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A COMPUTER CONTROL SYSTEM FOR THE ALTERNATING GRADIENT MAGNETOMETER

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by

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ABSTRACT

An alternating gradient magnetometer has been interfaced to a computer for the automation of data taking. Using a fast Fourier transform analysis system data can be acquired and processed in real time. Data is stored on disk and can be recalled for plotting and further analysis. With the addition of a simple liquid nitrogen cryostat, magnetization measurements can be carried out in the range from 300 K to 77K. Results are reported on three different types of piezoelectric transducers.

Acknowledgements

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I also wish to thank the ASEE and NASA for providing the opportunity for me to work at MSFC this Summer.

LIST OF FIGURES

Introduction

The discovery of the ceramic superconductor Y-Ba-Cu-O [1] and its related compounds has led to a renewed interest in the general field of superconductivity. The ceramic superconductors, which have transition temperatures ranging from 90K to 120K and perhaps higher [2-4] have given rise to expectations of great technological utility. Unfortunately, most of these materials have low critical currents, which limits their current carrying abilities. This is a serious drawback for applications involving superconducting magnets and power transmission and storage.

In order to understand the limitations to the critical current it is important to be able to characterize the magnetic properties of a superconductor, as the two are intimately related [5]. Measurements of magnetization and magnetic hysteresis allow one to determine the extent of magnetic flux pinning, which is related to the microscopic critical current.

In the current research an alternating gradient magnetometer, which was constructed in the Summer of 1988, was interfaced with a computer in order to automate the taking of magnetization data.

Objectives

The objectives of this experiment were to interface the alternating gradient magnetometer to a computer and to write the program which would automate data taking. The program must be capable of reading the magnetization, temperature, and applied magnetic field, in real time, and storing them on a disk for later analysis.

Theory

The internal magnetic field in a non-ferromagnetic material is described by the equation

$$B = H + 4\pi M \qquad \text{(cgs units)}$$

where B is the magnetic induction, H is the external applied field and M is the magnetization. For homogeneous paramagnetic and diamagnetic materials M is a linear function of H. Thus, in a homogeneous material $M = XH$, where X is the magnetic susceptibility. In a paramagnetic material X is positive and in a diamagnetic material it is negative. Superconductors are diamagnetic when in the superconducting state and (usually) paramagnetic or non-magnetic ($X=0$) in the normal state. So a graph of M as a function of H should yield a straight line of slope X. In a superconductor, this will be true as long as the applied field does not approach the lower critical field Hc_1. Once Hc_1 is exceeded, magnetic flux begins to penetrate the sample, in the form of quantized flux lines. These flux lines become pinned in the sample, reducing the diamagnetic magnetization. The presence of pinned flux, therefore, produces a hysteresis in the magnetization vs field curve. The extent of the hysteresis is an indication of the extent of flux pinning. If an electric current is introduced in the sample, once it exceeds some critical value the flux lines will begin to move, giving rise to an electrical resistance. So, the extent of the hysteresis is also related to the critical current, at which electrical resistance begins to appear.

If a paramagnetic or diamagnetic material is placed in an external, non-uniform, magnetic field, it experiences a force in the direction of the field gradient dH/dx. This force is directly proportional to the field gradient, and to M, the magnetization. If one can measure this force then, knowing the field gradient, the magnetization can be computed.

The theory and construction of an alternating gradient magnetometer has been described by Flanders[6] and by the author[7]. In the original design, the gradient field was swept sinusoidally and the force on the sample was measured using a piezoelectric transducer connected to a lock-in amplifier. In its present form the piezoelectric output is detected by a fast Fourier transform analyzer.

Apparatus

Magnetometer

A block diagram of the magnetometer and associated circuitry is shown in figure 1. The major components will be discussed separately in the following paragraphs. A complete description of the field coils and vane can be found in reference 7.

Wave Analyzer

The output of the piezoelectric transducer is processes by an Ono Sokki Mini FFT Analysis System. The FFT system is a small dedicated computer which performs a fast Fourier transform on the input signal and displays the wave spectrum in near real time. The amplitude of the peak corresponding to the driving frequency can be selected thereby eliminating other peaks caused by noise and overtones. The amplitude of the selected peak is read by the computer and stored in an array.

Function Generator

The driving current for the sweep coils is obtained from a Wavetek model 270 Function Generator. The drive voltage and frequency are input at the start of the program and written to the Wavetek by the computer. The frequency is set at the resonant frequency of the reed, or one of its overtones. The drive voltage is set to produce an rms current of 100 mA through the sweep coils.

Current Source

The current for the D.C. magnet is obtained from a Hewlett-Packard model 228A Current Source. The magnet current is ramped in steps of 0.10 Amp preceding each measurement of the signal amplitude. It was necessary to add a time delay of 2 to 4 seconds in order to allow the system to settle down between measurements. A further provision was added to allow the sample to be cooled initially in a preset magnetic field, in order to analyze the extent of flux pinning.

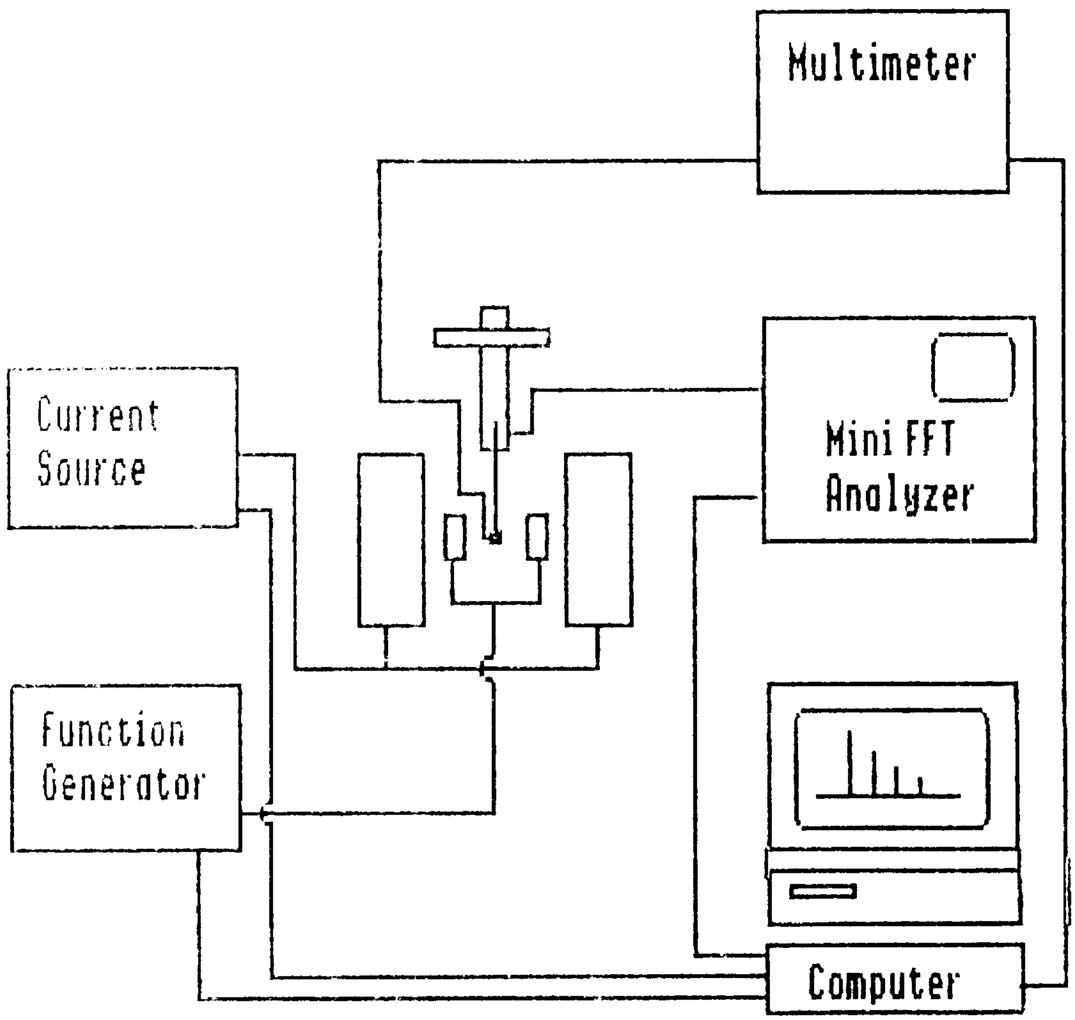

Figure 1. Magnetometer Block Diagram.

Computer

The HP 9133 computer was programmed in Basic to control the magnetometer and collect data on the magnetization, magnetic field, and temperature, through the GPIB bus. Data could be saved to disk and printed out or plotted. An HP 631 printer and an HP 7470A plotter were connected to the computer for these purposes.

Temperature Measurements

The temperature sensor is a Copper-Constantan thermocouple which is glued to the end of the vane, next to the sample, with GE 7031 varnish. The thermocouple output goes to an HP Model 3451A programmable multimeter. The thermocouple voltage is read by the computer and recorded as part of the data each time a measurement is made.

Programs

Four different variations of the Basic program were developed. (1) Magnitude, which measures the magnitude of the peak, at the sweep coil frequency, as a function of magnet current, from 0 to 1 A. (2) Cross Spectrum, which measures the real part of AxB, where A is the sweep coil drive signal and B is the transducer output signal. The field current is swept from 1 A to -1 A. (3) Quick, which measures the magnitude at five values of magnet current, from 0 to 0.5 A and calculates the average slope and (4) TC, which records the magnetization and temperature as a sample is warmed through the superconducting transition. The flow chart in figure 2 applies to all three programs. The programs are menu driven. The first section initializes the four instruments and sets the operating parameters. The operator selects the frequency and voltage for the sweep coils, the input voltage range for the analyzer, and the gain for the display Y-axis. In program 1 the option of field cooling is provided as well. Following the initialization the subroutine "Acquire" is called which manages the actual acquisition of data. Once the data is taken, the subroutine "Store" is called and the data is stored on disk. The operator is prompted for a filename and may elect to not store the data at this point by doing a reset, in which case the data is lost. Once the data is stored on disk the menu provides options of plotting on the screen, printing on the screen, plotting on the plotter, or printing on the printer. Program listings are given in the Appendix.

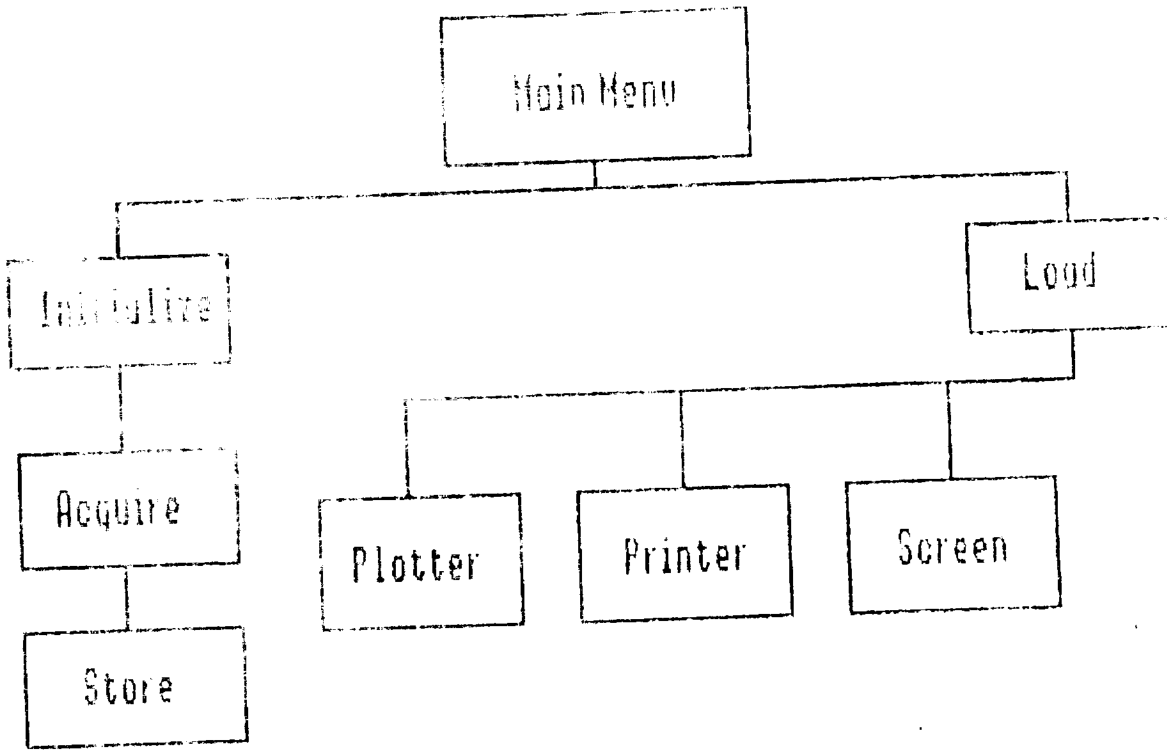

Figure 2. Program Flow Chart.

Results

Of the three types of piezoelectric transducers used, the PZT ceramic was found to give the most stable and reproducible results. This was largely due to the failure of the silver paint to properly bond the Kynar films to their copper supports. The response of the PZT reed to a white noise signal applied to the sweep coils is shown in **Figure 3**. This particular reed has a resonant frequency of 111 Hz. The peak at 10 Hz is due to vibrations of the isolation table on which the magnetometer was mounted. **Figure 4** shows the response curve for an unsupported Kynar film. No resonance is seen, the 10 Hz noise peak is particularly large, followed by peaks at 60 and 180 Hz due to line noise. The response of this reed was nearly independent of frequency but was not nearly as good as that of the PZT reed near resonance. All of the following data were taken with the PZT reed.

Initially, two types of curves were generated. The curves of magnetization vs magnetic field, and curves of susceptibility vs temperature, which were generated by taking average slopes of the magnetization curves, fitted to straight lines. **Figures 5** and **6** show a set of magnetization curves for $Er_1Ba_2Cu_3O_x$, the material which is refered to as Er123. The value of x is between 6.5 and 7 in the superconducting phase of this compound. In **figure 5** the material is superconducting and diamagnetic while in **figure 6** it is normal and paramagnetic, due to the Er ion in the lattice. The average slope of each curve was taken to determine the change in magnetic susceptibility with temperature, the result is shown in **figure 7**.

The degree of magnetic flux pinning can be determined by comparing magnetization curves for samples which have been field-cooled (Meissner effect) and zero-field cooled (shielding). If a sample is cooled below its superconducting critical temperature while in an applied magnetic field, the internal field is expelled, this is the Meissner effect. For type II materials, however, some magnetic flux can be pinned in the material and, for small fields, will not be expelled. This results in a positive contribution to the magnetization. Thus a difference in slope between field-cooled and zero-field cooled data on the same sample will give an indication of the extent of the flux pinning.

Figure 8 shows the magnetization vs magnetic field curves for a sample of Y123. The curves represent field-cooled (H=27 Oe) and zero-field cooled (H=0) conditions. The difference in slope between the two curves indicates the

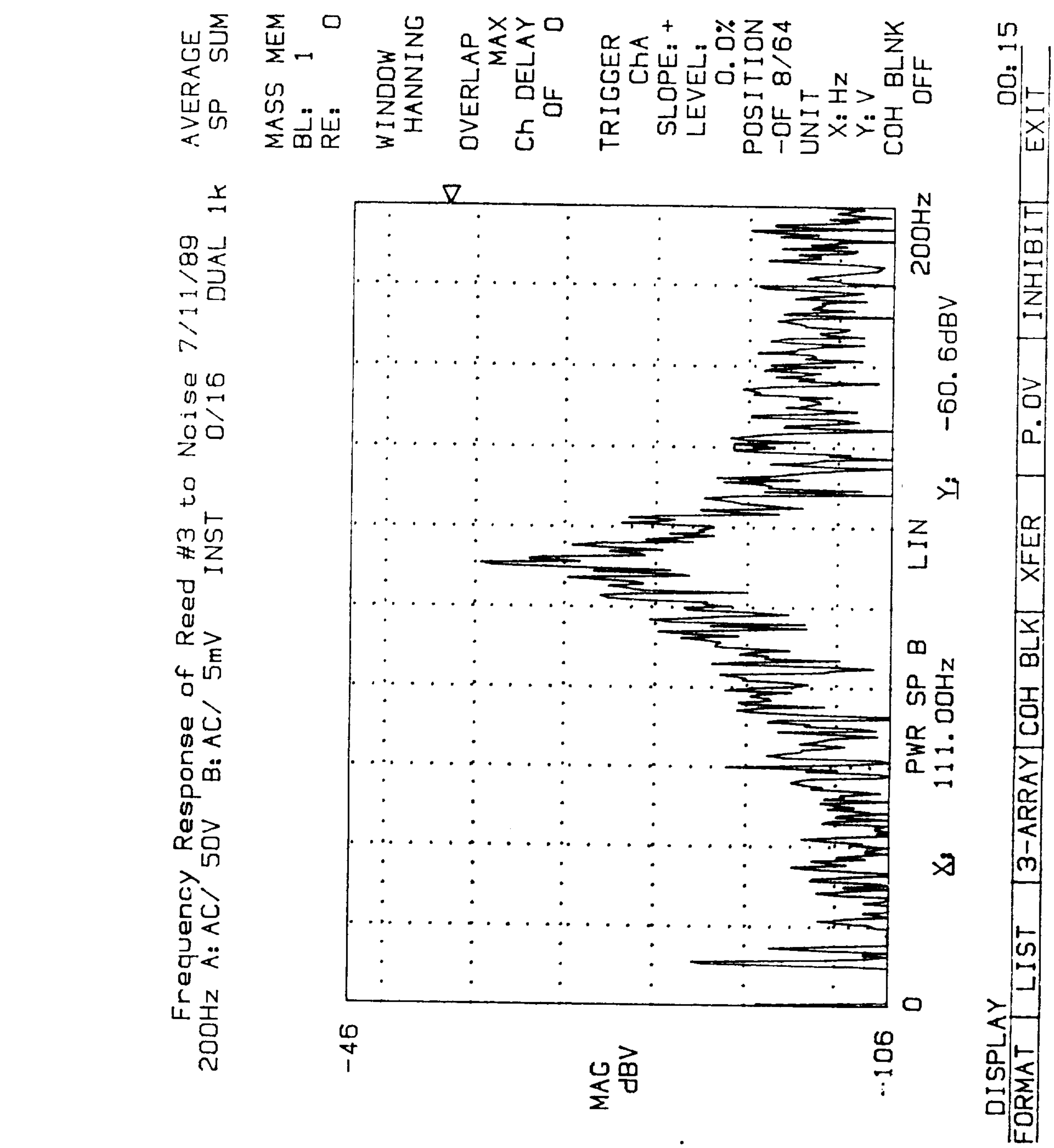

Figure 3. Frequency Response of the PZT Reed.

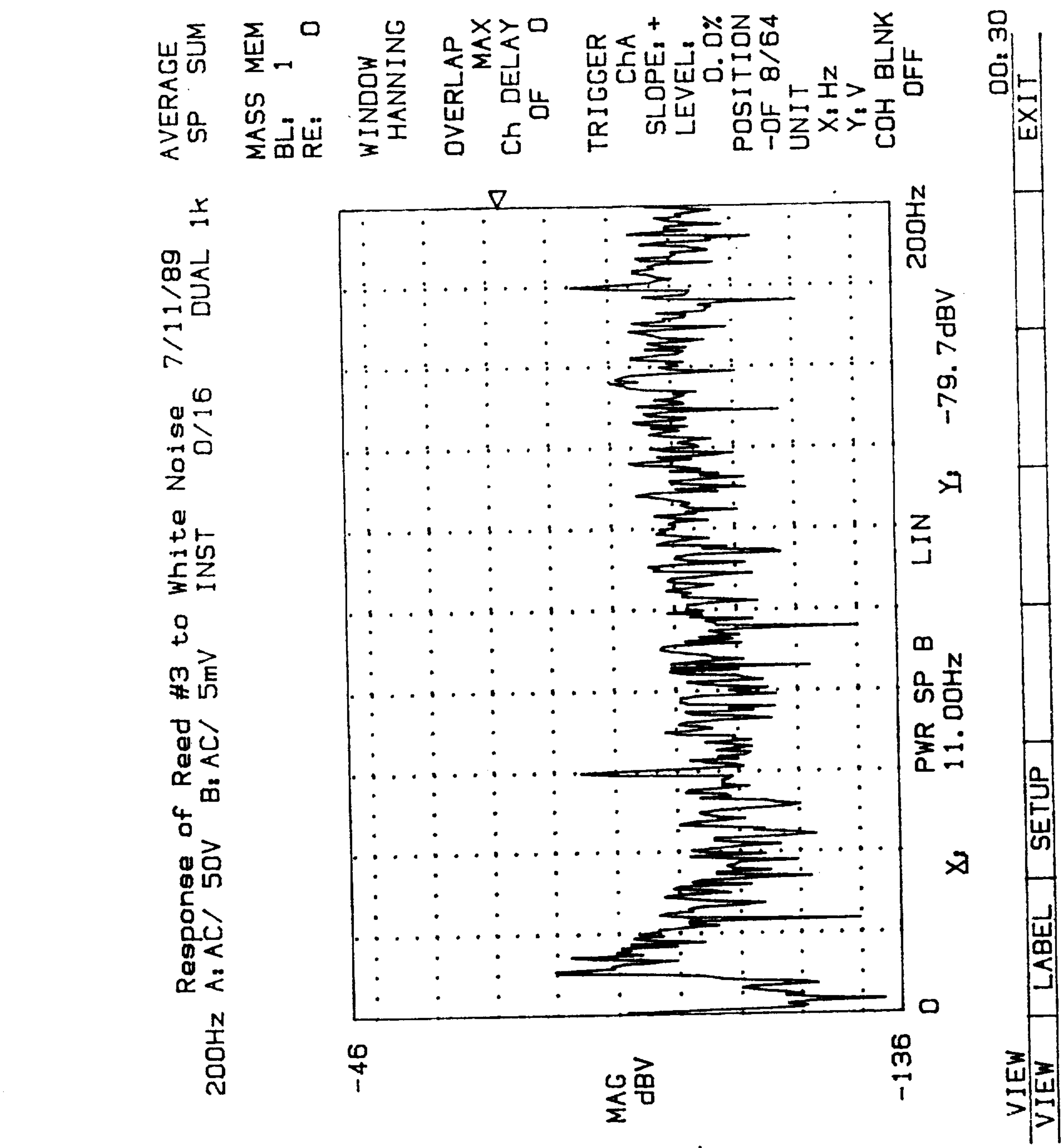

Figure 4. Frequency Response of Kynar Reed.

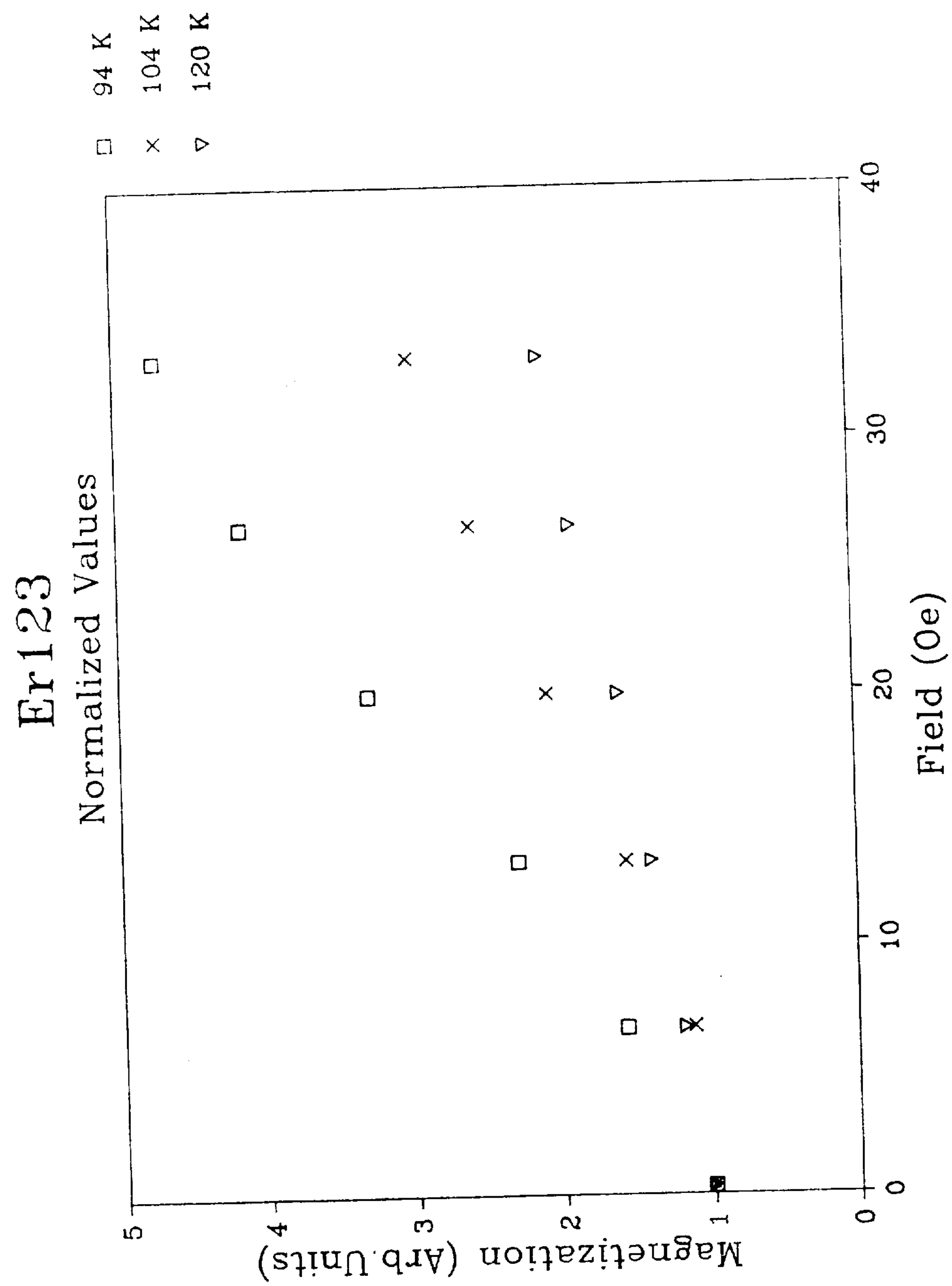

Figure 5. Magnetization Curve for Superconducting Er123.

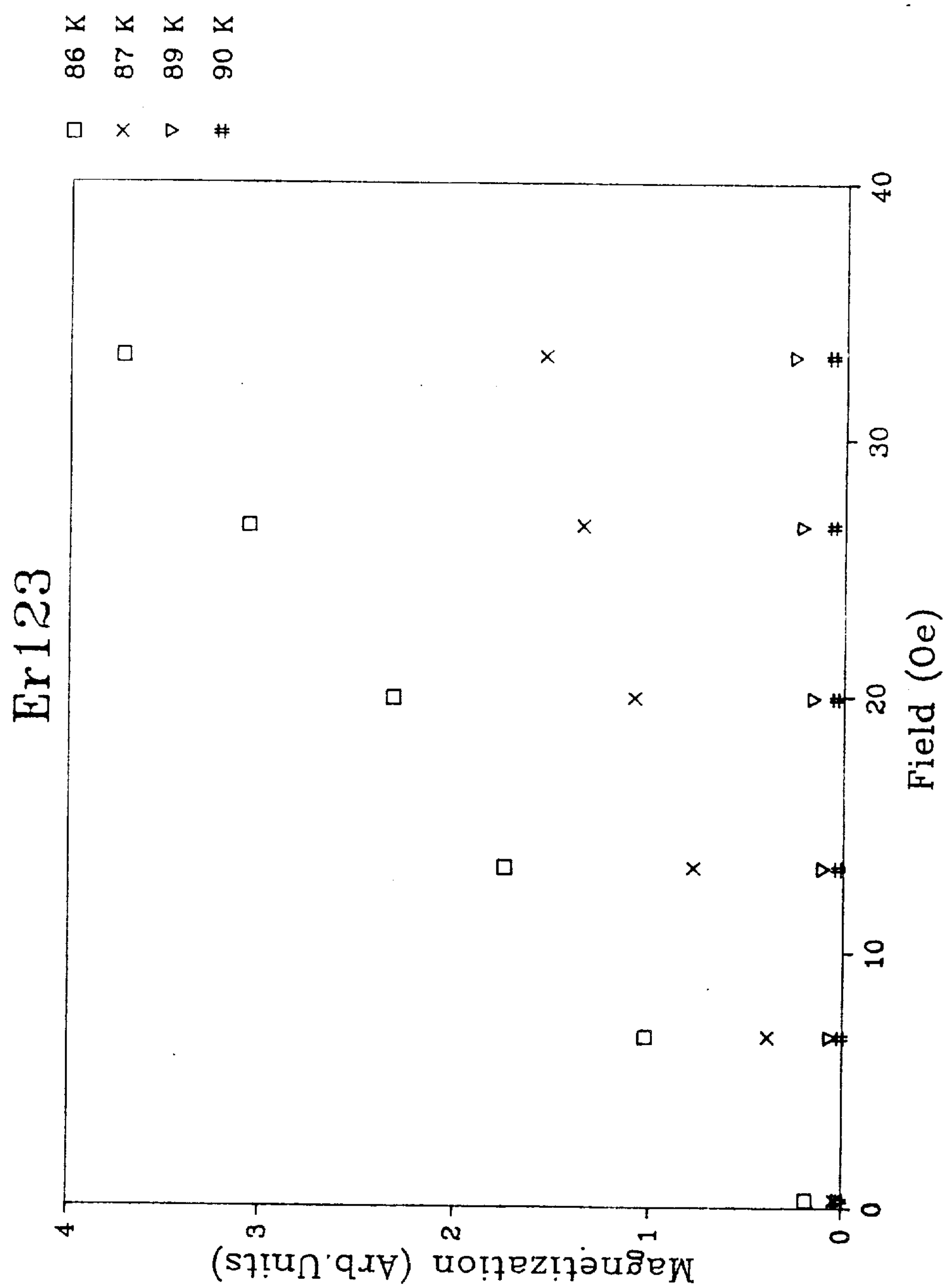

Figure 6. Magnetization Curve for Normal Er123.

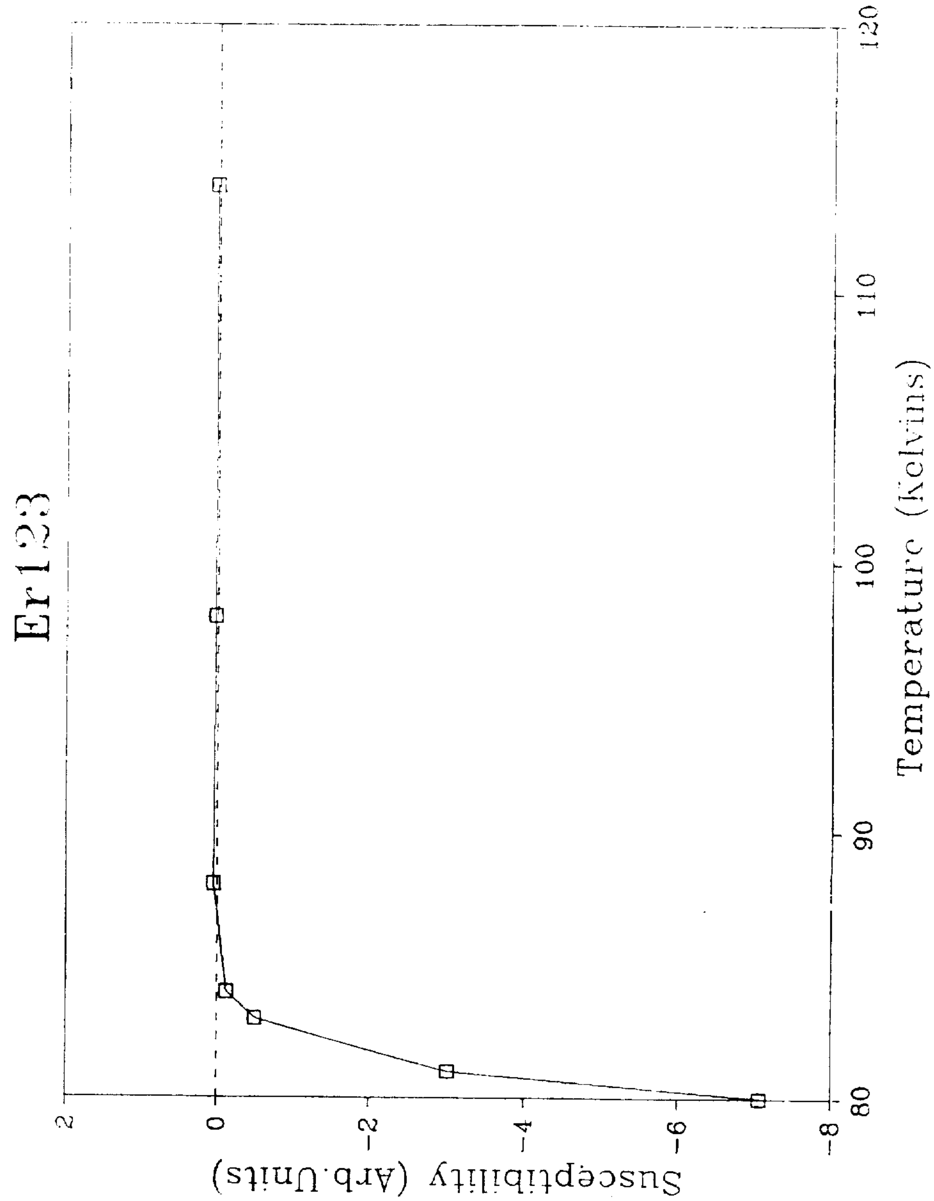

Figure 7. Susceptibility Curve for Er123.

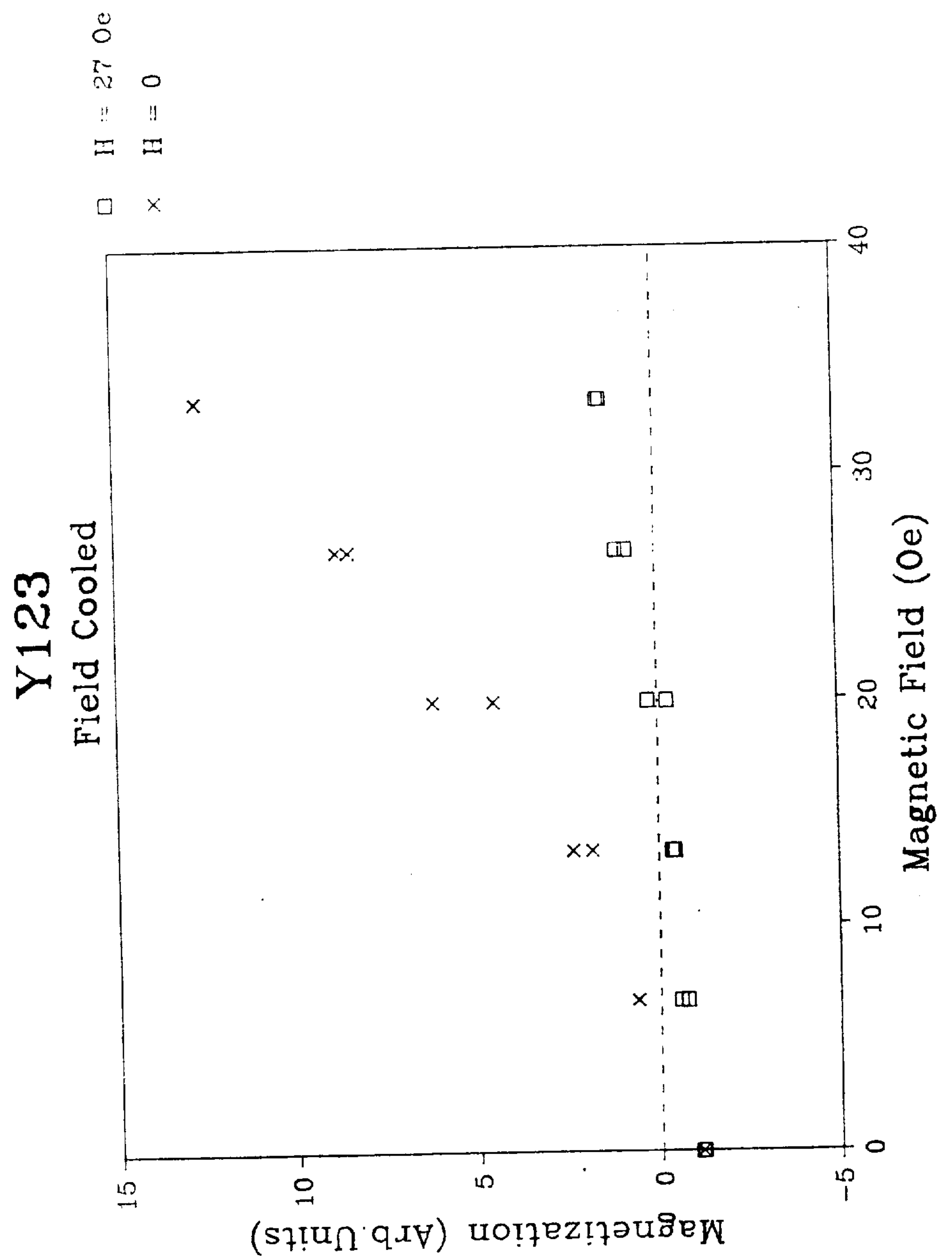

Figure 8. Magnetization Curve for Field-Cooled Y123.

extent of the flux pinning. **Figure 9** shows the same experiment for Y123 which has been doped with Ag. Here the slopes of the two curves are practically identical, indicating little flux pinning in the doped material.

The program "Cross Spectrum" has the capability of distinguishing between positive and negative magnetization and can be used to generate hysteresis curves for magnetic materials. **Figure 10** shows a hysteresis curve for a sample of Eu123+Ag which was zero-field cooled. The increase in (negative) magnetization on going once around the loop is a measure of the amount of trapped flux. The same sample is shown in **figure 11** after field-cooling in a 66.4 Oe magnetic field. The curve is now closed, indicating that flux was trapped upon cooling.

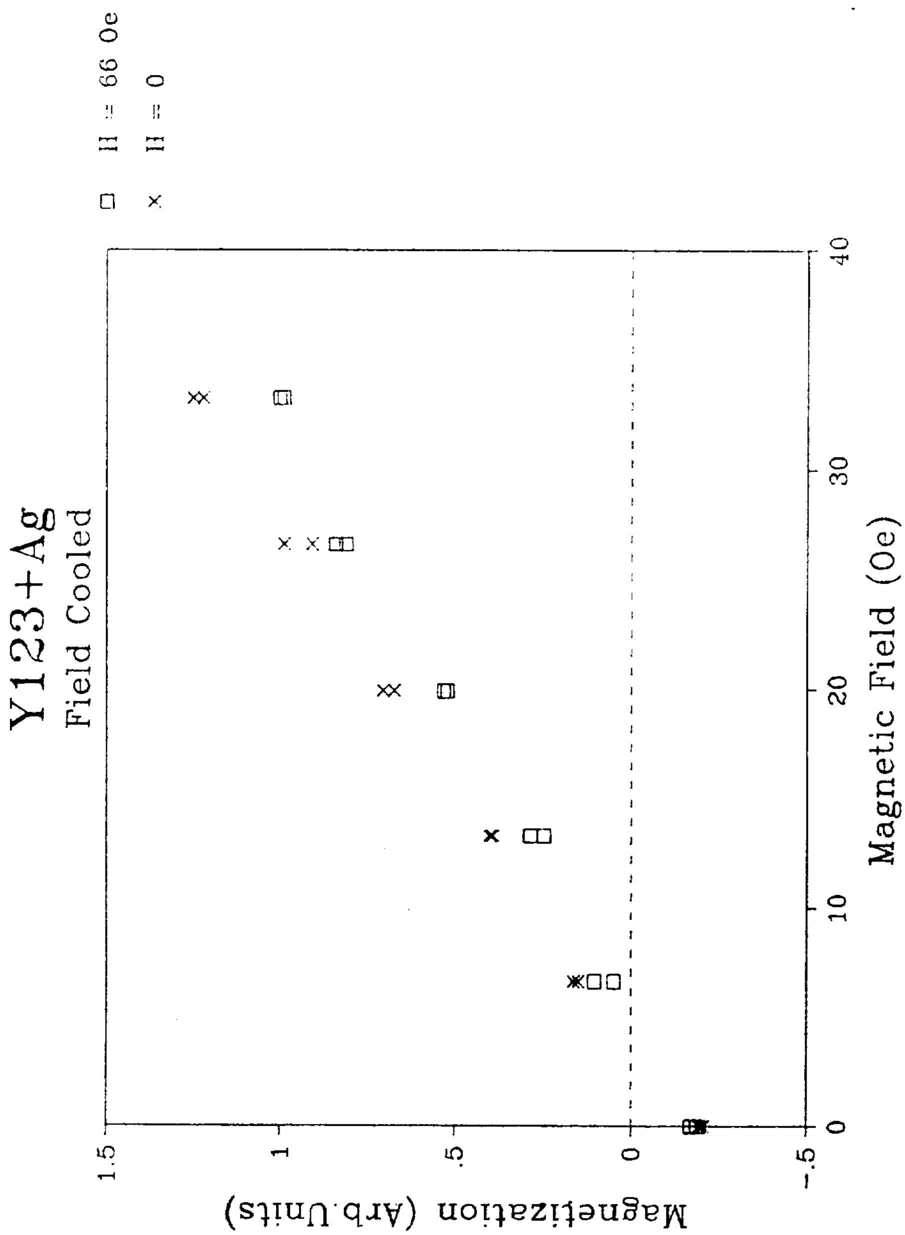

Figure 9. Magnetization Curve for Field-Cooled Y123+Ag.

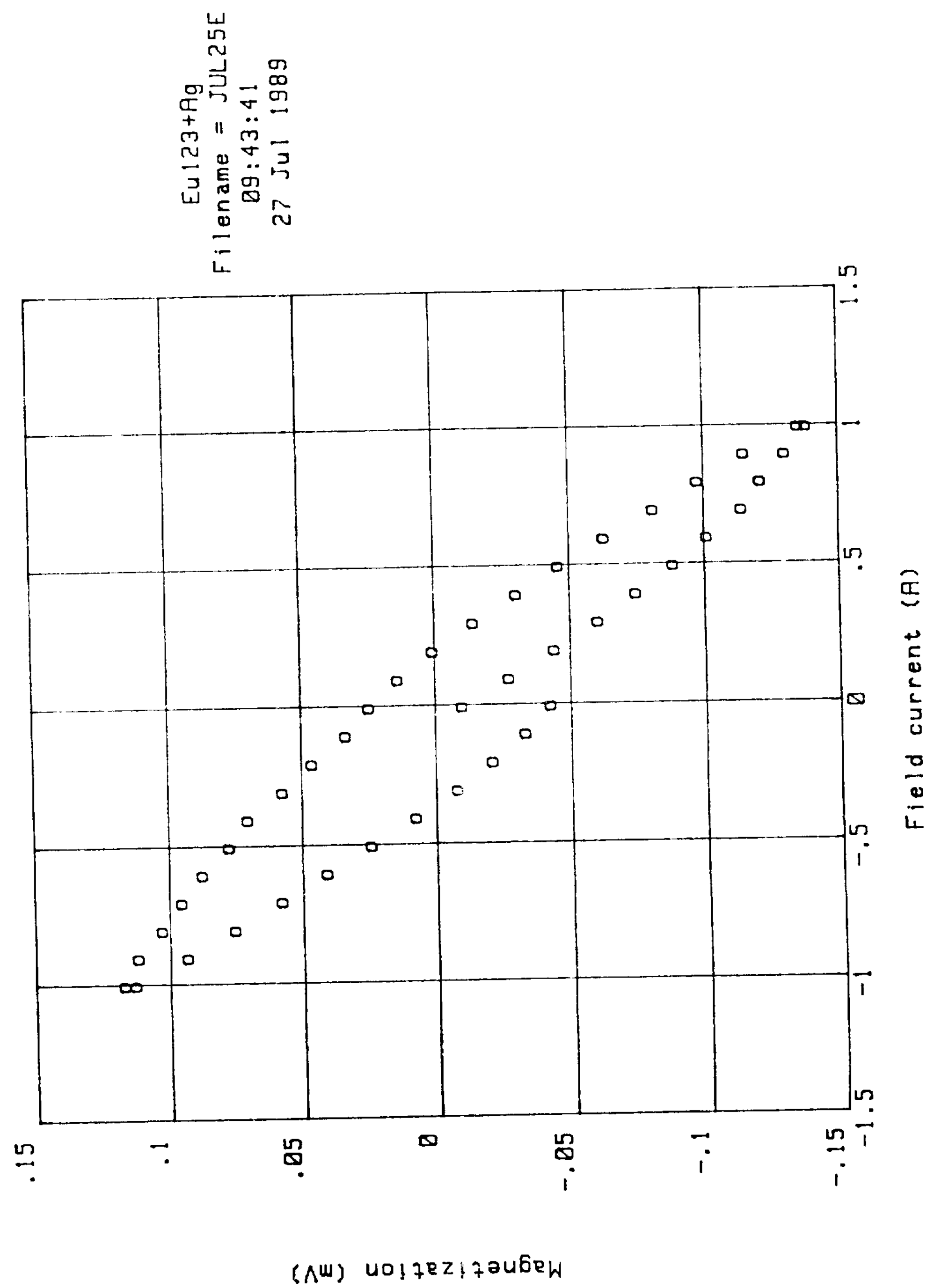

Figure 10. Hysteresis Loop for Eu123+AG.

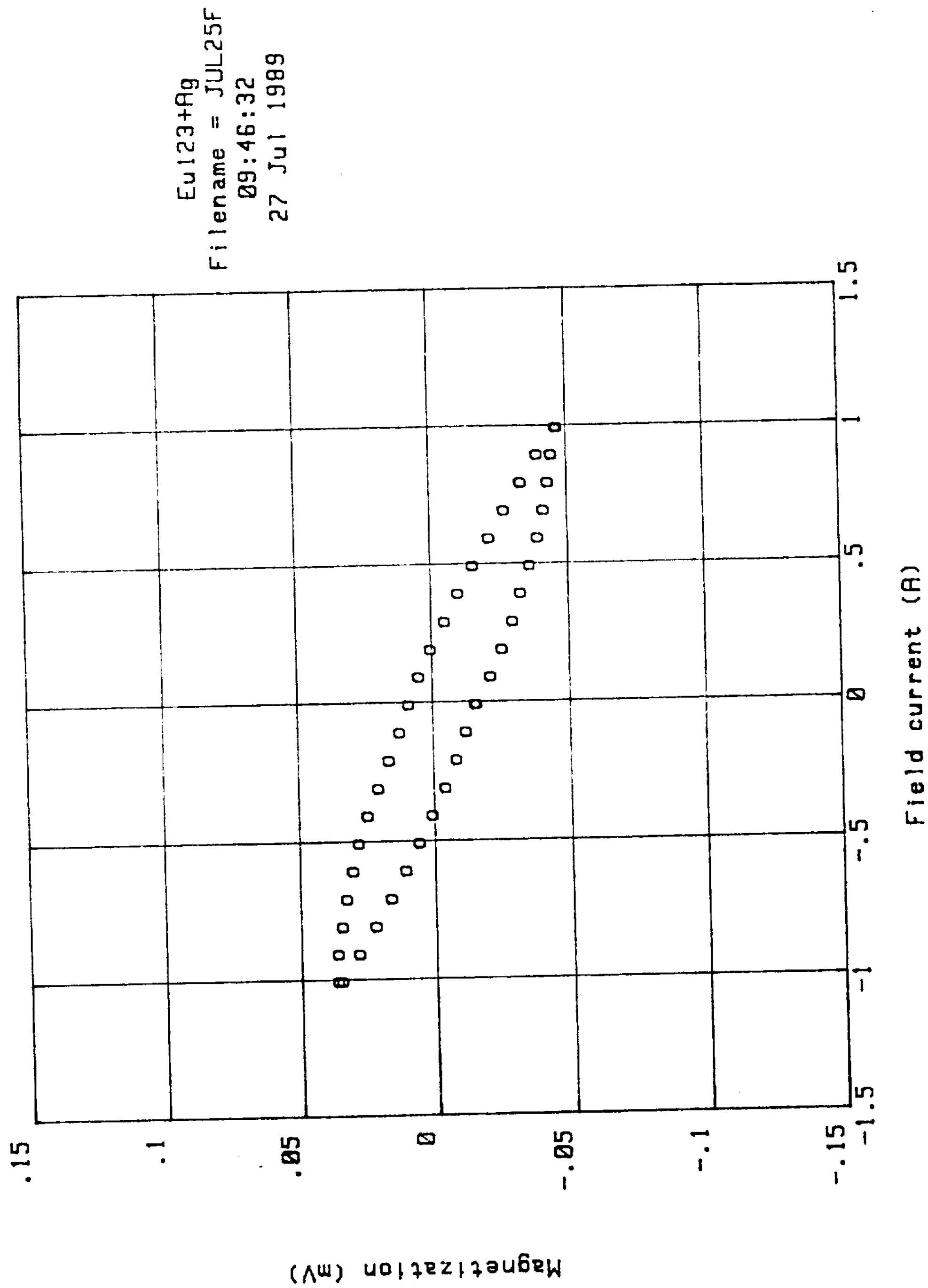

Figure 11. Hysteresis Loop for Field-Cooled Eu123+Ag.

C-4

Conclusions and Recommendations

The alternating gradient magnetometer can be a valuable tool for the characterization of the magnetic properties of materials. It should be particularly usefull in superconductivity research because of its sensitivity and ease of use. With the current data acquisition system, data may be taken more quickly than before and the data analysis is greatly simplified. The data which is acquired will become even more useful if the instrument is calibrated to measure magnetization in absolute units. This should not be difficult to do using a standard material, such as one of the rare-earth salts.

The chief difficulty in using this instrument is the lack of precise temperature control. The temperature of the sample changes with the liquid nitrogen level in the dewar. As the liquid evaporates the sample slowly warms. It would be convenient to be able to take a series of magnetization measurements at a fixed temperature. This is not possible with the current instrument although the rate of temperature change can be kept quite low, so that the temperature does not change more than about 0.1 K during the course of a measurement.

The computer program can be improved in several places. The program called Magnitude could be rewritten so that it would take a series of measurements, say one magnetization curve each degree of temperature change, and save them to disk automatically. The program called Cross Spectrum needs to have the temperature measuring routine added to it as well. Finally, some way needs to be devised to keep track of any variation in the resonant frequency of the reed and adjust the function generator accordingly.

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Appendix

```
10    !*****************************************************!
20    !                  PROGRAM: MAGNITUDE                  !
21    !                                                      !
30    !    PLOTS THE MAGNITUDE OF THE SIGNAL ON CHANNEL B    !
40    !         FROM ZERO TO 1/2 AMP MAGNET CURRENT          !
50    !          USING THE CF-920 FFT ANALYSIS SYSTEM        !
60    !                    JUNE 8, 1989                      !
70    !                                                      !
80    !    MODIFIED JULY 7, 1989 TO USE THE PZT TRANSDUCER   !
81    !    MODIFIED JULY 17, 1989 TO MONITOR TEMPERATURE     !
82    !                                                      !
90    !*****************************************************!
100   !
110   ! Number of Averages is in Line 580
120   !
130    OPTION BASE 1
140    CONTROL 1,12;1
150    DIM Magnitude(250),Fieldcurrent(250),Temperature(250)
160    PLOTTER IS 3,"INTERNAL"
170    GCLEAR
180    !
190    !*********************** MENU ***********************
200    !
210    PRINT CHR$(12)
220    PRINT "   (1)   Acquire magnetization data"
230    PRINT
240    PRINT "   (2)   Load magnetization data from disc"
250    PRINT
260    PRINT "   (3)   Plot magnetization data on screen"
270    PRINT
280    PRINT "   (4)   Print magnetization data on screen"
290    PRINT
300    PRINT "   (5)   Plot magnetization data on plotter"
310    PRINT
320    PRINT "   (6)   Print magnetization data on printer"
330    INPUT Selection$
340    IF Selection$="1" THEN GOSUB Initialize
350    IF Selection$="2" THEN GOSUB Load
360    IF Selection$="3" THEN GOSUB Screenplot
370    IF Selection$="4" THEN GOSUB Screenprint
380    IF Selection$="5" THEN GOSUB Plotterplot
390    IF Selection$="6" THEN GOSUB Printerprint
400    GOTO 210                     ! Clear Screen and Show Menu
410 Initialize:     ! Setup Display Window
420    PLOTTER IS 3,"INTERNAL"
430    GINIT
440    GCLEAR
450    VIEWPORT 0,100,0,100
460    WINDOW 0,1,0,3
470    GRID .25,1
480    GRAPHICS ON
490    FRAME
500                                                              !
510                                                              !
520                                                              !
530   !********************   SET UP FOR CF920   ************************
540                                                              !
550    INPUT "Channel B Range (1-15)",Br$
560    IF Br$="" THEN Br$="10"
570    OUTPUT 710;"AMS3"         !  Spectrum peak averaging
```

```
580    OUTPUT 710;"ANS5"          !  Take 5 squared averages
590    OUTPUT 710;"TRE"           !  Repeated trigger
600    OUTPUT 710;"TIA"           !  Channel a trigger
610    OUTPUT 710;"AAS2"          !  Channel A input voltage range
620    OUTPUT 710;"BAS"&Br$       !  Channel b input voltage range
630    OUTPUT 710;"FRS8"          !  Channel A&B input frequency range
640    OUTPUT 710;"BSP"           !  Display B spectrum
650    OUTPUT 710;"YLI"           !  Selects linear scaling
660  ! OUTPUT 710;"SON"           !  Search function on
670  ! OUTPUT 710;"SPS401"        !  Sets search marker for peak point
680                                                                        !
690    !*****************   CF920 SETUP COMPLETE   ***********************
700                                                                        !
710                                                                        !
720                                                                        !
730    !*****************SETUP FOR THE 228 CURRENT SOURCE*****************
740                                                                        !
750    CLEAR 711
760    OUTPUT 711;"V25"                           !  Voltage limits to 25 volts
770    INPUT "Initial Current (0-1)",Current           !Used for Field Cooling
780    IF Current=0 THEN GOTO 810
790    OUTPUT 711;"I"&VAL$(Current)
800    GOTO 820
810    OUTPUT 711;"I0"                        !  Initializes current to 0 amperes
820    OUTPUT 711;"F1X"                       !  Execute
830    INPUT "Press a Key to Continue",K$
840    !***********   SETUP FOR THE 228 CURRENT SOURCE COMPLETE   *********
850                                                                        !
860    !***********  SETUP FOR HP3457A TO READ TEMPERATURE ***************
870    !              USING A COPPER-CONSTANTAN THERMOCOUPLE               !
880    !
890  ! INTEGER I
900    ASSIGN @Temp TO 724
910    OUTPUT @Temp;"TRIG SYN"
920    OUTPUT @Temp;"NDIG 4"          ! Four Digit Accuracy
930    OUTPUT @Temp;"FIXEDZ OFF"
940    OUTPUT @Temp;"DCV"             ! Read DC Volts
950    OUTPUT @Temp;"AZERO 1"         ! Automatic Zero
960    OUTPUT @Temp;"NPLC 10"         ! Ten Power Line Cycle Delay
970    !
980    !******************** TEMPERATURE SETUP COMPLETE ******************
990    !
1000   !********************  SETUP FOR THE 270   ***********************
1010                                                                       !
1020   Rf$="100"                 !  Resonant frequency of PZT
1030   Swv$="4.40"               !  Sweep voltage of little coils
1040   PRINT CHR$(12)            !  Clears screen
1050   CLEAR 709
1060   INPUT "Resonant frequency",Trf$
1070   IF Trf$="" THEN
1080       Rf$=Rf$               !  Default value is 74.4 Hz
1090   ELSE
1100       Rf$=Trf$
1110   END IF
1120   INPUT "Sweep voltage",Tswv$
1130   IF Tswv$="" THEN
1140       Swv$=Swv$             ! Default value is 4.4 volts
1150   ELSE
1160       Swv$=Tswv$
1170   END IF
```

```
1180   Freq=VAL(Rf$)
1190   Rf$="F"&Rf$                 !  Adds a F for frequency to variable
1200   OUTPUT 709;Rf$              !  Sets frequency of Wavetek
1210   OUTPUT 709;"I"              !  Execute
1220   Swv$="A"&Swv$               !  Adds an A for amplitude to variable
1230   OUTPUT 709;Swv$             !  Sets voltage for Wavetek
1240   OUTPUT 709;"I"              !  Execute
1250   OUTPUT 709;"P1"             !  Output on
1260   OUTPUT 709;"I"              !  Execute
1270   OUTPUT 709;"TSI"            !  Displays frequency on front of 270
1280   OUTPUT 709;"F"              .
1290   !
1300   !*************  ENABLE CF920 DELTA SEARCH FUNCTION ******************!
1310   !
1320   OUTPUT 710;"SON"           ! SEARCH ON
1330   Hf=(Freq)*2+5             ! UPPER LIMIT OF SEARCH
1340   Lf=(Freq)*2-5             ! LOWER LIMIT OF SEARCH
1350   Lf$=VAL$(Lf)
1360   Hf$=VAL$(Hf)
1370   OUTPUT 710;"SPS"&Lf$       ! SET LOWER LIMIT
1380   OUTPUT 710;"DON"           ! DELTA FUNCTION ON
1390   OUTPUT 710;"DCS"           ! SET THE DELTA CURSOR
1400   OUTPUT 710;"SPS"&Hf$       ! SET UPPER LIMIT
1410   INPUT "Y-AXIS GAIN (1-5)",Yag
1420   FOR G=1 TO Yag
1430   OUTPUT 710;"YGU"
1440   NEXT G
1450   OUTPUT 710;"PAO"            ! PARTIAL OVERALL ON
1460                                                                    !
1470   !*************   SETUP FOR THE 270 WAVETEK COMPLETE   ****************
1480                                                                    !
1490                                                                    !
1500                                                                    !
1510   GOSUB Acquire               ! Take data
1520   !**********************************************************************
1530   GOSUB Store                 ! Write the data to disc
1540   RETURN                      ! Back to the Menu
1550   STOP
1560 Acquire:    ! Take data ************************************************
1570   I=0
1580   FOR Fieldi=0 TO .5 STEP .1      !  0 to 0.5 Amps in  5 steps
1590       IF Fieldi<1.E-9 AND Fieldi>-1.E-9 THEN Fieldi=0
1600       I=I+1
1610       Fieldi$="I"&VAL$(Fieldi)  !  Adds an I to the field current vairable
1620       OUTPUT 711;Fieldi$        !  Sends value of current to current source
1630       OUTPUT 711;"F1X"          !  Execute
1640       WAIT 3                     !  Wait for system to settle
1650       OUTPUT 710;"LYS"      !  Selects Display Y search value
1660       ENTER 710;Volts    !  Reads display Y search value ; volts
1670       Magnitude(I)=Volts
1680       Fieldcurrent(I)=Fieldi
1690       GOSUB Plot                !  Plot data on the screen
1700   NEXT Fieldi
1710   FOR Fieldi=.5 TO 0 STEP -.1    !  .5 to 0 amps
1720       IF Fieldi<1.E-9 AND Fieldi>-1.E-9 THEN Fieldi=0
1730       I=I+1
1740       Fieldi$="I"&VAL$(Fieldi)  !  Adds an I to the field current vairable
1750       OUTPUT 711;Fieldi$        !  Sends value of current to current source
1760       OUTPUT 711;"F1X"          !  Execute
1770       WAIT 3                    !  Wait for system to settle
```

```
1780       OUTPUT 710;"LYS"      !  Selects display Y search value
1790       ENTER 710;Volts    !  Reads display Y search value
1800       Magnitude(I)=Volts
1810       Fieldcurrent(I)=Fieldi
1820       GOSUB Plot                   ! Show data point on screen
1830   NEXT Fieldi
1840   ENTER @Temp;Voltage              ! Read the Temperature
1850   Volts=Voltage*1000               ! Convert to Millivolts
1860   GOSUB Temperature                ! Calculate the Temperature
1870   OUTPUT 711;"FOX"                 ! Put Current Source on Standby
1880   CLEAR 709
1890   OUTPUT 710;"PAF"                 ! DISABLE PARTIAL OVERALL
1900   OUTPUT 710;"DOF"                 ! DISABLE DELTA SEARCH
1910   OUTPUT 710;"SOF"                 ! DISABLE SEARCH FUNCTION
1920   CLEAR 710
1930   RETURN                           ! From ACQUIRE
1940 Plot:        ! Plot data points on the screen ***************************
1950   LORG 5                           ! Label origin at center
1960   MOVE Fieldcurrent(I),Magnitude(I)
1970   LABEL "*"                        ! Plot using asterisks
1980   PRINT I,Fieldcurrent(I),Magnitude(I)
1990   RETURN
2000 Store:     !  Store the data in a disc file ****************************
2010   N=I
2020   REDIM Magnitude(N),Fieldcurrent(N)
2030   GRAPHICS OFF
2040   ALPHA ON
2050   PRINT CHR$(12)                 ! Clear screen
2060   INPUT "File name ?",File$
2070   CREATE BDAT File$,INT(N*8/256)+2
2080   ASSIGN @Path TO File$
2090   OUTPUT @Path;N,Temp,Magnitude(*),Fieldcurrent(*)
2100   ASSIGN @Path TO *
2110   RETURN                         ! From STORE
2120 Load:  !
2130   PRINT CHR$(12)                 ! Clear screen
2140   Controller=1
2150   CAT;NAMES                      ! Display catalog filenames
2160   INPUT "Enter file name to be loaded from above list.",File$
2170   IF File$="" THEN 2240          ! Return if no entry
2180   ASSIGN @Track TO File$
2190   ENTER @Track;N                 ! Number of data points
2200   ENTER @Track;Temp
2210   REDIM Magnitude(N),Fieldcurrent(N)
2220   ENTER @Track;Magnitude(*),Fieldcurrent(*)
2230   ASSIGN @Track TO *             ! Close the file
2240   RETURN                         ! From LOAD
2250 Screenprint:  ! Print the data on the screen
2260   IF Controller=0 THEN
2270       DISP "LOAD A FILE FIRST!!!"
2280       GOTO 2480
2290   END IF
2300       PRINT "Filename = ";File$
2310       PRINT "Temperature = ";Temp
2320   FOR I=1 TO N
2330       PRINT I,Magnitude(I),Fieldcurrent(I)
2340   NEXT I
2350   FOR K=1 TO 4
2360   Mag(K)=Magnitude(K+1)-Magnitude(1)   ! Calculate slope
2370   NEXT K
```

```
2380    Sum=0
2390    FOR K=1 TO 4
2400    Sum=Sum+Mag(K)
2410    NEXT K
2420    Slope=Sum/.5                 ! Average slope of first 5 points
2430    PRINT
2440    PRINT "Initial Slope = ";Slope
2450    DISP "Hit CONTINUE to continue program."
2460    PAUSE
2470    Controller=0
2480    RETURN                       ! From SCREENPRINT
2490    !
2500 Printerprint:     !  Send data to the printer
2510    PRINTER IS 701
2520    GOSUB Screenprint
2530    PRINTER IS 1
2540    RETURN                       ! From PRINTERPRINT
2550    !
2560 Screenplot:     !     Plot the full graph on the screen
2570    PRINT CHR$(12)               ! Clear screen
2580    GCLEAR                       ! Clear graphic screen
2590    GRAPHICS OFF
2600    ALPHA ON
2610    GOSUB Sort                   ! Find min and max values
2620    GRAPHICS ON
2630    ALPHA OFF
2640    Yinta=Yint-(Maxy-Miny)/75
2650    Xinta=Xint-(Maxx-Minx)/75
2660    VIEWPORT 20,100,12,92
2670    FRAME
2680    WINDOW Minx,Maxx,Miny,Maxy
2690    AXES Xtic,Ytic,Minx,Miny,1,1,2
2700    PEN 1
2710    LORG 6                      ! Label origin above character
2720    GRID Xtic,Ytic              ! Draw a grid
2730    CLIP OFF
2740    CSIZE 3,.5                  ! Character size/aspect ratio
2750    FOR I=Minx TO Maxx+Xtic/100 STEP Xtic
2760        MOVE I,Miny             ! X-axis numbers
2770        IF ABS(I)<1.E-15 THEN
2780            J=0
2790            LABEL J
2800            GOTO 2830
2810        END IF
2820        LABEL I
2830    NEXT I
2840    LORG 7                     ! Label origin lower right
2850    FOR I=Miny TO Maxy+Xtic/100 STEP Ytic
2860        MOVE Minx,I            ! Y-axis numbers
2870        IF ABS(I)<1.E-15 THEN
2880            J=0
2890            LABEL J
2900            GOTO 2930
2910        END IF
2920        LABEL I
2930    NEXT I
2940    LORG 5                     ! Label origin to center
2950    PEN 2                      ! Pen for data points
2960    FOR I=1 TO N
2970        MOVE Fieldcurrent(I),Magnitude(I)
```

```
2980      LABEL "o"           ! Character for points
2990    NEXT I
3000    PEN 1
3010    VIEWPORT 20,100,15,95
3020    WINDOW 20,100,15,95
3030    CLIP OFF
3040    MOVE 60,5             ! Position of X-axis label
3050    LORG 5
3060    LDIR 0                          ! Horizontal
3070    LABEL "Field current (A)"       ! X-axis label
3080    MOVE 5,55             ! Position of Y-axis label
3090    DEG                   ! Use degrees
3100    LDIR 90               ! Orient vertically
3110    LORG 5                ! Center
3120    LABEL "Magnetization (mV) "      ! Y-axis label
3130    LDIR 0                          ! Horizontal
3140    MOVE 115,75                     ! Position for sidebar
3150    LABEL Title$                    ! Sidebar header
3160    LABEL "Temp. = ";Temp
3170    LABEL "Filename = ";File$
3180    LABEL TIME$(TIMEDATE)           ! Time
3190    LABEL DATE$(TIMEDATE)           ! Date
3200    RETURN                ! from SCREENPLOT
3210    !
3220 Sort:    !    Get max and min
3230    Minx=MIN(Fieldcurrent(*))
3240    Maxx=MAX(Fieldcurrent(*))
3250    Miny=MIN(Magnitude(*))
3260    Maxy=MAX(Magnitude(*))
3270    PRINT "Fieldcurrent ranges from";Minx;"to";Maxx
3280    PRINT
3290    PRINT "Magnetization ranges from";Miny;"to";Maxy
3300    PRINT
3310    INPUT "Input (Minx,Maxx,Miny,Maxy) to be plotted",Minx,Maxx,Miny,Maxy
3320    PRINT
3330    PRINT "Fieldcurrent plot ranges from";Minx;"to";Maxx
3340    PRINT
3350    PRINT "Magnetization ranges plot from";Miny;"to";Maxy
3360    PRINT
3370    INPUT "Input tick mark spacing and axes intercepts (Xtic,Ytic,Xint,Yint)"
,Xtic,Ytic,Xint,Yint
3380    PRINT
3390    INPUT "Title for graph",Title$        !  Sidebar title
3400    RETURN                                !  From SORT
3410    !
3420 Plotterplot:    !   Send plot data to plotter
3430    PLOTTER IS 705,"HPGL"
3440    GOSUB Screenplot
3450    RETURN          !  From PLOTTERPLOT
3460 Temperature:    ! Calculate the Temperature from Thermocouple Voltage
3470    LET V=Volts
3480    IF V>=-5.602 AND V<-5.439 THEN
3490    Temp=73+61.109*(V+5.603)
3500    END IF
3510    IF V>=-5.439 AND V<-5.261 THEN
3520    Temp=83+58.602*(V+5.439)
3530    END IF
3540    IF V>-5.261 AND V<-5.069 THEN
3550    Temp=93+54.159*(V+5.261)
3560    END IF
```

```
3570   IF V>-5.069 AND V<-4.865 THEN
3580   Temp=103+50.596*(V+5.069)
3590   END IF
3600   IF V>-4.865 AND V<-4.468 THEN
3610   Temp=113+47.587*(V+4.865)
3620   END IF
3630   IF V>=-4.468 THEN                    ! Just report the voltage
3640   Temp=V
3650   END IF
3652   PRINT Temp
3660   RETURN                               ! From Temperature
3670   END
```