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**Program NICOLET to Integrate Energy Loss
in Superconducting Coils**

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PROGRAM NICOLET TO INTEGRATE ENERGY LOSS
IN SUPERCONDUCTING COILS

by

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ABSTRACT

A voltage pickup coil, inductively coupled to the magnetic field of the superconducting coil under test, is connected so its output may be compared with the terminal voltage of the coil under test. The integrated voltage difference is indicative of the resistive volt seconds. When multiplied with the main coil current, the volt seconds yield the loss. In other words, a hysteresis loop is obtained if the integrated voltage difference $\phi = \int \Delta V dt$ is plotted as a function of the coil current i .

First, time functions of the two signals $\phi(t)$ and $i(t)$ are recorded on a dual-trace digital oscilloscope and these signals are then recorded on magnetic tape. On a CDC-6600, the recorded information is decoded and plotted, and the hysteresis loops integrated by the set of FORTRAN programs NICOLET described in this report.

I. INTRODUCTION

The Nicolet NIC-283A magnetic tape coupler is the interface between the Nicolet data scope model 1090A and a Kennedy Model 9000 continuous tape recorder for 7-inch magnetic tapes. Recording is done in 18-bit words, 7-track, 556 BPI.

Tape reading is controlled most conveniently from a Texas Instrument (TI) terminal connected to Machine 24 (CDC-6400) of the Los Alamos Scientific Laboratory's (LASL's) integrated computer network (ICN). For decoding, plotting, and integrating, the set of local programs NICOLET is used from a Tektronix 4015 terminal. Synoptical descriptions of the program follow, where NICOLET serves as program name, as well as generic name. NICOLET reads TAPE 1 as assigned to 6400/6600 disk under "Stranger" ("S") format, with parity error override, after being written by the NIC-283A. The NIC-283A word, formatted 7-track, 556 BPI, 512 addresses at 18 bits (= 3 bytes) per record, is decoded, and the decoded data are written on output files. TAPE 4 is the BCD output file formatted for line printer listing (after shifting right one character, to be done after program execution), and TAPE 12 is the plot file (binary). Note that, unfortunately, neither time nor scales are recorded by the Nicolet instruments and that the experimenter's notes have to be used. Final scaling is done by the appropriate program input at execution time of NICOLET.

SCAN42 is a system program to plot, on a Tektronix 4015, the file TAPE 12. Note that none of the programs described here will rewind TAPE 12, because it is intended for continuous recording.

Y12PLOT reads TAPE 4 as written by program NICOLET, rearranges the data so Y2 is plotted over Y1, with the output directed to TAPE 12 for plotting. Provision is made, by way of execution time input, for plotting the "first half," "second half," or "all" data according to the NIC-1090A setting at recording time. To select the proper execution time input, one must know the recording time setting or make the selection by trial and error.

ROBOTA reads TAPE 4 as written by program NICOLET, and fits, for any monotonously ascending or descending set of Y1 values, a spline function to the (Y1, Y2) table values. The ascending or descending sets must be delineated according to execution time input. Each such set may represent, for example, the upper or lower branch of a hysteresis loop. The original table function, the spline function, and its integral function are written on TAPE 12 for plotting on one graph, where up to eight branches may be plotted on the same graph. Similar data are written on BCD output, TAPE 5. For delimiting the branches properly, it is advisable to peruse the output from Y12PLOT and TAPE 4 before executing ROBOTA.

NICOLET and ROBOTA are described in the following sections. For SCAN42, CCF library documentation exists. Program Y12PLOT is, exactly in all I/O options, a subset of ROBOTA. Samples of the program outputs are shown in the Appendix.

II. PROGRAM NICOLET

This is a program to read TAPE 1, as written by the NICOLET-283A magnetic tape coupler, and to decode, plot, and list data on TAPE 4. TAPES 2 and 3 are scratch tapes. Procedure:

1. Set NIC283A to: TAG-1, record, auto advance.
2. Change tag word #1 before each record.
3. Push I/O execute to record data.
4. Unload tape and remove write ring and make sure label VOGEL is attached.
5. Take tape to CCF dispatcher for mounting on Machine 24.
6. Sign in on Machine 24 from a TI terminal and execute the lines:
Label, T1, D=HI, PO=NR, F=S, LB=NS, VSN=VOGEL. Seven-inch tape from dispatcher.
If T1 runs away,^a type "STOP"; nothing will be lost.
DEFINE, XYZ.
COPYEI, T1, XYZ.
CATALOG, XYZ, N, R.
UNLOAD, T1.
RETURN, T1.

^aThe message "bad tape" is being issued.

If there are more than nine files on XYZ, split the file as follows:
COPYBF, XYZ, XYZ1, 9.
COPYBF, XYZ, XYZ2, 9.
PURGE, XYZ.
SAVE, XYZ1, XYZ2.

7. Execute program NICOLET as compiled by FUN and equate XYZ1 to TAPE 1.

Input file:

.LE. 60-char. run identifier.

DX = abscissa length.

Fract = Fraction of Y1, Y2 data to be plotted, if for instance the second half of the data are 0, one may set fract=0.5.

DY1 = Ordinate length for curve 1.

DY2 = Ordinate length for curve 2.

(DY1 and DY2 are used for scaling the plot.)

IMAX = Leave out unless data were recorded originally under the ALL option on the scope. If IMAV=3 then one plot is done with all data, one plot is done with odd-numbered data (1H) and then superposed the even-numbered data (2H). IMAX=2 will skip the even numbered data.

The plot file is TAPE 12.

The NIC283A word is written in two's complement format. A continuous train, 512 words long, of 18-bit words is read by the FORTRAN BUFFERIN sequence into a continuous train of 60-bit words. Hence, the CDC-6600 record length is 154 to 155 words long. The last record of each file is a few words longer than this, because the NIC283A writes a set of 0's at the end of a record. The first record is 514 (18-bit) words long because two tag words are written at the start. The file length depends on the number of "halves" written under NIC1090A control and may be two, four, or eight records.

The main program reads the tape and writes the data on the binary scratch tape TAPE 2. Subroutine DECODE controls the program flow and writes the output tapes. Function IW sorts the data from the compact 60-bit word arrangement of the CDC. Function UNPAK unpacks the two's binary format, to obtain CDC integer format.

The program lists the two tag identifiers of each file in Hollerith character conversion. Use your device's CDC display code conversion for converting back to the NIC283A octal setting, where the blank corresponds to 00 as well as 55 on the NIC283A.

III. PROGRAM ROBOTA

Glossary

M = No. of branches of Y2 vs Y1 plot under consideration.

T1 (M), Y2(M) = Time limits defining the branch on TAPE 4, T2 to be .GT.
T1, branch defined as inclusive T1, T2.

JMAX(M) = No. of points defined within T1, T2, inclusive.

KMAX(M) = No. of knots = (JMAX-1)/6 + 1, truncated with remainder
of points located at high-Y1 end.

T(2049), Y1(2049), Y2(2049) = TAPE 4 - values for one file only.

TR(8,400), Y1R(8,400), Y2R(8,400) = Ascending values for up to eight branches.

Y1PLT(400), Y2PLT(400) = All points of the branch for plotting.

TS(8,67), Y1S(8,67), Y2S(8,67) = Knots only of up to eight branches.

X(67), Y(67) = Knots only, one of the branches, for spline fitting.

XX(268), F(268) = Spline-interpolated plot.

XI(67), YI(67) = Integral plot of one branch only.

The program first searches TAPE 4 for the TAGWORD1, TAGWORD2-combination entered upon the appropriate input prompt. It should be noted that the tagword search is executed in the forward direction only and the recurring REWIND TAPE 4 -- option provided by the input sequence should be exercised if the same or a previously scanned data set is to be used again.

Next, plotting information is requested. Here, IPLOT = 0 is used only if the respective data were recorded under the "all" setting on the 1090A scope. The next IPLOT request should be answered IPLOT = 1 or 2. This is because program NICOLET writes two or three tables on TAPE 4 for each TAPE 1 file, if an IMAX $\neq$ 1 value has been entered, where the first table combines the data of two halves of the NIC283A's memory in a form not well suited for plotting and unsuitable for integration. The distinction between IPLOT = 1 and 2 is explained as a part of the input prompt.

Following is a description of the method used for finding the spline function from the second-order derivatives.

From the set $(Y1R_{i,j}, Y2R_{i,j}, i=\text{branch identifier}, j=1, JMAX)$, every point $j=1, 7, 13, \dots \leq JMAX$ is treated as a knot for the spline function $s(X)$, where $S_1, X_2, \dots$ are equated to $Y1R_1, Y1R_7, \dots$, respectively. A knot is defined by equating $s(X_k) = y(X_k)$, where $1, 2, \dots, k \dots \leq [(JMAX - 1)/6 + 1]$. The method for finding a set of second-order derivatives of the spline function is described in several texts on numerical methods and is actually carried out by subroutine SPL1D1 (program E102 in the LASL library). The method of integration for finding, from the second derivatives, the spline function value $s(X)$ at any point X within the interval (a,b) used by ROBOTA is obtained from a Taylor expansion, i.e.,

$$s(X) = s(X_i) + (X-X_i) \cdot s'(X_i, X_{i+1}) + (X-X_i) \cdot (X-X_{i+1}) \cdot \bar{s}''(X),$$

where

$$s'(X_i, X_{i+1}) = [s(X_{i+1}) - s(X_i)] / (X_{i+1} - X_i),$$

$$\bar{s}''(X) = \frac{1}{6} [s''(X_i) + s''(X) + s''(X_{i+1})],$$

$$s''(X) = s''(X_i) + (X - X_i) \cdot s'''(X_i, X_{i+1}), \text{ and}$$

$$s'''(X_i, X_{i+1}) = [s''(X_{i+1}) - s''(X_i)] / (X_{i+1} - X_i).$$

The program provides a plot file in which $s(X)$ is drawn as a solid line, the knots are marked by the plotting characters +, and the original function values Y by plotting dots. The function SPLINT (program D117) is used to calculate the integral function $\int y(X) dX$ from the second derivatives $s''(X_i)$. Three options are provided for entering each of the two boundary values. A self-explanatory description is given for the options by the input prompt.

It should be noted that the boundaries (a,b) of the interval $j = 1, JMAX$ are defined by the input, upon the following request: "Enter the number of branches and for each branch the limits." The number of branches may not exceed eight; and the limits t_1, t_2 are entered in the form listed on TAPE 4. One should check the TAPE 4 listing to be sure the Y_1 values in the interval (t_1, t_2) are indeed monotonic, and that $t_2 > t_1$ in the input sequence t_1, t_2 .

REFERENCE

1. A. Ralston and H. Wilf, Mathematical Methods for Digital Computers, Vol. 2, (John Wiley & Sons, Inc., New York), in the input sequence t_1, t_2 .

APPENDIX

SAMPLE I/O

I. COMMENT REGARDING NICOLET

The lengths of the coordinate axes DX, DY_1, DY_2 are requested upon printout of the minimum and maximum Y_1, Y_2 values existing in the file, and of $Y_{1\max} - Y_{1\min}$. Requested is a number also of FRACT, which should in most cases be entered 1. Suppose half the points, i.e., $1025 \leq i \leq 2048$ are 0 or negligible and that we want the last point of significance, i.e., $I_{\text{last}} = 1024$ to correspond with $X_{\text{last}} = X_{\max} = DX$, then

$$f_X = \frac{DX}{2047.1/2}$$

so that $X_{\max} = 1024 f_X \approx DX$. The plotting point counter will count the range (1, II, $1/2 \cdot 2048$), and FRACT = 0.5 is entered.

II. OUTPUT PLOTS

Sample plots are shown in Figs. 1-4, which are self-explanatory.

Fig. 1. Plot generated by NICOLET with input parameters $DX=5.0$ $DY1=8.42$ $DY2=11.9$ $FRACT=0.5$.

Fig. 2. Plot generated by Y12 PLOT.

Fig. 3. Plot generated by ROBOTA.

Fig. 4. Plot generated by ROBOTA.