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Automated System for Ion-Beam Analysis and Temperature Ramping

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AUTOMATED SYSTEM FOR ION-BEAM ANALYSIS
AND TEMPERATURE RAMPING

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Abstract

An automated system has been developed to perform ion beam analysis with in situ temperature programming from ~120K to ~770K.

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I. Introduction

Ion beam analysis has been widely used in conjunction with in situ annealing to study such processes as corrosion¹, interdiffusion in a binary system², defect trapping of hydrogen^{3,4}, and surface permeability of hydrogen⁴. Such experiments typically require a large number of repetitive operations. Therefore, an automated system for data acquisition and in situ annealing has been developed.

The system to be described in this report allows a programmed variation of sample temperature between ~120K and ~770K. At preselected temperatures or times, ion beam analysis is automatically carried out with the data being accumulated in a computer. Programmed calculations are performed on the data and pertinent parameters are printed. Data storage is then cleared for the next analysis. The system will be discussed in the context of a specific experiment in which deuterium (D) release from 304 stainless steel was monitored during linear ramping of the temperature. Broader capabilities will be described where appropriate.

II. Overview

To investigate trapping of D in 304 stainless steel requires that a sample, with trapping sites previously introduced through ion implantation, be implanted with D at a temperature of ~120K. The sample is then heated linearly at 2K/min., and at 10K intervals the amount of D remaining within the trapping region is monitored using the ^3He -excited nuclear reaction $^2\text{D}(^3\text{He},p)^4\text{He}$. This entails integration of the area under the proton peak in the measured energy spectrum of the detected particles, after a known charge of incident $^3\text{He}^+$ ions has been accumulated.

Referring to the block diagram of the automated system shown in Fig. 1, a beam stop prevents the $^3\text{He}^+$ ion-beam from striking the sample surface until the sample reaches a predetermined temperature. The temperature is monitored by the computer from digital thermometer 2 (Fluke Model 2100A) and a chromel-constantan thermocouple through CAMAC input register 1, which is a dual 24-bit parallel input register (BiRa Systems Model 2322). The computer then initiates a reset through CAMAC output register 0, which is a dual 24-bit output register (BiRa Systems Model 3222), which causes the beam-stop to open and the ion beam to be incident on the sample. The ion beam is chopped by a current pickoff apparatus and the charge is counted by digital current integrator 1 (Ortec Model 439) and scaler 1 (Ortec Model 771). Also initiated is a data taking sequence through the detector (Ortec Model Ba-030-450-300), preamplifier (Ortec Model 124), amplifier (Ortec Model 450), analog-to-digital converter or ADC (Tracor Northern Model NS621) and computer network. The computer then prints the time and temperature. When a preselected amount of charge has been counted from the current pickoff apparatus, scaler 1 initiates a sequence which causes the beam to be blocked and the computer to evaluate and print the area of the proton peak from the accumulated data spectrum. The computer is then cleared and the sequence continues, at each temperature interval, until reaching a selected stopping temperature. The heating rate and the temperature interval at which data is accumulated may be varied.

The sample temperature is ramped linearly by a network consisting of the function generator (Hewlett Packard Model 3311A), linear voltage ramp unit, chromel-constantan thermocouple, digital

thermometer 1 (Fluke Model 2100A), voltage offset unit, process controller (Research, Inc. Model 639B) and temperature controller. The sample temperature is measured by the thermocouple and digital thermometer. The digital thermometer provides a linearized output voltage of 1 mV/°C to the voltage offset unit, which in turn divides this voltage and makes it positive when the sample temperature is below 0°C. This feedback voltage is then compared with the linearly ramped voltage provided by the function generator and linear voltage ramp unit. The difference voltage is supplied to the process controller which, in conjunction with the temperature controller, controls the heater current. The function generator provides variable clock pulse rates to the linear voltage ramp unit which contains a counter and a digital-to-analog converter (DAC) circuit. The counter provides the sum of the input clock pulses to the DAC which gives a corresponding output voltage.

If it is desired, the sample temperature may be brought under computer control by substituting the voltage output from a CAMAC digital-to-analog converter (Kinetic Systems Model 3112) for the function generator and linear voltage ramp unit. This permits more complicated heating schemes to be employed. In the present case, temperature control was done separately so that annealing could be carried out when the computer was unavailable. This independent control also frees the computer for more sophisticated data analysis. A detailed discussion of the electronics and computer programming may be found in Appendices A and B.

III. Description, Design, and Performance

A. Sample Holder (See Fig. 1)

Implanting a sample with D at a temperature of ~120K and

then performing ion beam analysis up to ~770K imposed several design constraints. The sample holder had to be mounted on a goniometer so that it could be rotated and implanted with D from a Lintott high-flux accelerator, and then rotated again for $^3\text{He}^+$ ion beam analysis using a 2.5 MeV Van de Graaff accelerator. The sample holder mount consisted of a thin-wall stainless steel tube attached to the goniometer by an insulating ceramic. The sample holder was made of OFHC copper because its melting temperature is 1336K, it has a high thermal conductivity of 4 J/cm/k, is readily machinable, and can be furnace brazed. To cool the sample and enable the sample holder to be rotated, the thermal link between the liquid nitrogen cold trap and sample holder was made of a double strand of half-inch wide copper braid. The cooling rate, using this configuration, is shown in Fig. 3.

Heat was applied to the sample holder using a coaxial line (Amperex Thermocoax) furnace brazed to the back of the holder and powered by a supply rated at 24 volts and 2.0 amperes. The coaxial line resistance was 18 ohms. A discussion of the process and temperature controllers may be found in Appendix A.

B. Beam Stop (See Fig. 1)

A beam stop designed by D. Buller of Sandia National Laboratories was used to block the analysis beam. The device was mounted so that the rotary feedthrough, with the beam stop plate attached, was electrically isolated. This allowed the beam current to be measured between data points, thereby enabling one to adjust the Van de Graaff accelerator during runs which typically lasted 6 hours. The electronics needed to operate the beam stop are discussed in Appendix A.

C. Current Pickoff System (See Fig. 1)

To determine the analysis beam charge accumulated on the sample, it was necessary to measure currents on the order of nano-amperes. Our sample had to be heated to ~770K and at this temperature the ceramic insulation (MgO) in the heater coax was sufficiently conducting to perturb the measurement. It was therefore decided to monitor the ion beam current by chopping it with a current pickoff. The pickoff was mounted on a magnetically coupled vacuum feedthrough (Varian Model 954-5026) which rotated about a vertical axis and was driven by a 60 RPM synchronous motor. Two stainless steel fingers, mounted 90° apart about the axis of rotation, cut the beam four times per second. Insulators were used to electrically isolate the rotary feedthrough from the chamber and the synchronous motor. The ratio of average pickoff current to average sample current was calibrated with the heater disconnected and found to be 0.32. To ensure that secondary electrons knocked off by the analysis beam were retained, the pickoff was biased at 150 volts by a battery in series with digital current integrator 1.

It should be noted that electrical continuity through the rotary magnetic feedthrough was found to be poor. This problem was circumvented by attaching a stainless steel wiper to the flange of the rotary feedthrough and allowing it to contact the rotating shaft. It should also be noted that the current pickoff apparatus should not be located close to beam defining slits because of the possibility of picking up secondary electrons.

D. Performance

An illustrative segment of data secured during an experimental

run where D release from 304 stainless steel was monitored during linear ramping of the temperature is shown in Fig. 2. The computer initiated the data acquisition sequence at preselected temperatures, the interval between points being 10°C. Fractions of a degree were not read by the computer for reasons of design economy. Consequently, at 0°C and below, the temperature is actually 0.9°C lower than recorded. Therefore, -129°C implies -129.9°C in Fig. 2. Data taken at positive temperatures is correct. Fig. 3 shows a plot of temperature vs. time for a typical run. The straight line is included on the plot as a visual aid to the reader. It will be noted that the temperature ramp is linear, except at the beginning and at 0°C. For a discussion of the perturbation at 0°C refer to the Fluke digital thermometer modifications in Appendix A. The process and temperature control unit typically takes 10 minutes to fully accommodate to a selected ramp rate and therefore the sample is usually cooled below where one actually wishes to take data. Slight fluctuations in the sample temperature might also be realized when liquid nitrogen in the cold trap is allowed to boil off at temperatures above ambient. This occurred at 100°C as shown in Fig. 3.

IV. Conclusion

A system has been developed to allow collection of ion beam analysis data between ~120K and ~770K while ramping the sample temperature at a predetermined rate. In situ ion implantation prior to temperature ramping is also incorporated. In addition, more complex temperature profiles can be programmed. The temperature profiling, ion beam data collection, data analysis and data recording are all fully integrated and automated. System performance is demonstrated by analysis of implanted deuterium retention in 304 stainless steel with a $^3\text{He}^+$ analysis beam upon ramp heating.

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Appendix A: Electronics

A.1. Linear Voltage Ramp (See Figs. 1 and 4)

This circuit is powered by two modular supplies, rated at 5 volts and 2.0 amperes (Raytheon/Sorenson Model MMS5-2.00) and ± 15 volts and 150 milliamperes (Computer Products Model PM570). Capacitors C2-C5 provide supply voltage filtering. The clock pulse input to IC1 is shunt terminated by R1 to match the transmission line impedance. A low pass filter is formed by R2 and C1 to provide noise immunity. A function generator (Hewlett Packard Model 3311A) provides the clock pulses to the clock pulse input. The pulse rate is divided by a factor of ten by IC1 to achieve a frequency range of .01 Hz to 100 KHz. These pulses are then provided to IC2-IC4, which together make up a 12-bit binary counter. The 12-bit binary counter sums the pulses from IC1 and this output is complemented by IC5-IC6 and then provided as an input to IC7, a 12-bit digital-to-analog converter (Burr Brown DAC 80-CBI-V). The DAC gives an output voltage from 0 to 10 volts corresponding to its complemented sum input. The DAC has a resolution of 2.44 millivolts and a maximum nonlinearity of $\pm 1/2$ LSB. (Recent improvements have been cited by the manufacturer of this DAC.)⁵ Light emitting diodes (LEDs), driven by open collector inverters, IC8-IC9, give a visual indication of the binary sum input to the DAC and therefore give an indication of the output voltage and qualitatively the input clock pulse rate. Switches S1-S4 are debounced by IC10-IC11 and provide control logic to the circuit. The logic

levels of the Start/Stop switch S2 and the Up/Down switch S3 are input to D type flip-flops contained in IC12. This ensures that any change in the logic implemented by these switches is carried out on the positive edge of the incoming clock pulse. The Start/Stop switch, when in the start position, enables the counting circuitry and disables it when in the stop position. To initialize the circuitry the Run/Inhibit switch S1 loads a BCD zero into IC1 and disables counting by presetting IC12-A, when in the inhibit position. The Up/Down switch controls the direction of counting by the 12-bit binary counter and therefore allows one to ramp the output voltage up or down. The output voltage of the DAC may be preset, asynchronously, by the Run-Preset switch S4 and the load switches S5-S16, which function as a broadside load binary input. The DAC output voltage offset and gain may be adjusted by potentiometers R3 and R4.

A.2. Beam Stop Controller (See Figs. 1 and 5)

The beam stop solenoid is actuated by a Darlington transistor arrangement made up of Q1 and Q2. This configuration allows the solenoid to be turned on by a 5 volt logic signal from the Interval Output of Ortec scaler 1. The holding current needed to keep the solenoid actuated could be reduced by additional circuitry, but was deemed unnecessary because in a typical run the beam stop has a duty cycle of 20%. The circuit is powered by a supply (Lambda Model LM228) rated at 24 volts and 2 amperes.

A.3. Voltage Offset Unit (See Figs. 1 and 6)

This circuit is mainly used to offset the negative voltage

output from digital thermometer 1 when the thermometer reads temperatures below 0°C. A 10 volt power supply (Acopian Model 10E12) is used in conjunction with current limiting resistor R1 and potentiometer R2 to provide this offsetting voltage. Switch S1 also allows one to offset positive voltages from the thermometer, should one wish to start a temperature ramp at positive temperatures. Any voltage not being offset is applied to the resistive divider made up of R3 and R4. This divider limits the voltage applied at the process controller to a range of 0 to 10 millivolts. All resistors used were of metal film construction because their temperature coefficient of resistance (TCR) is typically 25 ppm/°C or better and their tolerance is 1%.

It should be noted that the 10 volt DC supply should be isolated from chassis ground. If the analog output of the digital thermometer is allowed a path to ground through the wiper of R2, it will destroy one of the output amplifiers of the digital thermometer.

A.4. Process and Temperature Controller (See Figs. 1 and 7)

The process controller (Research, Inc. Model 639B) was chosen for this application because of its versatility and low cost. (The reader is referred to the manufacturer's instruction manual for details.) The controller was used in the automatic operating mode. This allowed closed loop control of the sample temperature through comparison of the thermocouple feedback voltage, coming from Fluke digital thermometer 1 and the voltage offset unit, and a setpoint voltage provided by the linear voltage ramp (or a CAMAC DAC) unit.

Any difference between these signals is amplified and used to provide an output control voltage of 0 to 5 volts. The process controller provides for stabilizing temperature fluctuations through proportional band, rate, and reset controls.

The process controller output voltage is used to drive a DC amplifier which controls the heater current. The DC amplifier consists of a Darlington transistor pair Q1 and Q2. Power transistor Q2 is mounted on a heat sink to minimize heating effects and a nichrome wire with a resistance of 1 ohm (R3) is used to provide further stability through emitter feedback. A power supply (Lambda Model LM288) rated at 24 volts and 2 amperes was used to supply the heater current.

A.5. Fluke Digital Thermometer and CAMAC I/O Registers (See Figs. 1 and 8)

It was necessary to provide computer interfacing so that the computer (Tennecomp TP5000 Pulse Height Analysis System using a PDP11/05 processor) could read the sample temperature from a digital thermometer (Fluke 2100A) and initiate a data taking sequence through a scaler (Ortec Model 771). CAMAC input/output (I/O) registers consisting of a dual 24-bit input register (BiRa Systems Model 2322) and a dual 24-bit output register (BiRa Systems Model 3222) were used to provide this interface. (The reader should refer to the instruction manuals and schematics of these devices for further information.) The digital thermometer provides a BCD output which was inputted to register 1 as shown in Fig. 8. Only the second, third, and fourth significant digits were used. Control lines from the digital thermometer were also interfaced to the I/O registers, digital thermometer, and scaler as indicated. The reader is referred to the computer

programs (Appendix B) for a discussion on the utilization of these interface signals.

In the Fluke digital thermometer, circuit modifications consisted of replacing the CMOS integrated circuits U30 and U31 with CMOS Hex/Buffer (CD4010) ICs and replacing the CMOS IC U17 with a Hex/Inverter (CD4009) IC. This allowed the Fluke to drive the long control cable lines (50 ft.) necessary to reach input register 1.

The computer and CAMAC interface system is set up to accommodate multiple users and therefore caused some design constraints. The input registers were already set up to accept low true data input without handshaking signals, and therefore, to maintain this configuration the Fluke digital thermometer circuitry was modified and the computer programs were written to accommodate these conditions. The CAMAC output register 0 was set up to provide totem pole outputs and register 1 was configured to make open collector outputs available. The open collector outputs were necessary to interface the TTL register logic with the CMOS logic of the Fluke digital thermometer.

In observing the performance of the Fluke digital thermometer it was noted, while taking data, that there was a perturbation of the heating rate at 0°C. This appears to occur because the linearized output voltage from the Fluke is made available from a dual ended operational amplifier setup. The manufacturer of this digital thermometer has recently introduced another improved digital thermometer (Fluke Model 2190A) with a single ended output, and this version will be evaluated to see if it corrects the perturbation.

Appendix B: Computer Programs

B.1. Introduction

Two computer programs are included in this discussion. The first program performs the data acquisition as discussed in this report and the second is included only to illustrate how the computer could be used for controlling the sample temperature. A Tennecomp TP5000 computing system was used to implement these programs and they were written in operating languages compatible with this system, mainly Tennecomp Interpretive Language (TIL) and Tennecomp Operating System (TPOS). The reader is referred to the programming manuals for a discussion of these languages.

B.2. Automated Data Acquisition Routine (See Figs. 1, 8 and 9)

This program performs an automated data acquisition sequence. Lines 1.01 to 1.30 allow the user to initialize the sequence by setting the computer clock and then specifying the temperature at which he wants to start taking data and when he wants to stop taking data. The user then specifies the temperature interval at which he wishes to take data, with multiple intervals possible. Lines 1.34 to 1.76 set up the CRT to display the temperature and data and read the temperature from the digital thermometer. The temperature is read by pulling the arm enable signal line low (line 1.40), checking the thermometer for a busy status (line 1.47) and then, by a masking technique (lines 1.50 and 1.55), converting the BCD output from the thermometer to a decimal number. The polarity of the temperature is then determined (line 1.60) and the temperature is displayed on the CRT. The temperature is then compared to the temperature at which the data point should start (line 1.72 or 1.73) and if

it is equal to this temperature, the process is repeated, for a total of ten iterations, thereby ensuring that the temperature read is a true value. Then a data taking sequence is initiated by resetting an Ortec scaler (line 1.76), which in turn gives an interval output signal. The time and temperature are printed and the data accumulated is displayed on the CRT, with the area under the peak of interest integrated and also displayed. When the Ortec scaler reaches a preset value, it pulls the interval output signal low. The computer checks for this condition (line 1.80) and when it occurs, the area accumulated under the peak of interest is printed and the CRT and data storage buffer is cleared for the next sequence (line 1.84). The computer sets up for the next interval (lines 1.90 to 1.93) and then returns to line 1.35 to start the next sequence.

Two lines were included in the program (lines 1.43 and 1.79) which allow the user to stop the program at any point, by actuating toggle switch 1. Also, it is possible to manually initiate a data taking sequence (line 1.44) by resetting Ortec scaler 1. However, it should be noted that the computer will then skip to the interval point following the one that was to be initiated next.

B.3. Linear Voltage Ramp and Data Acquisition Routine (See Figs. 1 and 10)

This program uses a CAMAC digital-to-analog converter (DAC) unit (Kinetic Systems Model 3112) to provide a linear voltage ramp to the process controller. This is done by calculating an update interval time from a user supplied starting voltage and ramp rate (lines 1.05 to 1.09). The program then sequentially adds one to the DAC input register at each update interval (lines 1.20 and 1.25)

which correspondingly increases the output voltage. Using this technique, more complicated heating schemes could be employed.

When using this program, the data is secured manually, by resetting the Ortec scaler.

Fig. 1 Block diagram of automated system.

```

STARTING TEMPERATURE [DEGREES C]=-130
STOPPING TEMPERATURE [DEGREES C]=500
TAKE DATA AT TEMPERATURE INTERVAL=10
STOP INTERVAL AT TEMPERATURE=500
DO YOU WANT OTHER INTERVALS? NO=0, YES=1      0
TIME= 1048.38  TEMPERATURE=- 129  AREA=      2055
TIME= 1051.41  TEMPERATURE=- 119  AREA=      2133
TIME= 1057.30  TEMPERATURE=- 109  AREA=      2004
TIME= 1102.32  TEMPERATURE=-  99  AREA=      2058
TIME= 1107.23  TEMPERATURE=-  89  AREA=      2139
TIME= 1112.24  TEMPERATURE=-  79  AREA=      2026
TIME= 1117.23  TEMPERATURE=-  69  AREA=      2125
TIME= 1122.16  TEMPERATURE=-  59  AREA=      1972
TIME= 1127.18  TEMPERATURE=-  49  AREA=      2111
TIME= 1132.09  TEMPERATURE=-  39  AREA=      1956
TIME= 1137.11  TEMPERATURE=-  29  AREA=      2082
TIME= 1142.05  TEMPERATURE=-  19  AREA=      2085
TIME= 1147.05  TEMPERATURE=-   9  AREA=      2103
TIME= 1151.25  TEMPERATURE=   0  AREA=      2146
TIME= 1154.43  TEMPERATURE=  10  AREA=      2095
TIME= 1159.16  TEMPERATURE=  20  AREA=      1993
TIME= 1204.32  TEMPERATURE=  30  AREA=      2021
TIME= 1209.20  TEMPERATURE=  40  AREA=      2047
TIME= 1214.12  TEMPERATURE=  50  AREA=      1963
TIME= 1219.04  TEMPERATURE=  60  AREA=      1987
TIME= 1224.03  TEMPERATURE=  70  AREA=      2031

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Fig. 2 Representative computer printout of data.

Fig. 3 Time vs. temperature for typical experimental run.

Fig. 5 Beam stop controller schematic.

*** 10Ω POT IS PRECISION BECKMAN MODEL 7266 (LINEARITY .5%)**

****DAMAGE WILL RESULT TO FLUKE DIGITAL THERMOMETER UNLESS +10V POWER SUPPLY IS ISOLATED FROM GROUND.**

Fig. 6 Voltage offset unit schematic.

Fig. 7 Temperature controller schematic.

Fig. 8 Control lines schematic.

W A
C TIL-0102

```

01.01 C AUTOMATED DATA ACQUISITION ROUTINE
01.02 I [SCLK-1]1.03,1.05
01.03 D 9
01.05 O CT; S M=0; S J=1
01.07 X FX[-2,167342,3]
01.10 A "STARTING TEMPERATURE [DEGREES C]="T
01.12 A "STOPPING TEMPERATURE [DEGREES C]="K
01.15 A "TAKE DATA AT TEMPERATURE INTERVAL="I
01.20 A "STOP INTERVAL AT TEMPERATURE="P
01.23 S M=M+1
01.25 S I[M]=I; S P[M]=P
01.30 A "DO YOU WANT OTHER INTERVALS? NO=0, YES=1" "0
01.34 I [0-1]1.35,1.15
01.35 O C
01.36 S R=-10
01.40 X FX[-2,167342,2]
01.43 I [FTGL[1]-1]1.44,1.95
01.44 I [FX[0,167300,1]-1]1.77,1.47
01.47 I [FX[0,167302,8192]-8192]1.47,1.50
01.50 S D1=FX[0,167302,15]; S D2=FX[0,167302,240]; S D3=FX[0,167302,3840]

01.55 S DT=D1 + [D2/2^4]*10 + [D3/2^8]*100
01.60 I [FX[0,167302,4096]-4096]1.63,1.65,1.95
01.63 S DT=DT*[-1]
01.65 T %6,DT,!
01.67 X FX[-2,167342,3]
01.71 I [DT]1.72,1.73,1.73
01.72 I [DT-[T+1]]1.36,1.74,1.36
01.73 I [DT-T]1.36,1.74,1.36
01.74 S R=R + 1; I [R-1]1.40,1.76
01.76 X FX[-2,167340,1]; X FX[-2,167340,0]
01.77 O T; T "TIME=",%6,02,FTDAY[ ]
01.78 T " TEMPERATURE=",%4,DT,0 C
01.79 I [FTGL[1]-1]1.80,1.95
01.80 I [FX[0,167300,1]-1]1.81,1.84
01.81 T " C1=",%4,FCUR[1], " C2=",%4,FCUR[2]
01.82 T " AREA=",%8,FSUM[FCUR[1],FCUR[2]],!
01.83 G 1.79
01.84 D 1.81; D 1.82; O T; D 1.82; T !; X FZER[FCUR[1],FCUR[2]]
01.90 I [DT-P[J]]1.93,1.91,1.91
01.91 I [DT-K]1.92,1.95,1.95
01.92 S J=J+1
01.93 S T=T+I[J]; G 1.35
01.95 O T; T "FINISHED",!; X FX[-2,167340,0]; X FX[-2,167342,0]; O

09.01 C SET COMPUTER CLOCK
09.05 A "SET H,M,S ",H,M,S; T !
09.10 X FSET[H,M,S]; S SCLK=1; R

```

Fig. 9 Automated data acquisition program.

W A
C TIL-0102

```

01.01 C LINEAR VOLTAGE RAMP AND DATA ACQUISITION ROUTINE
01.02 X FDLV[0,0]; I [SCLK-1]1.03,1.05
01.03 D 9
01.05 O CT; A "STARTING VOLTAGE=",V; S V=V*409.6; T !
01.07 A "RAMP RATE [DEGREES[C]/MIN]=",C
01.08 S K=[666.67E-03/[C*1.0E-03*[1/60]]] + [3204/C]; T !
01.09 S R=FITR[[K/4096]/.1+.5]*.1
01.10 T "DAC UPDATE INTERVAL=",%5.01,R," SEC",!,!
01.11 T "TOTAL RAMP TIME=",%6.04,R*[4096-V]/3600," HRS",!,!
01.13 S M=0
01.15 I [V-4095]1.20,1.20,1.60
01.20 X FDLV[1.22,R]; R
01.22 I [FTGL[1]-1]1.23,1.60
01.23 I [FTGL[2]-1]1.25,1.23
01.25 S V=V+1
01.27 O C; D 2.15; O T
01.30 X FX[-2,166542,V]
01.35 I [FX[0,167300,1]-1]1.45,1.50,1.60
01.45 I [M-1]1.46,1.20
01.46 T "TIME=",%6.02,FTDAY[ ]; S M=1; G 1.20
01.50 I [M-1]1.20,1.55
01.55 D 2; S M=0; I [V-4096]1.20
01.60 T "FINISHED",! X FX[-2,166542,0]; O

02.01 C SUM BETWEEN CURSORS FOR LINEAR RAMP
02.10 O C; T " C1=",%4,FCUR[1]," C2=",%4,FCUR[2]
02.15 T " AREA=",%8,FSUM[FCUR[1],FCUR[2]],!
02.17 O T; D 2.15
02.20 X FZER[FCUR[1],FCUR[2]]

09.01 C SET COMPUTER CLOCK
09.05 A "SET H, M, S ",H,M,S; T !
09.10 X FSET[H,M,S]; S SCLK=1; R

```

Fig. 10 Linear voltage ramp and data acquisition program.

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