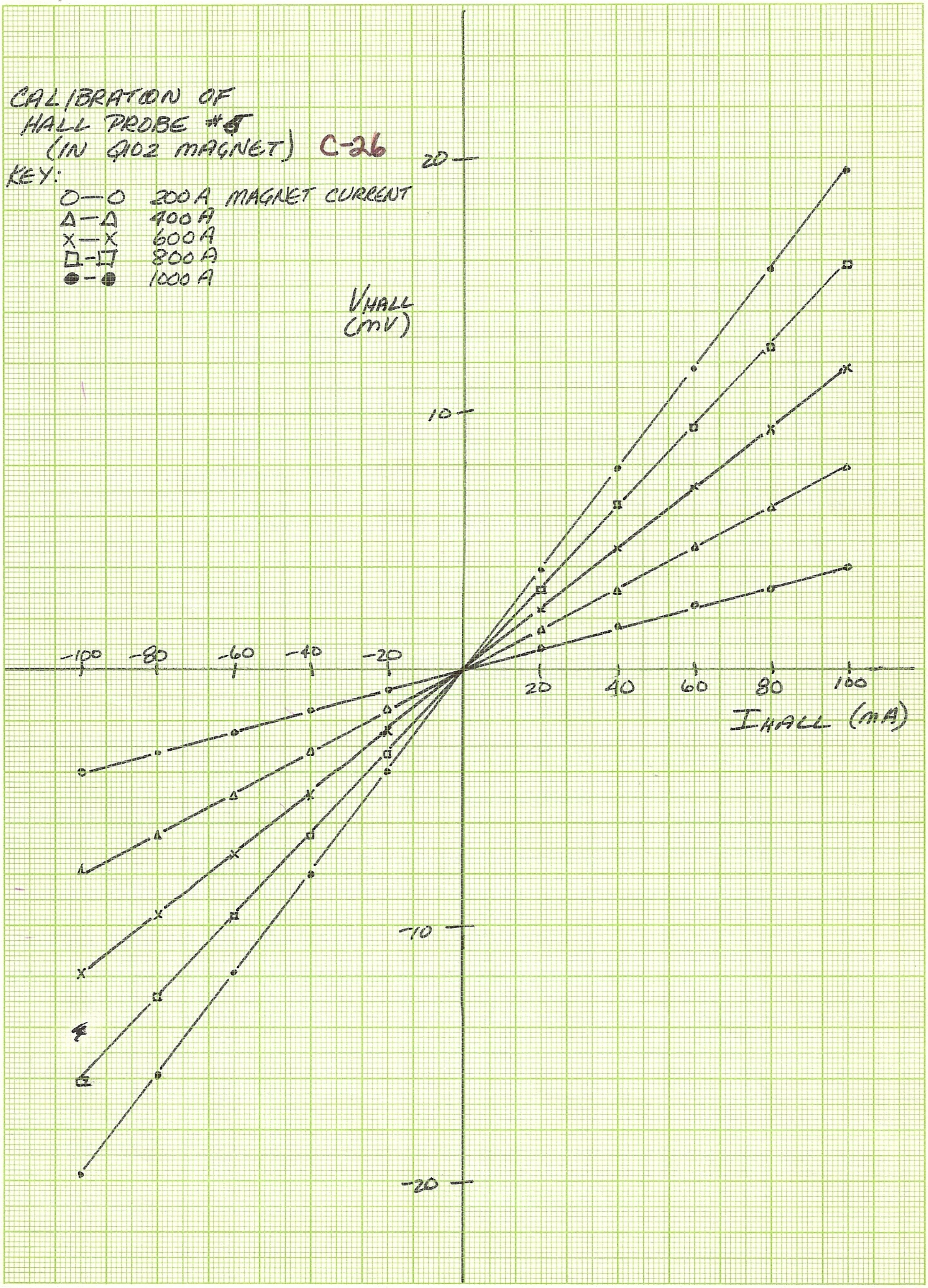

CALIBRATION OF
HALL PROBE #3
KEY: O—O 200 AMP MAG CURRENT
Δ—Δ 400 AMP
X—X 600 AMP
□—□ 800 AMP
●—● 1000 AMP
VHALL
(mV)
IHALL (mA)
60
50
40
30
20
10
-10
-20
-30
-40
-50
-60
-100
-80
-60
-40
-20
20
40
60
80
100

FIGURE 3



CALIBRATION OF
HALL PROBE #5
(IN Q102 MAGNET)
C-26
KEY:
O—O 200 A MAGNET CURRENT
Δ—Δ 400 A
X—X 600 A
□-□ 800 A
●-● 1000 A
VHALL (mV)
IHALL (mA)
20
10
-10
-20
-100
-80
-60
-40
-20
20
40
60
80
100

FIGURE 4

Report on the Test of AMI[1] Gas Cooled Power Leads

Karen Rutherford and Lynne Talley

Introduction

The procedure used for testing power leads is now routine and has been described in an earlier report[2] of March 1974. Two 1300 amp leads were tested for use in the high field pulsed dipole magnet, and three 1000 amp leads were tested for use as back-up for the power leads in the 8^{o} magnet system.

Experimental Setup

The setup for these tests was basically similar to the setup of March 1974[2]. As previously, foam and superinsulation were put around each lead to simulate the vacuum jacket in the 8^{o} dewar. The thermocouples were placed 18-in. from the bottom of each lead and were not moved as previously during the measurement process. This is the presumed hottest spot of the leads according to the last measurement[2]. The helium flow rate was calibrated again, and was found to follow the same graph as before. However, additional points were calibrated for high flow rate which showed non-linearity above 55 SCFH. According to the linear extrapolation of the previous calibration, a flow meter reading of 95 is equivalent to 73 SCFH. Actually, the measured flow at this flow meter reading is 66 SCFH.

Experimental Procedure

The same procedure was followed as before, with the exception that the voltage across each lead was continuously monitored to ensure that the cooling was adequate for both leads. The thermocouple reading on each lead was monitored alternately as a secondary precaution against overheating. The current would be reduced or turned off if each individual voltage reading exceeded 200mV, or if the thermocouple reading exceeded $100^{o}C$. The flow was first set to the manufacturer's specified value, and then current was brought up to the full capacity. When the voltage across the independent lead was within the specification and the temperature at the hottest spot was below $100^{o}C$, the steady state data were then taken and the lead was judged to be satisfactory. When the voltage across the lead kept climbing, the flow rate would be adjusted until a steady state reading around 100mV was reached. If the flow rate exceeded the specification by a large amount, the lead would be judged as unsatisfactory.

Conclusion

Of the five leads tested, all were judged satisfactory except one 1300 amp lead which needed excessive cooling. The test results are tabulated below and compared with the manufacturer's specifications[3].

	1000 amp			1300 amp	
	#3	#4	#5	#1	#2
Flow (SCFM)	45	45	44	57.5	66.2
Hot spot temp. (K^o)	260	330*	292	315	375*
V (lead) (mv)	65	60	77	135	135
Exit gas temp. (K^o)	290	294	298	312	316

*Note the temperature indicated by one of the thermocouples is consistently higher than the other thermocouple reading, while the voltage across the lead does not agree with this indication. It was judged that this thermocouple reading was erroneous, therefore these temperatures were not used to determine the quality of the lead.

References

1. American Magnetics, Inc., Oak Ridge, Tenn. 37830.
2. Informal Internal Report: Magnetic Measurement Group.
3. 1000 amp lead 75 SCFH/1000 amp pair with voltage drop of 100mV across each lead

   1300 amp lead 97.5 SCFH/1300 amp pair with voltage drop of 100mV across each lead

Thermal Conductivity of Pure Aluminum Between 4^{o} - $20^{o}K$

S.Y. Hsieh and Lynne Talley

Introduction

The thermal conductivity of aluminum with 5 9's and 6 9's purity was measured both for processed and unprocessed ribbons[1]. It is desirable to know both the temperature dependence of the thermal conductivity and its magnitude from $4^{o}K$ to $20^{o}K$ for application to superconducting magnet stabilization. Combined with previously measured data[2] on electric resistivity of high purity aluminum, information relevant to the variation of the Lorentz ratio[3], $^{k}/\sigma T$, could be obtained.

Experimental

A very simple sample holder and vacuum chamber was designed and constructed as shown in Fig. 1. It consists mainly of a vacuum chamber which contains the sample holder and heat station. Lead wires from the room temperature connector on the top of the stainless steel tube were soldered on one side of this heat station to minimize the heat leak, and then connected from the other side to the various sensors and heater on the sample as shown in the same diagram. This heat station was found to be inadequate and thermal errors were introduced in the data. Vacuum was maintained at all times to well below 10^{-6} mm Hg to isolate the sample from other sources of heat leak from the environment, and the copper vacuum can served as a radiation shield for the sample. However, no precautions were taken and corrections made concerning possible temperature gradients of this vacuum can.

The vacuum chamber was raised upward to increase the sample temperature up to $20^{o}K$. The measuring circuit is shown in Fig. 2. A measurement was made when the temperature stabilized at the desired value. The calibration of the carbon resistors against a Germaninum thermometer was done first at this temperature with the heater off. The heater was then turned on to determine the temperature difference developed between the sensors. The length between the sensors, the width and the thickness of the sample were premeasured. The thermal conductivity k(t) was then determined using the following formula:

$$k(T) = P \frac{L}{A} \frac{1}{\Delta T}$$

where P is the power input to the heater, L is the distance between the two sensors, and A is the cross section area of the sample.

The cryostat is a 3-ft. deep, 3-in. ID glass dewar surrounded by liquid nitrogen. The vacuum of the nitrogen dewar was poor during the last run and almost continuous transferring of the liquid was required.

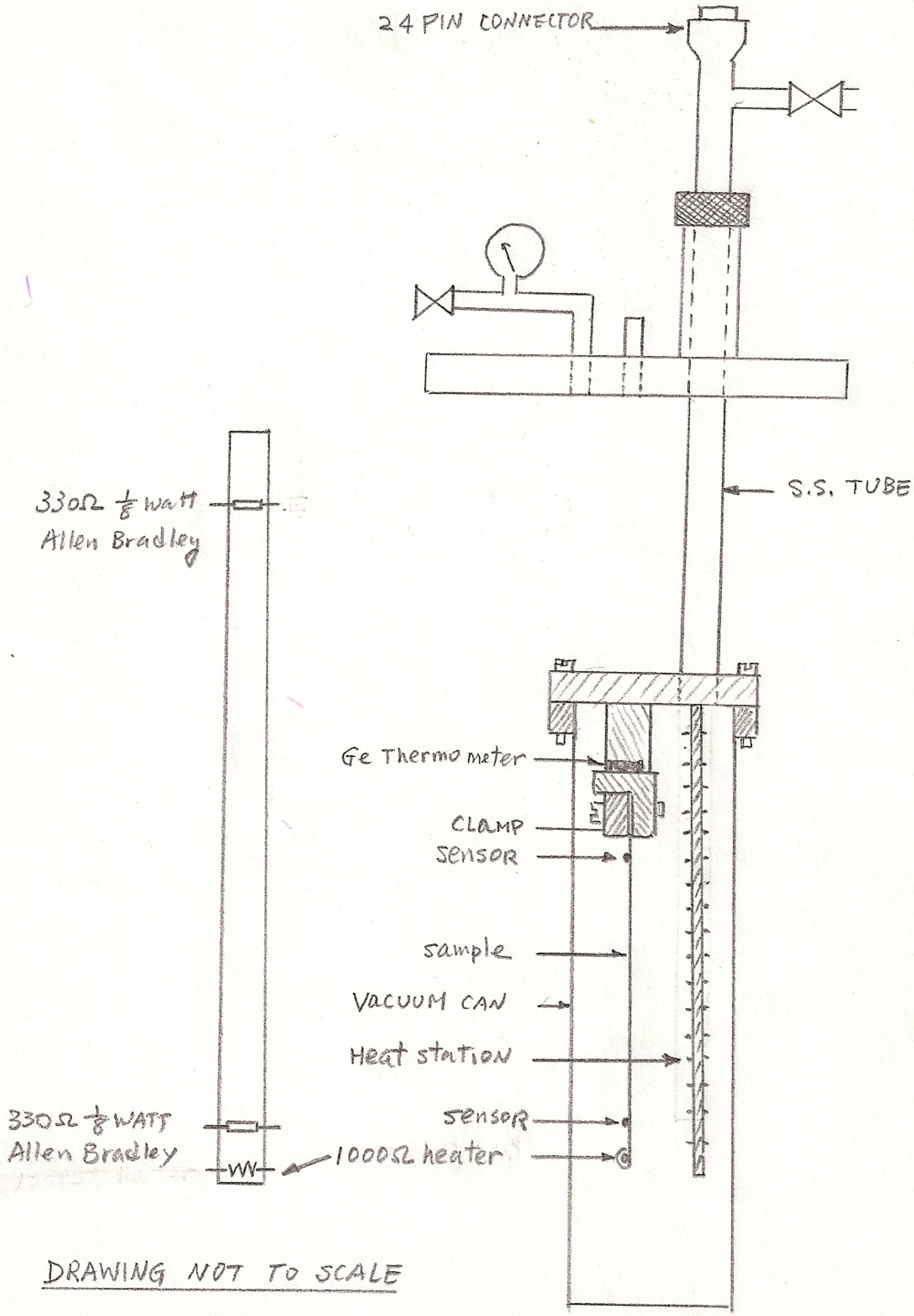
The control circuit was built with a regular rotary switch, and the system was not shielded against noise pickups. Low thermo solder was not used, and no attempt was made to reduce the thermal potentials at the solder joints or junctions, except that measurements were taken for both current directions and then averaged. An ordinary 6V battery was used as current source instead of a mercury battery.

Result and Discussion

The data are shown in Fig. 3. It is clear that the scatter is rather large due to the crude setup and sample holder construction. Also, another source of error was due to the calibration of the sensors since the data points were not uniformly distributed. This could introduce errors due to the weighting factor in the least square fit program. However, this experiment was not aimed at precision measurement, but rather to obtain a rough idea about the magnitude of the thermal conductivity and the relative difference between various samples. It can be seen that the general trend of the data agrees well with the data given by Wadd Tech. Report 60-56[4] for aluminum with 4 9's purity. It also demonstrates the higher thermal conductivity of the processed 5 9's against unprocessed 5 9's aluminum. As far as the 6 9's sample is concerned, the data on the third sample did not make sense after computer analysis, and the data on the fourth sample gives the same thermal conductivity as the 5 9's. There was no time for remeasurement since this was all done on the very last day of this program. It is, therefore, suggested to repeat these measurements again in the future with a more sophisticated setup to find out if the 6 9's sample is truly 6 9's, and how different the thermal conductivity is from 5 9's. No attempt was made to compute the Lorentz ratio since the data is poor.

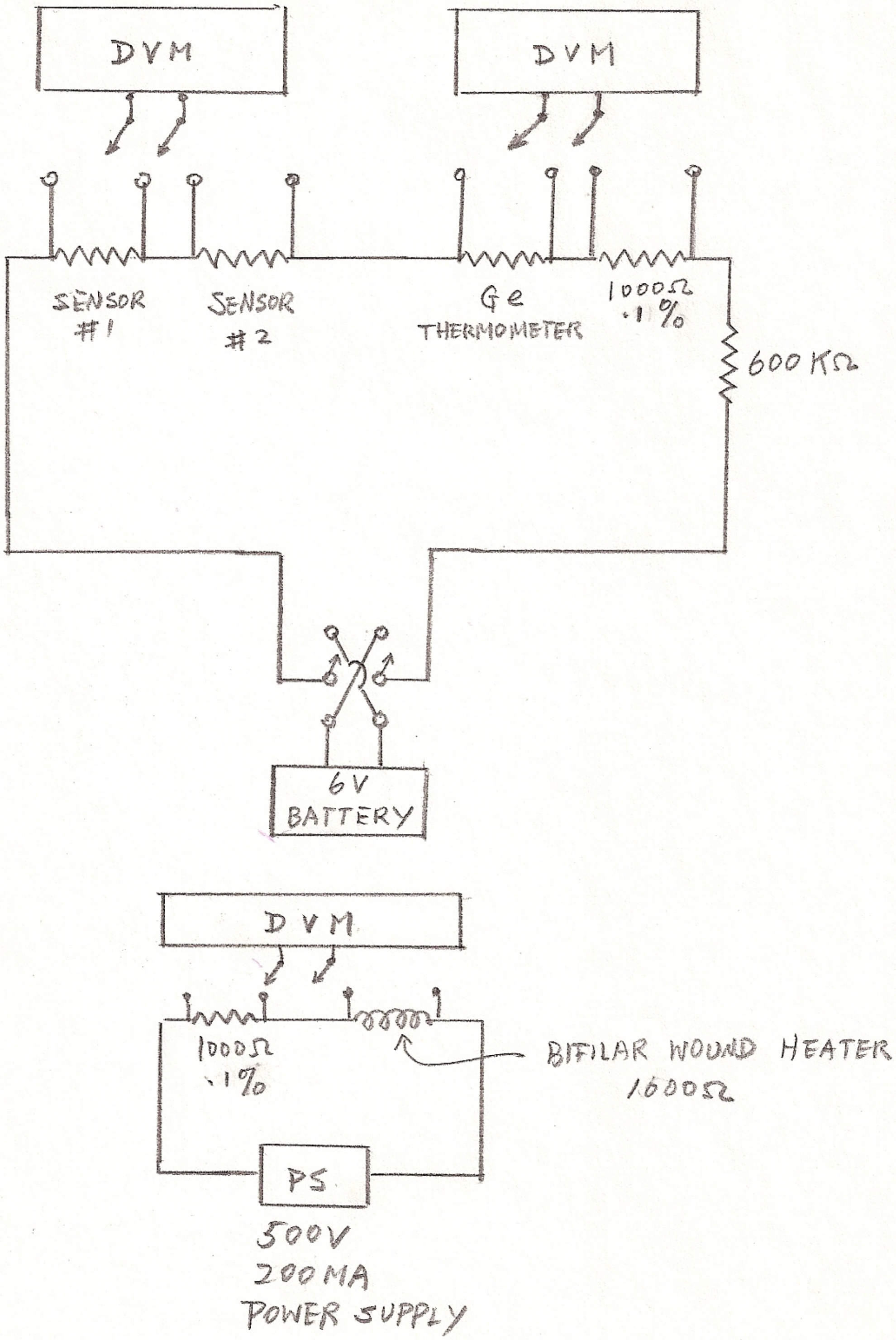
References

1. Cleaned with acetone and acid then annealed at $\sim 435^{\circ}C$ for 1.5 hours and slowly cooled down to room temperature ($<3^{\circ}C/min$).
2. The resistivity ratio was measured by John Jackson on both 5 9's and 6 9's aluminum ribbons, but was only done at $4.2^{\circ}K$.
3. R.L. Powell, W.J. Hall and H.M. Roder, J. of Applied Physics 31, 496 March 1960.
4. Bubble chamber group BNL, selected Cryogenic data notebook section VII-E-3.



DRAWING NOT TO SCALE

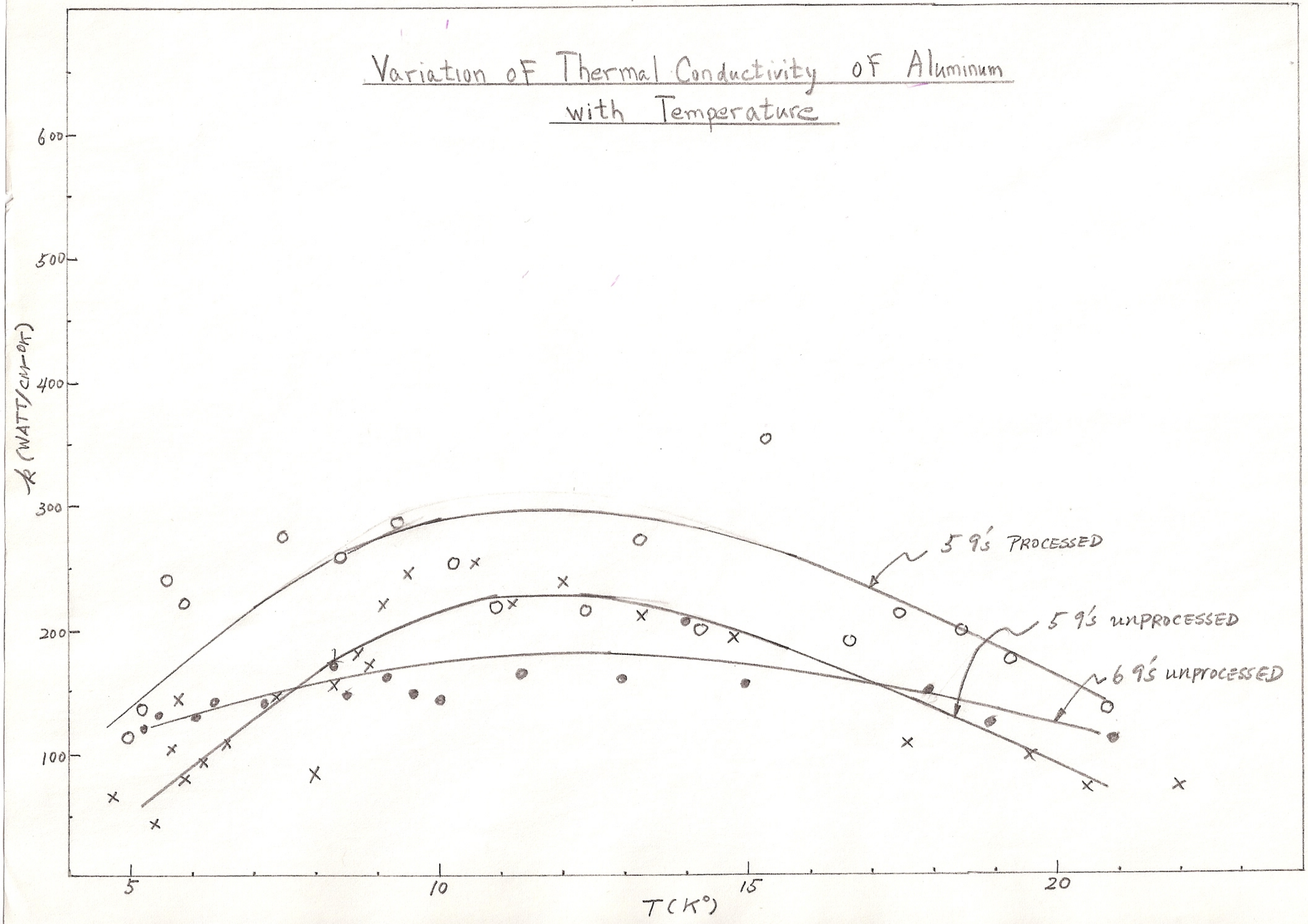
FIG. 1



DVM
DVM
SENSOR #1
SENSOR #2
Ge THERMOMETER
1000Ω .1%
600 KΩ
6V BATTERY
DVM
1000Ω .1%
BIFILAR WOUND HEATER 1600Ω
PS
500V
200 MA
POWER SUPPLY

FIG. 2

FIG. 3


Variation of Thermal Conductivity of Aluminum with Temperature
k (WATT/CM-°K)
600
500
400
300
200
100
5
10
15
20
T (K°)
5 9's PROCESSED
5 9's unprocessed
6 9's unprocessed

Measurement on the Normal Zone Propagation in a 1D7 Superconducting Model Magnet

S.Y. Hsieh and Karen Rutherford

Introduction

The sudden release of a large amount of energy during a change of phase from the superconducting state to the normal resistive state of a superconducting magnet could have serious consequences. Quench characteristics resulting from such a transition have not been fully investigated for various magnet construction and different methods of cooling and stabilization. Furthermore, studies of this sort have only been done on straight wires or simulated coils. As far as is known, no work has been done on a real magnet. It was, therefore, proposed to measure the quality of the aluminum stabilization and how a normal zone propagates to determine how future magnets may better be protected.

Experimental

Model No. 1 superconducting magnet was used for these experiments. This magnet has 81 turns in 9 layers, each separated by aluminum cooling sheets except at the ends. The last one and a half turns were unwound and two 500 ohm wire heaters were wound bifilarly around the superconducting magnet conductor, each about 1/8-in. wide. Eight voltage taps, each 4-in. apart, were indium soldered to the superconductor as shown in Fig. 1. There were six 1000 ohm bifilar wound heaters implanted in the magnet. Four heaters were glued on the outside of the coil and two on each side. Sheet micarta was used to back up the heaters on one side, while aluminum cooling sheet was used to back the heaters on the other side. Two heaters placed in the cavity of the phenolic form block were glued to the superconductor at the inner side of the coil. The location of these heaters is also shown in Fig. 1. Five voltage taps were indium soldered to every other layer, and four voltage taps on every other turn of the coil. The voltage taps were brought out and connected to a series of unit gain isolation amplifiers and then to the 4-channel storage scope as shown in Fig. 2. The trigger of the scope was synchronized with the SCR switch which discharges the capacitance through the heater upon firing.

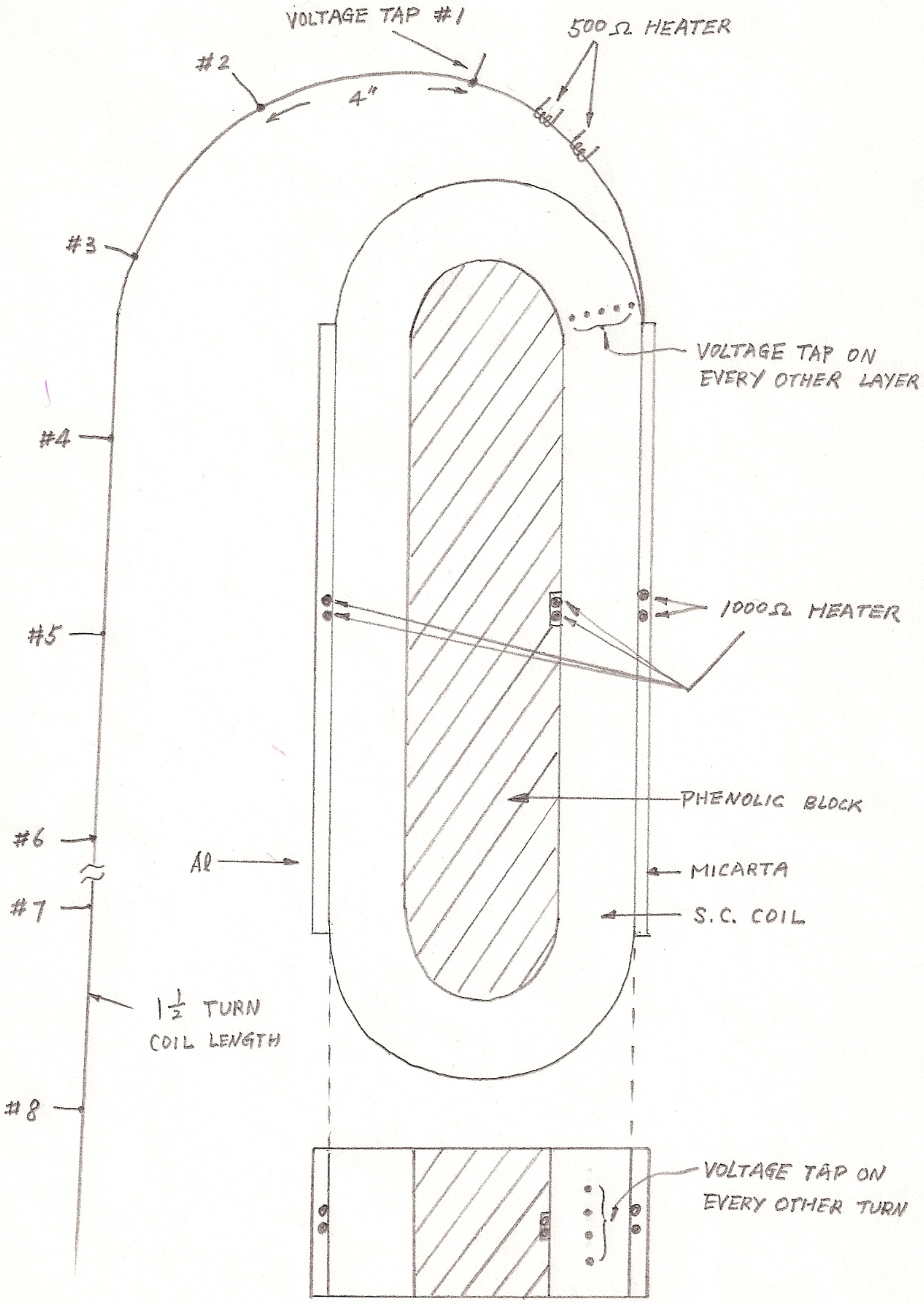
The cryogenic setup was the same as described in the previous report on loss measurement of 1D7 magnet.

Result and Discussion

After the size of the capacitance and charging voltage had been determined, a quench was initiated and the propagation of the normal zone was displayed by the storage scope as shown in Fig. 3. The graph suggests that the propagation velocity of the normal region at the magnet current of 700 amps is approximately 100cm/sec. This data agrees with Hagedom's data[1]. The experiment was carried out successfully at this first trial run and is certainly worthwhile for further detailed study.

References

1. D. Hagedom and P. DullenKopt, Cryogenics, May 1974.



VOLTAGE TAP #1
500 Ω HEATER
#2
4"
#3
VOLTAGE TAP ON
EVERY OTHER LAYER
#4
#5
1000 Ω HEATER
PHENOLIC BLOCK
#6
Al
MICARTA
#7
S.C. COIL
1½ TURN
COIL LENGTH
#8
VOLTAGE TAP ON
EVERY OTHER TURN

FIG. 1

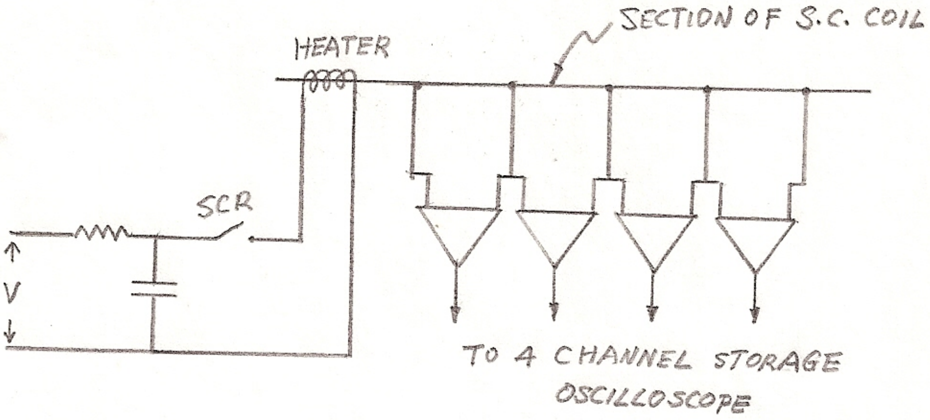


FIG. 2 BASIC MEASURING CIRCUIT

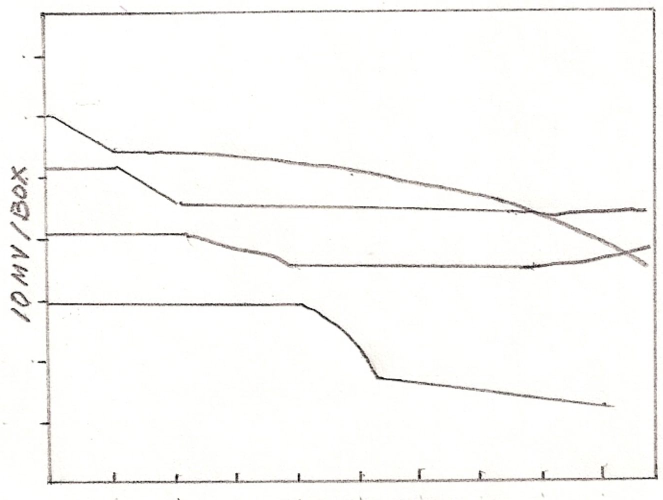


FIG. 3 STORAGE OSCILLOGRAM FOR NORMAL ZONE PROPAGATION

Energy Loss Measurement of Model 3 Superconducting Magnet

Karen Rutherford and Lynne Talley

Introduction

This experiment was carried out to repeat some of the previous wattmeter measurements on energy losses per cycle, and to take further data in the previously uncovered region.

Experimental

The circuit used in this part of the experiment is shown in Fig. 1. The energy loss per cycle as a function of rise time and magnetic field was measured.

The 1D7 was connected as before, except the dipole copper bus leads were replaced by two 1000 amp gas-cooled current leads. The 600V ACME power supply was used to power the 1D7. The level of liquid helium was maintained at 2½-inches above the top of the coil which was 1 inch below the end of the power leads. The Hall current was supplied by the voltage across the two power leads. The induced Hall voltage was then fed into an integrator and observed on an oscilloscope.

After having observed the energy loss for various magnetic fields and rise times, it was noted that there was a consistent resistance being integrated into each pulse in addition to the energy loss while the field was kept the same. It was found that the voltage taps were not soldered directly to the superconductor. This part of the experiment was discontinued until the voltage taps could be connected correctly. Calibrations were then begun, and during this procedure the magnet was pulsed to 500 amps. Although the level of helium was one inch above the coil, the magnet quenched and burned (see attached picture). After the quench, the level of liquid was just to the top of the coils, so one inch of helium had been boiled off.

There was no apparent reason for the quench; i.e., liquid level was high enough and the current was low. But it could happen due to the movement of superconducting lead wire caused by the deteriorating solder joint. This happened once before. It was later discovered, however, that the water pipe shunt had inadvertently been left out of the circuit. This was the cause of the burn because, first, the stored energy cannot be dumped outside and, second, there wasn't any protection circuit which would automatically turn off the power supply when it first detected a voltage surge due to the quench. Therefore, all the stored energy was absorbed by the model magnet and eventually melted the superconducting lead wire as can be seen in Fig. 2.

The inner part of the coil; i.e., that which was contained in the iron core, was not burnt or damaged in any way. This can be explained by the presence of the high purity aluminum cooling channel ships inserted between each layer, and also the presence of the iron. The aluminum, having very high thermal conductivity, conducted away the heat rapidly, whereas the ends have no aluminum cooling channel strips and the cooling depends on direct heat transfer to helium. The rate of heat transfer to helium at the ends vary with the temperature of the conductor, and a relatively small temperature rise can cause the heat transfer to move into the film boiling regime. The removal of heat at the ends then becomes more inefficient than in the middle sections of the coil, and it is believed that this effect caused the heat damage to the magnet coil at the ends.

Acknowledgements

I would like to thank Gordon Danby and Al Prodell for allowing me to be a part of the Group, David Hsieh for guiding me through the summer and for being an immense help, and all the great technicians for their patience and understanding.

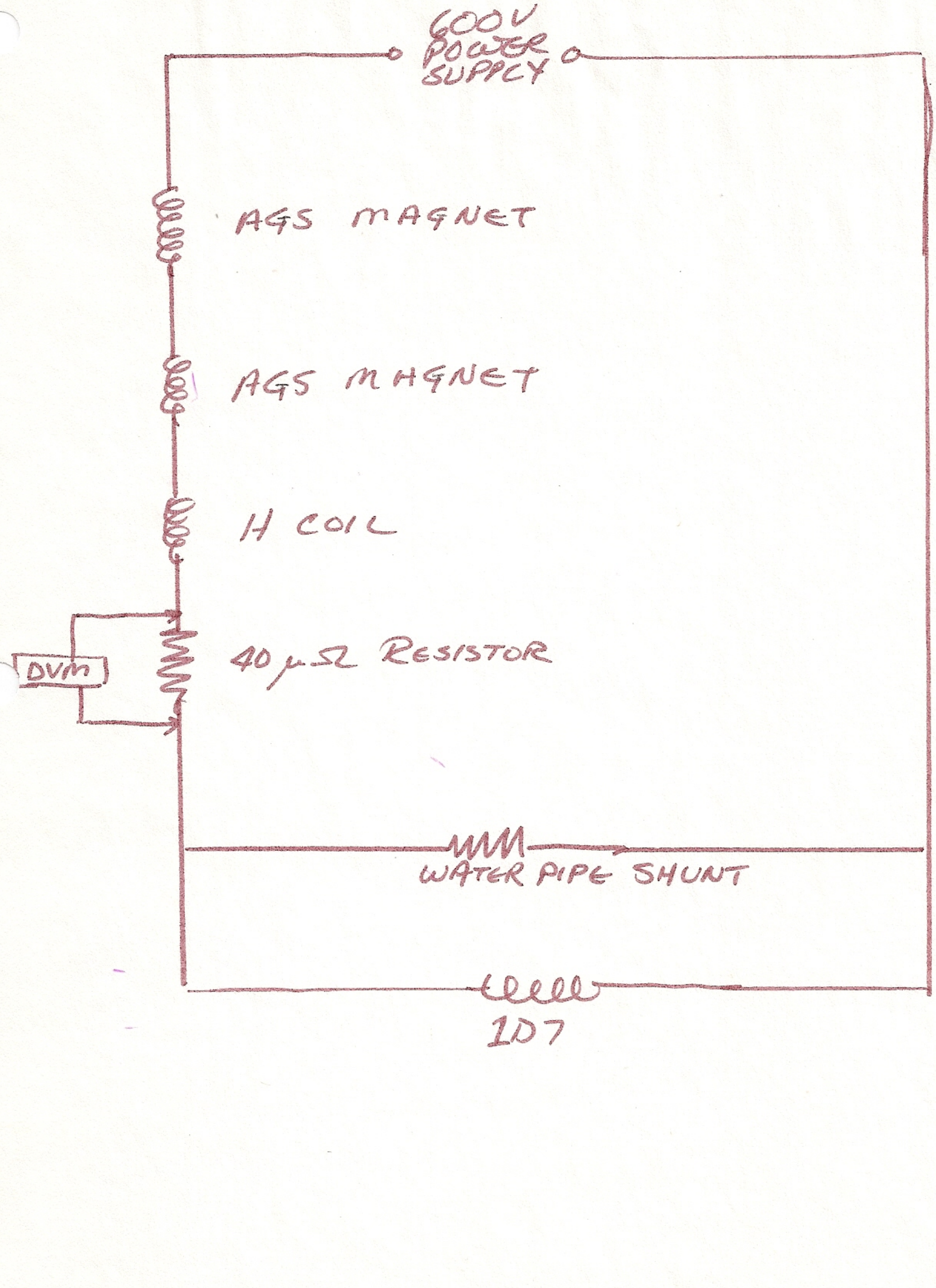

600V POWER SUPPLY
AGS MAGNET
AGS MAGNET
H COIL
DVM
40 μΩ RESISTOR
WATER PIPE SHUNT
1D7

FIGURE 1

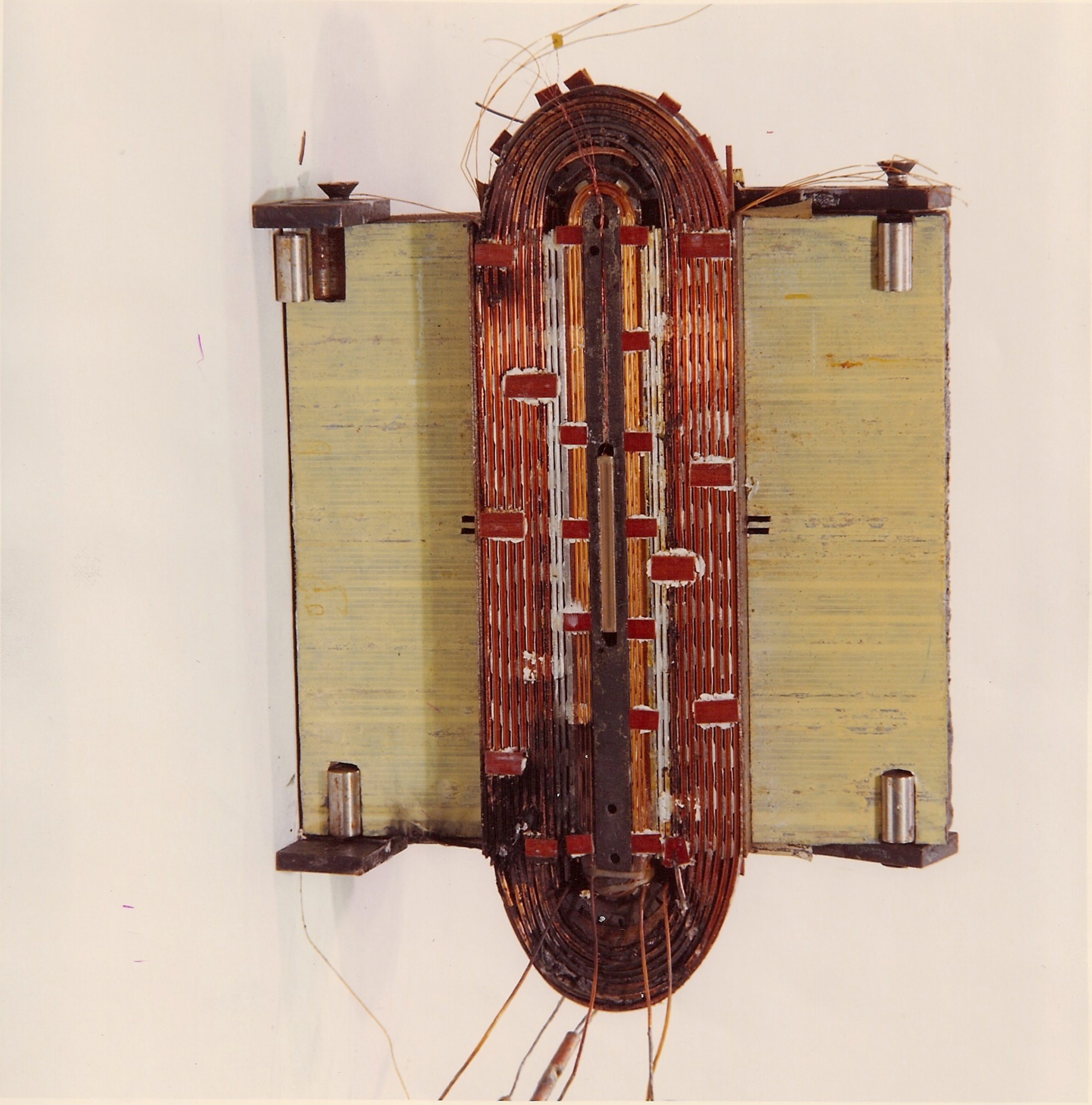


FIGURE 2