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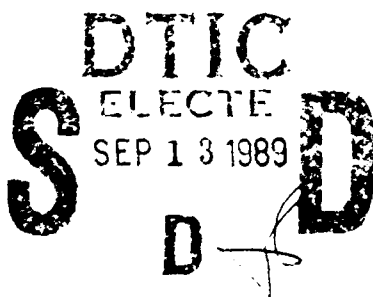
TECHNICAL COMMUNICATION 89/307

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IBM PC ANALYSIS
OF
POLARIZATION RESISTANCE DATA

A. E. Hardy - C. M. Hanham



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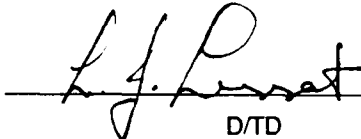
IBM PC ANALYSIS OF POLARIZATION RESISTANCE DATA

A. E. Hardy - C. M. Hanham

July 1989

Approved by R.S. Hollingshead
H/Dockyard Laboratory Section

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TECHNICAL COMMUNICATION 89/307

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ABSTRACT

An IBM PC has been set up to control an EG&G PARC M273 potentiostat to perform electrochemical corrosion experiments using PARC's M342 corrosion measurement software. Modifications to the software permit the measurement of corrosion current over long periods of time using the Polarization Resistance measurement technique. A computer program, PCCORROS, is used to analyze the polarization resistance data to determine the polarization resistance, corrosion current, anodic and cathodic tafel constants, and the corrosion potential.

RÉSUMÉ

Un IBM PC a été configuré de manière qu'il puisse commander un potentiostat EG&G PARC M273 en vue de la réalisation d'expériences sur la corrosion électrochimique au moyen du logiciel de mesure de la corrosion PARC M342. Le logiciel a été modifié de manière à permettre la mesure du courant de corrosion pendant de longs intervalles par la méthode de mesure de la résistance de polarisation. On utilise le logiciel PCCORROS pour analyser les données de résistance de polarisation afin de déterminer la résistance de polarisation, le courant de corrosion, les constantes de Tafel anodique et cathodique, ainsi que le potentiel de corrosion.

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1. INTRODUCTION

The corrosion properties of a metal can be determined by direct methods, such as weight loss measurement and corrosion pit depth measurement, or indirectly by electrochemical techniques. Electrochemical techniques are an important tool in determining the corrosion susceptibility of metals. They utilize a potentiostat or galvanostat to apply a current or voltage to a sample and measure the resulting current or voltage. These methods provide rapid quantitative and qualitative results which can be used to study corrosion under environmental conditions that can be easily controlled in a lab.

DREA Dockyard Laboratory has used two computer controlled corrosion measurement systems from EG&G, Princeton Applied Research Corporation (PARC). The Model 350 (M350) Corrosion Measurement System consists of a central processing unit, a potentiostat and a plotter integrated into a single unit. The Model 351 (M351) is composed of two separate units; a Model 1000 System Processor and a Model 273 (M273) Potentiostat/Galvanostat. It also has a Houston Instrument's HILOT DMP-40 plotter for presenting results.

Polarization Resistance measurements are used at DREA to determine the variation of corrosion current with time. They have traditionally been carried out at DREA by using the experiment rerun option on the M350 corrosion measurement system. The data was stored on the DREA DEC20 computer and analyzed using a program called CORROS¹. It was desirable to perform this same task using the M273 potentiostat in order to carry out simultaneous experiments. Since the M351's software does not provide a rerun option and cannot be modified, it was necessary to purchase a microcomputer to control the M273 potentiostat. An IBM PS/2 Model 50Z personal computer (IBM PC) was obtained along with a National Instruments General Purpose Interface Bus (GPIB) to connect the microcomputer to the M273 potentiostat.

The Model 342 (M342) SOFTCORR Corrosion Measurement Software was obtained from EG&G PARC to be used with the IBM PC to communicate with the M273 potentiostat. The software was written in IBM Advanced BASIC (BASICA) and was modified to perform polarization resistance measurements over long periods of time. CORROS¹ was modified to run on the IBM PC. This modified program is called PCCORROS.

2. IBM PC BASED CORROSION MEASUREMENT SYSTEM

The GPIB was installed in the IBM PC^{2,3}. The IBM PC's back-up Reference Disk was updated to include the GPIB in its system configuration. The M342 software was installed on the IBM PC's hard disk. Installation instructions are located on the M342 source disk in the file, README.342.

The M342 software performs the nine standard electrochemical corrosion experiments listed below.

1. Potentiodynamic Polarization
2. Polarization Resistance
3. Potentiokinetic Reactivation
4. Cyclic Polarization
5. Tafel Plot
6. Ecorr vs Time
7. Galvanostatic
8. Potentiostatic
9. Galvanic Corrosion

The M342 software's operating manual⁴ explains how to use the software to perform the above experiments.

The M342 software is run by a batch file⁵, M342.BAT (Appendix A), which can be executed by typing M342 at the Disk Operating System's⁵ (DOS) prompt and pressing the "ENTER" button. A formatted disk, inserted in drive B, is used to store the experimental results and data files (.T and .D files respectively). The DOS command, CHKDSK⁵, can be used before an experiment is run to ensure that the disk has sufficient memory to store these files. The memory required depends on the experiment performed and the parameters used. A typical polarization resistance experiment requires 500 bytes of storage space for the results and data files. If a polarization resistance experiment was run once every hour for 200 hours, 100 kbytes of storage space would be required.

Modifications made to S-F.BAS of the M342 software package are listed in Appendix B. They enable experiments to be run over a long period of time by performing subsequent runs of the same experiment. The M342 software limits the experiment name to seven characters⁴. The run number is appended to the experiment name, limiting its length by the number of digits in the run number. For example, run number 123 of experiment FE55 would be saved as experiment FE55123. The data is saved at the end of each run to ensure that it is not lost if the program is inadvertently halted before all the runs are completed.

Before an experiment can be run, the following five questions must be answered.

1. DO YOU WISH TO DO RERUNS (Y=YES; N=NO)?

The next four questions will not appear and a single experiment will run if you press N and the "ENTER" button.

To perform an experiment over a long period of time press Y.

2. HOW MANY RUNS DO YOU WANT?

This is the total number of runs that will be done before the program ends. For example, to do 200 Polarization Resistance experiments on a sample, enter 200.

3. HOW LONG BETWEEN THE START OF EACH RUN (MIN)?

This is the length of time, in minutes, from the start of one run to the start of the next run. Enter the desired number of minutes and press the "ENTER" button.

4. AT WHAT NUMBER WOULD YOU LIKE TO BEGIN?

This is the number at which the runs begin to be numbered. If 65 is entered the runs will be numbered 65, 66, 67, ... until the desired number of runs has been performed.

5. CONTINUE (Y=YES)?

Enter Y to run the experiment. Enter N to change the answers to any of the above questions. The program will start over at question 1.

The computer display between runs is shown in Figure 1. Pressing S advances the program immediately to the next run. Pressing D exits the program to BASICA's DOS shell. All DOS commands, including executing .EXE, .BAT and .COM files, are permitted. BASICA cannot be used from the shell. Typing EXIT and pressing the "ENTER" button exits the shell and returns you to the program. The current directory MUST be the PARC subdirectory before exiting the shell or the M342 software will not work properly.

The modifications to the original M342 software can be made, using BASICA, by following the six steps listed below.

The software must be installed, according to the instructions supplied with it, before the modifications can be made.

1. At the DOS prompt type CD\PARC and press "ENTER".
2. Type BASICA and press "ENTER".
3. Type LOAD "S-F.BAS" and press "ENTER".
4. Type in the modifications listed in Appendix B.
5. Type SAVE "S-F.BAS" and press "ENTER".
6. Type SYSTEM and press "ENTER".

The software is now ready to run following the instructions for the original version.

If an experiment that is not part of the M342 software package is needed, it can be created from scratch using HEAD START⁶, a software package distributed by EG&G PARC. The M342 software lacks the high quality plots available with the previously used systems. Various plotting packages are available that can take the raw data from any M342 corrosion experiment and make high quality plots. A new, compiled version of the M342 software, which includes an improved plotting utility, is now available from EG&G PARC. Unfortunately the compiled version cannot be modified to perform reruns.

3. PCCORROS

CORROS¹ is written in PASCAL with several subroutines⁷ in FORTRAN. It was converted to TurboPASCAL 4.0 in order to run on an IBM PC. The modified version, called PCCORROS, will only run on a computer with a math coprocessor installed. PCCORROS consists of four files, PCCORROS.BAT, DATA.EXE, PCCOR.EXE, and PCCORSUB.TPU.

PCCORROS is run by the batch file PCCORROS.BAT (Appendix C). The data files created by the M342 software are read by the program DATA.EXE (Appendix D), which is written in Microsoft QuickBASIC. It reads the compressed data file from a data disk in drive B and converts it into ASCII (human readable) form. The data, in ASCII form, is stored in the file HOLD.ASC on a disk in drive A. HOLD.ASC is read by PCCOR.EXE (Appendix E), the main program of PCCORROS. PCCOR.EXE performs the analysis of the data until there is "No Further Improvement Available", according to the conditions set up in the original CORROS¹ program, or until 25 iterations have been performed. After 25 iterations, the program will pause and ask the user if he wishes to continue. An answer of 1, for yes, will cause the program to continue

running for a maximum of 25 more iterations. Any other answer will cause the program to save the results and terminate the program. PCCORSUB.TPU (Appendix F) is a TurboPASCAL unit used by PCCOR.EXE to perform the tasks of the FORTRAN subroutines of CORROS¹. Extended real variables⁸, with 19 significant digits, were used to ensure the accuracy of the calculations. The results of the analysis are saved in a user specified file with the extension .RES on a disk in drive A. If the file does not exist, a new file is created. Otherwise, the results are appended to the existing file. The raw data is saved on drive A in a file with the same name as the original data file, but with the extension .DAT. Points on the curve that PCCOR.EXE fits to the raw data is stored on drive A in a file with the same name but with the extension .FIT. These files can be printed out to compare the actual data to the fitted curve used by PCCORROS. Figure 2 shows the raw data and the fitted curve on a plot created by ENPLOT⁹.

PCCORROS is run by typing PCCORROS at the DOS prompt and pressing the "ENTER" button. An example run of PCCORROS is given in Appendix G. The data analyzed is listed in Appendix H. The results can be printed out by typing in the following line at the DOS prompt.

```
TYPE A:\filename.RES>PRN
```

Where *filename* is the name of the PCCORROS results file to be printed out. An example printout is given in Appendix I.

PCCORROS was used to analyze data from a Tafel plot experiment¹⁰. Table 1 shows the results of the analysis along with the results from CORROS¹ and the original Tafel plot analysis performed on the same data. The results from PCCORROS and CORROS are both significantly close to the Tafel plot analysis.

A distribution copy of PCCORROS, including its source code, has been made. The program can be installed in an IBM compatible microcomputer that has a math coprocessor. To install PCCORROS, insert the floppy disk into a drive, type *d:* (where *d* is the drive letter) and press the "ENTER" button. Type INSTALL and press "ENTER". The batch file INSTALL.BAT (Appendix J) installs PCCORROS on disk drive C. The files are copied into a subdirectory, PCCORROS, created by INSTALL.BAT. The batch file PCCORROS.BAT is copied to the root directory. PCCORROS is ready to run from the root directory of drive C.

4. CONCLUSION

The system has been set up for ease of use. All of the corrosion experiments and data analyses can be performed from the root directory. The M342 corrosion measurement software has been modified to perform reruns of polarization resistance experiments. This software is difficult to modify due to its complexity and lack of documentation. PCCORROS is easy to run and explains each step to the user as it performs the analyses of polarization resistance data. It can easily be modified, using the source code and the proper compiler, to best suit individual corrosion systems.

Table 1 Results from CORROS¹, PCCORROS, and original Tafel Plot¹⁰ analysis of a Tafel Plot experiment.

	Ecorr (mV)	ba (mV)	bc (mV)	Rp (kohms)	Icorr (mA/cm ²)
Tafel Plot	200	40	120	---	1.0
CORROS	200	40.57±0.71	126.70±13.15	0.01±0.0	1.07±0.03
PCCORROS	200	40.57±0.71	126.70±13.15	0.01±0.0	1.07±0.03

```
12:59:12
Run 12 will begin in 12 : 16 MIN
Total number of runs: 100
Press 'S' to advance to next run.
Press 'D' to go to DOS shell. Type EXIT to exit
the DOS shell. NOTE: You MUST be in the PARC
subdirectory before exiting the DOS shell.
```

Figure 1 Modified M342 corrosion software's display screen between runs.

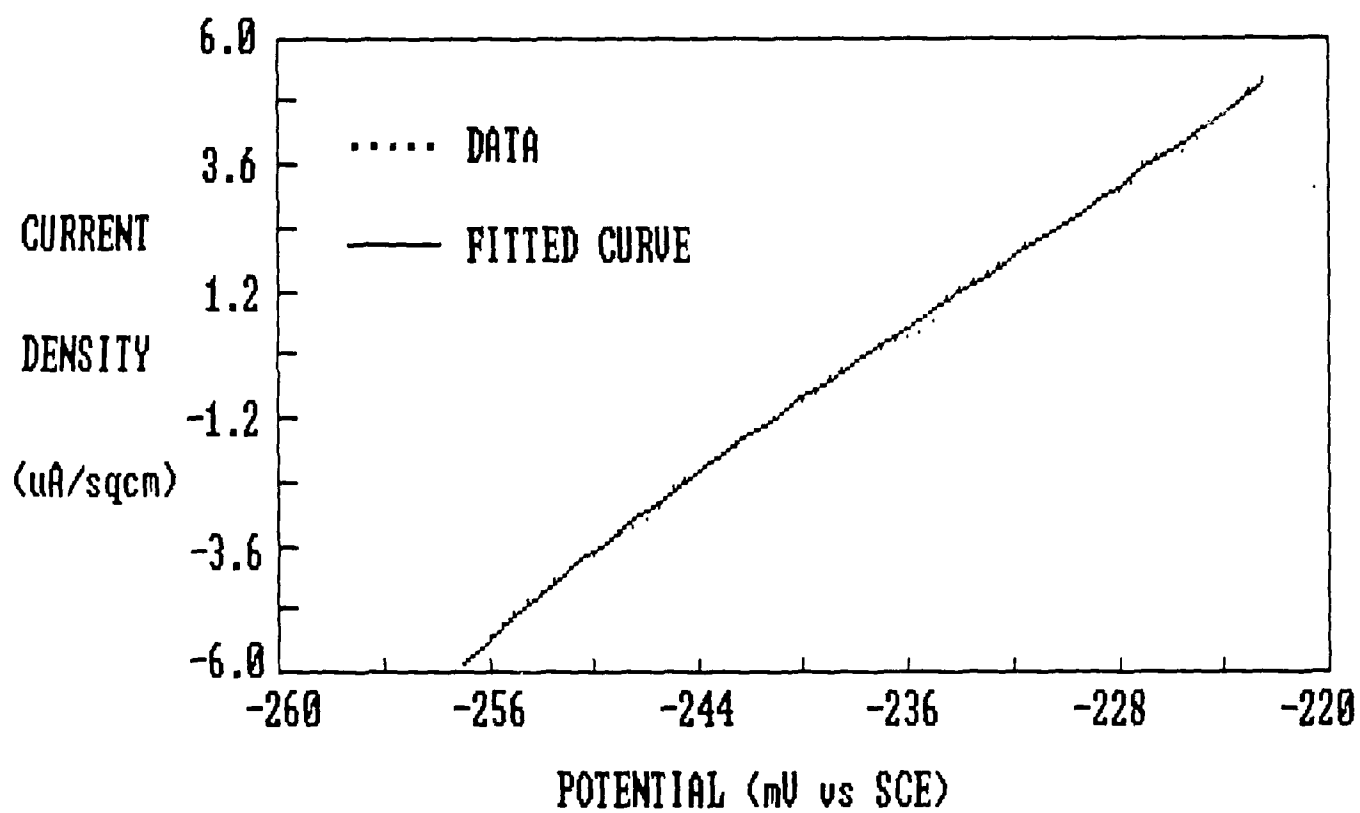


Figure 2 Plot of PCCORROS analysis of data file FE551.DAT.

APPENDIX A

M342.BAT: BATCH FILE THAT RUNS THE M342 SOFTWARE

```
@ECHO OFF
CD\PARC
MODE CO80
BASICA HELLO
CD\
MODE MONO
MENU
```

APPENDIX B

MODIFICATIONS MADE TO S-F.BAS

This allows the M342 corrosion software to perform reruns.

```
15450 CLS:INPUT "                DO YOU WISH TO DO RERUNS (Y=YES;  
N=NO)";RERUN$:IF RERUN$ = "Y" THEN GOSUB 24520 ELSE IF  
RERUN$ <> "N" GOTO 15450  
15451 CLS:LOCATE 1,20:PRINT L$;;LOCATE 3,20:PRINT L$:A$=  
E$(EX) + " TECHNIQUE":LOCATE 2:GOSUB 19860  
15470 TSTART=TIMER:LOCATE 12:A$="    CHECKING SYSTEM    ":GOSUB  
19860:LOCATE 23:A$=STRING$(40,32):GOSUB 19860:LOCATE  
16:GOSUB 19860:GOTO 17700  
17280 R$(0)=E$(EX):A$=R$(1)+".T":DR=2:A=52:GOSUB  
18140:RN=1:GP18140:RN=1:GP=1:GOSUB 15370:IF FRUN% = 1 THEN GOTO  
24700  
17281 GOTO 20050  
  
24520 'THIS IS THE RERUN SETUP ROUTINE  
24530 INPUT "                HOW MANY RUNS DO YOU WANT";  
NRUNS%  
24535 INPUT "HOW LONG BETWEEN THE START OF EACH RUN (MIN)";  
TRUNS  
24540 INPUT "                AT WHAT NUMBER WOULD YOU LIKE TO BEGIN";  
SNRUN%  
24545 INPUT "                CONTINUE (Y=YES)";  
NUE$  
24546 IF NUE$ <> "Y" THEN GOTO 15450  
24550 TRUNS = TRUNS*60  
24560 RCOUNT%=SNRUN% - 1  
24570 FRUN%=1  
24580 BASE$=R$(1)  
24585 GOSUB 24600  
24590 RETURN  
24600 'THIS IS THE RERUN ROUTINE TO CHANGE THE NAME  
24610 RCOUNT%=RCOUNT%+1  
24620 ADD$=STR$(RCOUNT%)  
24640 ADD$ = RIGHT$(ADD$, (LEN(ADD$)-1))  
24650 R$(1) = BASE$ + ADD$  
24660 IF RCOUNT%>= (NRUNS%+SNRUN%-1) THEN FRUN%=0  
24670 RETURN  
24700 'MAIN RERUN ROUTINE  
24710 GOSUB 24600  
24720 GOSUB 24860  
24730 WHILE TIMR < (TSTART+TRUNS) 'LOOP TO WAIT BETWEEN RUNS  
24740     GOSUB 24940: WHILE INT(TIMER) = INT(TIMR)  
24750     IF INKEY$ = "D" THEN GOSUB 24800 'EXITS TO DOS SHELL
```

```

24760     IF INKEY$ = "S" THEN TIMR=(TSTART+TIMR): WEND
24770 WEND
24780 SCREEN 0,0,0: CLS: WIDTH 80
24790 GOTO 15470
24795 'GO TO DOS SHELL, REINITIALIZE WHEN THE SHELL IS EXITED
24800 CLS: WIDTH 80: SCREEN 0,0,0: SHELL :WIDTH 40
24810 BIB=1146!: BIB728=481!: IBINIT1=65535!-BIB-BIB728-8
24820 IBINIT2=IBINIT1+3: DEF SEG: BLOAD "BIB.M",IBINIT1
24830 IBINIT3=IBINIT1+BIB: BLOAD "BIB728.M",IBINIT3
24840 GOSUB 24860
24850 RETURN
24860 'PRINT OUT DISPLAY BETWEEN RUNS
24865 CLS: SCREEN 0,0,0: PRINT
24870 PRINT "Run          will begin in          MIN":LOCATE 2,4:
      PRINT RCOUNT%
24880 PRINT "Total number of runs: ";NRUNS%
24890 PRINT "Press 'S' to advance to next run."
24900 PRINT "Press 'D' to go to DOS shell."
24910 PRINT "Type EXIT to exit the DOS shell.":PRINT
24920 PRINT "NOTE:": PRINT "You MUST be in the PARC
      subdirectory"
24930 PRINT "before exiting the DOS shell."
24940 'PRINTS TIME AND TIME LEFT
24950 LOCATE 1,12: PRINT TIME$: TIMR = TIMER
24960 IF TIMR < TSTART THEN TIMR = TIMR + 86400!
24970 TR%=INT(TRUNS+TSTART-TIMR)+1: TMIN%=TR%\60:
      TSEC%=TR%-TMIN%*60
24980 LOCATE 2,23: PRINT TMIN%;": ";TSEC%
24985 RETURN
24990 'LINES CHANGED IN ORDER TO DO RERUNS ARE 15450, 15451,
      15470, 17280, 17281, 24520-24990.

```

APPENDIX C

PCCORROS.BAT: BATCH FILE THAT RUNS PCCORROS

```
ECHO OFF
CLS
CD\PCCORROS
DATA
PCCOR
CD\
```

APPENDIX D

DATA.EXE: READS THE M342 DATA DISKS FOR PCCORROS

'This program reads the data saved by the M342 EG&G PARC software from Polarization Resistance experiments. It then converts it to ASCII (human readable) form to be analysed by the program PCCOR.EXE. The M342 data disk must be in drive 'A and the PCCORROS results disk must be in drive B.

'February, 1989. Allison Hardy.

'VARIABLES:

'CURRENT%: RAW DATA IN THE FORM SAVED BY BASICA

'R\$: SETUP PARAMETERS IN THE .T FILE CREATED BY THE M342 SOFTWARE

'FNVALR: CONVERTS A R\$ VALUE INTO NUMERICAL FORM TO USE IN CALCULATIONS

'FNA1,FNA2,FNCALC: USED TO CONVERT THE CURRENT DATA INTO $\mu\text{A}/\text{CM}^2$

'B1,B2: CONSTANTS

'NAMEOFI\$E: M342 POLARIZATION RESISTANCE DATA FILE

'D\$E: NAMEOFI\$E WITH THE PATH AND DRIVE ADDED

'OUTFILE\$: OUTPUT FILE, HOLD.ASC, ON DRIVE A: USED BY PCCOR.EXE

'NOFPOINTS%: NUMBER OF DATA POINTS

'STYLE\$: OUTPUT FORMAT FOR THE FILE HOLD.ASC

'EREF: REFERENCE POTENTIAL (E_{corr} OR 0)

'VOLTINIT: INITIAL POTENTIAL

'VOLTS\$END: FINAL POTENTIAL

'DVOLTS: INCREMENTAL POTENTIAL

'VOLTS: POTENTIAL IN mV VERSES REFERENCE ELECTRODE

'AMPS: CURRENT DENSITY IN $\mu\text{A}/\text{CM}^2$

DIM CURRENT%(4100)

DIM R\$(53)

ON ERROR GOTO ERRORHANDLER

'CALCULATIONS

B1 = 4096

B2 = 2048

DEF FNVALR (X) = VAL(R\$(X))

DEF FNA1 (X) = INT(X / B1)

DEF FNA2 (X) = X - FNA1(X) * B1

DEF FNCALC (X) = -(FNA2(X) + B1 * (FNA2(X) > B2)) * (10 ^
(FNA1(X) + 3)) / (FNVALR(27) - 1 *
(FNVALR(27) = 0))

CLS

```

READDATA:
PRINT "INSERT M342 DATA DISK INTO DRIVE B:."
PRINT "INSERT PCCORROS RESULTS DISK IN DRIVE A:."
INPUT "Data File: "; NAMEOFFILE$
DFILE$ = "B:\\" + NAMEOFFILE$
OUTFILE$ = "A:\HOLD.ASC"
OPEN DFILE$ + ".T" FOR INPUT AS #1
FOR I = 0 TO 52
    INPUT #1, R$(I)
NEXT I
CLOSE #1
IF R$(0) <> "POLN RESISTANCE" THEN
    PRINT "**This file is not a M342 PARC Polarization
        Resistance data file.**"
    INPUT "Do you wish to continue with the analysis?";ANSWER$
    IF ANSWER$ <> "Y" THEN
        GOTO READDATA
    END IF
END IF
NOFPOINTS% = FNVALR(13)
BLOAD DFILE$ + ".D", VARPTR(CURRENT%(0))
OUTPUTDATA:
STYLE$ = " #####.####      #####.####"
OPEN OUTFILE$ FOR OUTPUT AS #2
PRINT #2, NAMEOFFILE$
FOR I = 1 TO NOFPOINTS%
    IF RIGHT$(R$(2), 1) = "E" THEN EREF = FNVALR(20) ELSE EREF
        = 0
    VOLTSINIT = FNVALR(2) + EREF
    VOLTSEND = FNVALR(3) + EREF
    DVOLTS = FNVALR(21) * SGN(VOLTSEND - VOLTSINIT)
    VOLTS = VOLTSINIT + (I - 1) * DVOLTS
    AMPS = FNCALC(CURRENT%(I))
    PRINT #2, USING STYLE$; AMPS, VOLTS
NEXT I
CLOSE #2

END

ERRORHANDLER:
IF ERR = 53 THEN      'FILE NOT FOUND
    PRINT "File not found!"
    RESUME READDATA
ELSE
    PRINT "Error "; ERR; " occured."
    ON ERROR GOTO 0
END IF

```

APPENDIX E

PCCOR.EXE: MAIN PROGRAM USED BY PCCORROS

PROGRAM CorrosionAnalysis;{\$N+}

{A program to find the corrosion potential Ecorr, the anodic}
{and cathodic tafel constants ba and bc, the polarization }
{resistance Rp and the corrosion current density Icorr, from}
{the mixed potential region around Ecorr. The data is read }
{from a polarization resistance data file created by the }
{EG&G PARC Model 342 Corrosion Measurement Software using }
{another program, DATA.EXE. The program's basic routine is }
{a nonlinear least squares fit of the data. Output includes }
{the corrosion parameters, their estimated errors, and the }
{relative RMS error of the fitted data. These parameters }
{are stored in a user named output file on drive A. This }
{program was originally written for use on the DEC-20 and }
{has been modified for use on the IBM PS/2 M50Z using Turbo }
{Pascal 4.0. }

USES PCCORSUB;

{Contains procedures spline, decomp, solve, and seval.}

VAR

DATA, PLOTS, LIST, OUT	:text;
gradstore, Jac	:matrix;
gradient, mgradient, work	:svector;
potential, current, voltdata, currddata, BB, CC, DD	:vector;
ipvt	:isvector;
i, j, m, n, numofpts, count, ans, asn	:integer;
Rp, Ecorr, Icorr, ba, bc, cond	:real;
detailed	:boolean;
results, prin, infile	:string;

PROCEDURE dataheader;

CONST

size = 6;
blank = ' ';

TYPE

wordtype = ARRAY[1..size] of char;

VAR

ch	:char;
i	:integer;
seive, keyword	:wordtype;

```

PROCEDURE skipblanks;
BEGIN
    REPEAT read(DATA,ch) UNTIL (ch<>' ');
END;

PROCEDURE initseive;
VAR    i :integer;
BEGIN
    skipblanks;
    seive[1] :=ch;
    FOR i := 2 TO size DO
        BEGIN
            read(DATA,ch);
            seive[i] := ch;
        END;
    END;
END;

PROCEDURE lookfor(keyword:wordtype);
VAR i    : integer;
BEGIN
    initseive;
    REPEAT
        write(seive[1]);
        read(DATA,ch);
        FOR i := 1 TO size-1 DO
            seive[i] := seive[i+1];
        seive[size] := ch;
    UNTIL (seive = keyword);
    writeln;
    FOR i := 1 TO size DO
        write(seive[i]);
    END;
END;

BEGIN {dataheader}
    writeln('Would you like to read the introduction? yes =
1');
    read(ans);
    IF ans = 1 THEN
        BEGIN
            writeln('PCCORROS is a program to find the corrosion
potential Ecorr, the anodic');
            writeln('and cathodic tafel constants ba and bc, the
polarization resistance Rp,');
            writeln('and the corrosion current density Icorr, from
the mixed potential region');
            writeln('around Ecorr. The data is read from a
polarization resistance data file,');
            writeln('created by the EG&G PARC Model 342 Corrosion
Measurement System, by');

```

```

        writeln('another program, DATA.EXE. The program can be
run in two modes: detailed');
        writeln('or simple. The only difference is the amount
of output to the screen.');
```

```

        writeln('In detailed mode the program outputs the
gradient, the Jacobian and its');
        writeln('construction, the correction vector and its
treatment at each iteration.');
```

```

        writeln('The simple mode operates the same routines but
suppresses output.');
```

```

END;
writeln;
writeln('Do you want a detailed run? yes = 1');
readln;read(ans);
IF ans = 1 THEN detailed := TRUE
ELSE detailed := FALSE;
repeat
    writeln;
    assign(DATA,'a:\HOLD.ASC');
    {$I-}
    reset(DATA);
    {$I+}
    I := IOResult;
    IF I <> 0 THEN
        begin
            writeln('FILE DOES NOT EXIST: MAKE SURE RESULTS DISK
IS IN DRIVE A');
            writeln('PRESS "ENTER" TO CONTINUE');
            readln;
            readln;
            end;
        writeln;
    UNTIL (I = 0);
    readln(DATA,infile);
END;{dataheader}
```

```

PROCEDURE DataGenerator;
```

```

{Takes raw data from the data file HOLD.ASC on drive A and}
{converts current density from uAmps per sqcm to mAmps per}
{sqcm and passes a cubic spline through the data to allow }
{access to points 'between' data points. }
```

```

VAR
    voltage,amperage,vstp : real;
```

```

PROCEDURE SCALE; {Scales uAmps to mAmps}
BEGIN
```

```

    FOR i := 1 TO numofpts DO
    BEGIN
        current[i] := current[i] /1.0E3;
    END;
END;

PROCEDURE reorder; {Reorders decreasing voltage data}
VAR    tempvolt,tempamp    :real;
        i,nexti            :integer;
BEGIN
    writeln('reordering');
    FOR i := 1 TO (numofpts DIV 2) DO
    BEGIN
        nexti                :=numofpts + 1-i;
        tempvolt             :=potential[i];
        tempamp              :=current[i];
        potential[i]         :=potential[nexti];
        current[i]           :=current[nexti];
        potential[nexti]     :=tempvolt;
        current[nexti]       :=tempamp;
    END;
END;{reorder}

PROCEDURE viewdata;
BEGIN
    writeln;
    writeln('Do you want to see the data tabulated ? yes =
1');
    readln;read(ans);
    IF ans = 1 THEN
    BEGIN

writeln('*****
*****');
        writeln;
        writeln('      Potential          Current          Potential
Current');
        writeln('      (mVolts)          (mAmps)          (mVolts)
(mAmps)');
        writeln;
        FOR j := 1 TO numofpts DIV 2 DO
            writeln(j:2,potential[j]:8:2,current[j]:15:6,
                (j+numofpts DIV 2):8,potential[j+numofpts DIV
                2]:8:2, current[j+numofpts DIV 2]:16:6);
writeln('*****
*****');
        END;
    END;{viewdata}

BEGIN {datagenerator}

```

```

i := 0;
WHILE NOT eof(DATA) DO
BEGIN
    i := i + 1;
    read(DATA,current[i],potential[i]);
END;{WHILE}
numofpts := i-1;
scale;
writeln(numofpts:4,' data points read in');
IF potential[1] > potential[4] THEN reorder;
viewdata;
spline(numofpts,potential,current,BB,CC,DD);
END; {datagenerator}

PROCEDURE screendata(window : real);
{Screens out data more than a 'window' away from Ecorr.}

BEGIN
    FOR i := 1 TO numdata DO
    BEGIN
        voltdata[i] :=0;  currdata[i] :=0;
    END;
    j := 0;
    FOR i := 1 TO numofpts DO
    BEGIN
        IF abs(potential[i] - Ecorr) <= window THEN
        BEGIN
            j := j+1;
            voltdata[j] := potential[i];
            currdata[j] :=current[i];
        END;
    END;
    count := j;
    writeln(count:4,'points in range');
END; {screendata}

PROCEDURE datafit;
{Let L=ln(10), Ecorr be the corrosion potential and E-Ecorr}
{be the overpotential, oP, in millivolts. Let I be the }
{total current density in mAmps/cm^2 and Icorr be the }
{corrosion current density in mAmps/cm^2. Then the equation}
{that governs I wrt P is: }
{
    1.   $I = I_{corr} * (\exp(L * oP / b_a) - \exp(-L * oP / b_c))$  }
{where b_a and b_c are the anodic and cathodic Tafel }
{constants. Further, the slope of the I vs oP curve at }
{oP=0 is a constant @ oP=0, (dI/doP)=1/Rp, where Rp is the }
{polarization resistance and @ oP=0, (dI/doP)=Icorr*ln(10)}
{*(1/b_a+1/b_c). Thus }
{
    2.   $1/I_{corr} = L * R_p * (1/b_a + 1/b_c)$ . }

```

```

{Now substitute u=L/ba and v=L/bc and 2. into 1. and get: }
{ 3. I=(exp(oP*u)-exp(-oP*v))/(Rp*(u+v)). }
{Now substitute u=w+a and v=w-a and get: }
{ 4. I=exp(P*a)*sinh(P*w)/(Rp*w) }
{The variables in equation 4 can be partly or wholly }
{separated. Consider I=I(oP): i)I(oP)/I(-oP)=-exp(2*oP*a) }
{contains only a, ii)sqrt(I(oP)*-I(-oP))=sinh(oP*w)/(Rp*w) }
{only Rp and w, or substituting Icorr into (ii), }
{iii) sqrt(I(oP)*-I(-oP))=2*Icorr*sinh(oP*w). One variable}
{which has not been delt with yet, Ecorr, is hidden in P or}
{oP and since these appear as arguments to the exponential }
{it is very necessary to accurately determine Ecorr. The }
{initial approximation to Ecorr is the potential E at which}
{the current density I(E)=0. This is found by solving for }
{the root of spln(E)=0, where spln is the cubic spline }
{which interpolates the data and this is done using }
{Newton's method, x1=x0-y/y'. }

```

VAR

```

V,oP,oPincr,minoP,w0,sum1,sum2,sum3,sum4,yval,dyval,
templ,temp2,L,kp,delta,w,sumw,sdevw,estEcorr,range,a,
suma,sdeva,den,z,IoP,Iplus,Iminus,Ip3half,Im3half,
oPrange,rms,newrms,epsilon,alpha,beta,gamma,sdevIcorr,
sdevba,sdevbc,sdevRp,X : real;
i,j,num,rej,iterations : integer;

```

```

FUNCTION sinh(X:real):real;
VAR Xext :extended;
BEGIN
  Xext := X;
  Xext := (exp(Xext)-exp(-Xext))/2;
  sinh := Xext;
END;

```

```

FUNCTION eval(V:real):real;
{Returns from the data spline a current value for a given}
{input potential in mvolts.}
BEGIN
  seval(numofpts,V,potential,current,BB,CC,DD,yval,dyval);
  eval := yval;
END;

```

```

FUNCTION deval(V:real) :real;
{Returns the rate of change of current at a potential.}
BEGIN
  seval(numofpts,V,potential,current,BB,CC,DD,yval,dyval);
  deval := dyval;
END;

```

```

FUNCTION fitcurrent(V,Ecorr,ba,bc,Icorr:real):real;

```

```

BEGIN
  oP := V-Ecorr;
  IF oP <> 0 THEN
    fitcurrent := Icorr*(exp(L*oP/ba)-exp(-L*oP/bc))
  ELSE
    fitcurrent := 0.0;
END;

FUNCTION rmserr(Ecorr,ba,bc,Icorr:real):real;
VAR      sum1,sum2      :real;
          i,j            :integer;
BEGIN
  sum1 := 0;sum2 := 0;j := 0;
  FOR i := 1 TO count DO
    BEGIN
      oP := voltdata[i] - Ecorr;
      IF ((abs(oP)>=minoP) AND (abs(oP)<=oPrange+1)) THEN
        BEGIN
          sum1 := sum1 + sqr(currdata[i] - fitcurrent(oP
+Ecorr,Ecorr,ba,bc,Icorr));
          sum2 := sum2 + sqr(currdata[i]);
          j := j+1;
        END;
      END;
    rmserr := sqrt(sum1/sum2);
  END;

PROCEDURE improve(VAR Ecorr,ba,bc,Icorr :real);
{This routine takes initial values of Ecorr, ba, bc, and }
{Icorr and returns improved values, least squares sense, by}
{applying a non-linear Newton iteration in four variables. }
{The iteration is of the form J0*dX=-G(X) where dX is the }
{correction vector, J0 is the Jacobian matrix evaluated at }
{X0 and G0 is the gradient of the sum of squared errors at }
{X0, the initial parameters. Since there are orders of }
{magnitude difference between the actual parameters Ecorr, }
{ba, bc and Icorr this routine accepts these values as }
{constants and creates its own set of variables epsilon, }
{alpha, beta, and gamma. These new variables are put into }
{the equation for I as multipliers of Ecorr, ba, bc, and }
{Icorr respectively. They are chosen this way so that each}
{of their initial values will be 1(one), negating any size }
{effect that would have existed if Ecorr, ba, bc, and Icorr}
{were used directly. After each successful iteration the }
{'constants' Ecorr, ba, bc and Icorr are corrected by }
{multiplication by their corresponding new variable and the}
{new variables are reset to 1(one) for the next iteration. }
{The procedure is continued until epsilon, alpha, beta and }
{gamma remain constant at a value of 1(one) or the routine }
{iterates past its maximum allowed runs (user set, default }

```

{of 50}.

}

```
VAR
temp1,temp2,predcurr,error,
pepsilon,palpha,pbeta,pgamma      :real;
i,j,m,n                             :integer;

PROCEDURE grad(eps,alp,beta,gam :real);
VAR   maxgrad : real;
      i       : integer;
BEGIN
  {'p' is used to represent differentiation}
  pepsilon := 0;pgamma := 0;palpha := 0;pbeta := 0;
  FOR i := 1 TO count DO
    BEGIN
      oP := voltdata[i] - eps*Ecorr;
      IF ((abs(oP) >= minOP) AND (abs(oP)<=oPrange+1)) THEN
        BEGIN
          predcurr := fitcurrent(voltdata[i], eps*Ecorr,
alp*ba, beta*bc, gam*Icorr);
          error := currdata[i] - predcurr;
          temp1 := exp(L*oP/ba)/ba;
          temp2 := exp(-L*oP/bc)/bc;
          pepsilon := pepsilon + (2*error*Icorr*L*Ecorr*
(temp1+temp2));
          pgamma := pgamma +(-2*error*predcurr);
          palpha := palpha + (2*error*Icorr*L*oP*temp1);
          pbeta := pbeta + (2*error*Icorr*L*oP*temp2);
        END;
      END;
      gradient[1]:=pepsilon;
      gradient[2]:=palpha;
      gradient[3]:=pbeta;
      gradient[4]:=pgamma;
    END; {grad}
  END;
```

```
PROCEDURE jacobian(Ecorr,ba,bc,Icorr :real);
{The Jacobian matrix is made up of the derivatives of}
{the gradient in the form:Jac[i,j] = dgrad[i]/dX[i]. }
{This routine approximates the derivatives by a      }
{divided difference and further assures that the     }
{matrix is exactly symmetric, accounting for some    }
{roundoff.                                           }
```

```
VAR   m,n,i   :integer;
CONST del = 1E-5;
BEGIN
  grad(1+del,1,1,1);
  FOR m := 1 TO 4 DO
```

```

        gradstore[1,m]:=gradient[m];
grad(1,1+del,1,1);
FOR m := 1 TO 4 DO
    gradstore[2,m] := gradient[m];
grad(1,1,1+del,1);
FOR m := 1 TO 4 DO
    gradstore[3,m] := gradient[m];
grad(1,1,1,1+del);
FOR m := 1 TO 4 DO
    gradstore[4,m] := gradient[m];
{Writes out the gradient at the 4 points around current}
{estimate, for use in finding Jacobian.}
IF detailed THEN
BEGIN
    writeln;
    writeln('gradient at each parameter + del');
    FOR m := 1 TO 4 DO
    BEGIN
        FOR n := 1 TO 4 DO
            write(gradstore[m,n]:18);
        writeln;
    END;
    writeln;
END;
grad(1,1,1,1);
IF detailed THEN
BEGIN
    writeln('gradient: dEcorr,dba,dbc,dIcorr');
    FOR m:=1 TO 4 DO
        write(gradient[m]:18);
    writeln;writeln;
END;
FOR m:= 1 TO 4 DO
    FOR n := 1 TO 4 DO
        Jac[m,n] := (gradstore[n,m]-gradient[m])/del;

        {Writes out the Jacobian before forced symmetry.}
IF detailed THEN
BEGIN
    writeln('Jacobian before symmetry check');
    FOR m := 1 TO 4 DO
    BEGIN
        FOR n := 1 TO 4 DO
            write(Jac[m,n]:18);
        writeln;
    END;
END;
FOR m:= 1 TO 4 DO
    FOR n:= 1 TO 4 DO
    BEGIN

```

```

        IF m<>n THEN
        IF m<n THEN Jac[m,n] := (Jac[m,n]+Jac[n,m])/2;
        END;
    FOR m := 1 TO 4 DO
        FOR n := 1 TO 4 DO
            IF m>n THEN Jac[m,n]:=Jac[n,m];
        IF detailed THEN
        BEGIN
            writeln;
            writeln('Jacobian matrix');
            FOR m := 1 TO 4 DO
            BEGIN
                FOR n := 1 TO 4 DO
                    write(Jac[m,n]:18);
                    writeln;
                END;
            writeln;
            END;
            FOR m := 1 TO 4 DO
                mgradiant[m] := -gradient[m];
            END; {jacobian}

BEGIN {improve}
    jacobian(Ecorr,ba,bc,Icorr);
    decomp(order,order,Jac,cond,ipvt,work);
    IF abs(cond - 1) < 1E-6 THEN
    BEGIN
        IF detailed THEN
            writeln('Jacobian is singular to working
precision.');
```

```

        FOR n := 1 TO 4 DO
            mgradiant[n] := 20* mgradiant[n];
        IF detailed THEN
            writeln('Negative gradient followed to a new
point.');
```

```

        END
        ELSE
        BEGIN
            solve(order,order,Jac,mgradiant,ipvt);
        END;
        IF detailed THEN
        BEGIN
            writeln('Initial correction vector.');
```

```

            FOR n := 1 TO 4 DO
                write(mgradiant[n]:18);
            writeln;
        END;
        WHILE((abs(mgradiant[1])>0.5)
            OR(abs(mgradiant[2])>0.5)

```

```

OR (abs(mgradient[3])>0.5)
OR (abs(mgradient[4])>0.5))DO
BEGIN
  FOR i := 1 TO 4 DO
    mgradient[i] := mgradient[i]/2;
  IF detailed THEN
    write(' 50% parameter change exeeded:');
  IF detailed THEN
    writeln(' Reduced correction by half');
  END; {while}
  newrms := rmserr(Ecorr*(1+mgradient[1]), ba*(1+
mgradient[2]), bc*(1+mgradient[3]),Icorr*(1+mgradient[4]));
  j := 0;
  WHILE ((newrms > rms) AND (j < 25)) DO
  BEGIN
    FOR i := 1 TO 4 DO
      mgradient[i] := mgradient[i]/2;
    IF detailed THEN
      writeln('Error overshoot: reduced correction by
half');
    newrms := rmserr(Ecorr*(1+mgradient[1]),ba*(1+
mgradient[2]), bc*(1+mgradient[3]),Icorr*(1+mgradient[4]));
    j := j+1;
    IF j = 25 THEN
      begin
        writeln('No further improvement available.');
```

ans := 99;

```

      end;
    END;{while}
    epsilon :=1+mgradient[1];
    alpha :=1+mgradient[2];
    beta :=1+mgradient[3];
    gamma :=1+mgradient[4];
    IF ((abs(mgradient[1])<1E-6) AND (abs(mgradient[2])<1E-6)
AND (abs(mgradient[3])<1E-6) AND (abs(mgradient[4])<1E-6))
THEN
  BEGIN
    writeln('No further improvement available.');
```

ans := 99;

```

  END;
  if j = 25 THEN
    newrms := rms;
  ELSE BEGIN
    Ecorr :=Ecorr*epsilon;
    ba :=ba*alpha;
    bc :=bc*beta;
    Icorr :=Icorr*gamma;
  END;
  IF((ba <= 0)OR(bc <= 0)) THEN
  BEGIN
```

```

        writeln('Negative tafel constants reached.');
```

END;

```

Rp := ((ba*bc)/(ba+bc))/(L*Icorr);
if detailed then begin
    writeln;
    writeln(' Ecorr      ba      bc      Icorr Rp');
    writeln(Ecorr:8:2,ba:10:2,bc:10:2,Icorr:12:6,Rp:12:0);
end;
END;{improve}
```

PROCEDURE stats;

VAR i :integer;

BEGIN

```

    j:=0; m:=0 ; n:=0;
    sdevIcorr :=0; sdevba:=0; sdevbc:=0; sdevRp:=0;
    FOR i := 1 TO count DO
        BEGIN
            oP := voltdata[i]-Ecorr;
            IF ((abs(oP)>=minoP) AND (abs(oP)<=oPrange)) THEN
                BEGIN
                    j :=j+1;
                    IoP :=currddata[i];
                    temp1 :=exp(L*oP/ba);
                    temp2 :=exp(-L*oP/bc);
                    sdevIcorr :=sdevIcorr+sqr(Icorr-IoP/(temp1-temp2));
                    sdevRp :=sdevRp+sqr(Rp-((temp1-temp2)/(L*(1/ba +
1/bc) *IoP)));
                    IF oP > 0 THEN
                        BEGIN
                            m:=m+1;
                            sdevba:=sdevba+sqr(ba-L*oP/ln(temp2+IoP/Icorr))
                        END
                    ELSE
                        BEGIN
                            n:=n+1;
                            sdevbc:=sdevbc+sqr(bc+L*oP/ln(temp1-IoP/Icorr));
                        END;
                    END;
                END;
            sdevIcorr :=sqrt(sdevIcorr/(j-1));
            sdevRp :=sqrt(sdevRp/(j-1));
            sdevba :=sqrt(sdevba/(m-1));
            sdevbc :=sqrt(sdevbc/(n-1));
        END;{stats}
    END;
```

```

BEGIN {datafit}
  L:=ln(10);
  {This is Newton's iteration loop for Ecorr. The initial}
  {guess is the rest potential Erest.}
  estEcorr := (potential[1]+potential[numofpts])/2;
  REPEAT
    Ecorr := estEcorr;
    estEcorr := Ecorr-(eval(Ecorr)/deval(Ecorr));
  UNTIL(abs((estEcorr-Ecorr)/Ecorr)<=1E-6);
  Ecorr := estEcorr;
  writeln('Estimated Ecorr is: ',Ecorr:8:2);
  IF abs(potential[1] - Ecorr) <=
abs(potential[numofpts]-Ecorr)
  THEN oPrange := abs(potential[1]-Ecorr) + 0.000001
  ELSE oPrange :=abs(potential[numofpts]-Ecorr) + 0.000001;
  writeln('Range around Ecorr reduced to: ',oPrange:4:1);
  range := oPrange;
  screendata(range);
  sum1:=0; sum2:=0; sum3:=0;
  oP:=5;i:=0;
  REPEAT
    i:=i+1;
    Iplus := eval(oP+Ecorr);
    Iminus := eval(-oP+Ecorr);
    a := ln(abs(Iplus/Iminus))/(2*oP);
    IF odd(i) THEN
      BEGIN
        write(' at oP=',oP:5:1);
        write(' a = ',a:8:6);
      END
    ELSE
      BEGIN
        write(' at oP=',oP:5:1);
        writeln(' a = ',a:8:6);
      END;
    sum1 := sum1 + a;
    oP := oP + 0.5;
  UNTIL (oP > oPrange);
  num := i;
  a := sum1/num;
  writeln('Average a is: ',a:8:6);
  REPEAT
    write('Enter starting oP: ');
    writeln('minimum oP where a becomes reasonably
constant');
    readln;read(minoP);ans := 99;
    IF minoP <= 2 THEN
      BEGIN
        writeln('WARNING : do not start at less than 2');
        ans := 98;

```

```

END
ELSE IF minOP >= oPrange THEN
BEGIN
    writeln('WARNING : data only good to ',oPrange:4:1);
    ans := 98;
END;
UNTIL(ans <> 98);
i:=0;sum1:=0;sum2:=0;
oP:=minOP;
REPEAT
    Iplus :=eval(oP+Ecorr);
    Ip3half :=eval(1.5*oP+Ecorr);
    Iminus :=eval(-oP+Ecorr);
    Im3half :=eval(-1.5*oP+Ecorr);
    temp1 :=sqrt(abs((Ip3half*Im3half)/(Iplus*Iminus)))/2;
    temp1 :=(temp1+sqrt(sqr(temp1)+1))/2;
    IF temp1 > 1.0 THEN
    BEGIN
        w:=2*ln(temp1+sqrt(sqr(temp1)-1))/oP;
        i:=i+1;
        sum1:=sum1+w;
    END
    ELSE
        writeln('Data too scattered at ',oP:4:1,' to give a
w. ');
        oP:=oP+0.5;
    UNTIL(oP>=2*oPrange/3);
    num:=i;
    w:=sum1/num;
    writeln('Average w is: ',w:8:6);
    i :=0;
    sum1 :=0;
    oP :=minOP;
    REPEAT
        Iplus :=eval(oP+Ecorr);
        Iminus:=eval(-oP+Ecorr);
        a :=ln(abs(Iplus/Iminus))/(2*oP);
        sum2 :=sum2+a;
        Rp :=sinh(w*oP)/(w*(sqrt(abs(Iplus*Iminus))));
        sum1 :=sum1+Rp;
        i :=i+1;
        oP :=oP+0.5;
    UNTIL(oP >= oPrange);
    num :=i;
    a :=sum2/num;
    Rp :=sum1/num;
    writeln('Re-estimate of a is: ',a:6:4,' Average Rp is:
',Rp:8:0);
    Icorr:=1/(Rp*2*w);
    writeln('Estimated Icorr is: ',Icorr:10:8);

```

```

sum1:=0;i:=0;oP:=-oPrange;
REPEAT
  IF (abs(oP)>=minoP) THEN
    BEGIN
      i      :=i+1;
      IoP    :=abs(eval(oP+Ecorr));
      temp1  :=IoP/(2*Icorr*exp(a*oP));
      w      :=(ln(temp1+sqrt(sqr(temp1)+1)))/(abs(oP));
      IF detailed THEN
        writeln(' at ',oP:4:1,' w = ',w:8:6);
      sum1   :=sum1+w;
    END;
    oP := oP +0.5;
  UNTIL (oP>=oPrange);
num  :=i;
w    :=sum1/num;
writeln('Re-estimate of w is: ',w:10:8);
ba   :=L/(w+a); bc:=L/(w-a); Icorr:=1/(2*w*Rp);
writeln('Initial Ecorr,ba,bc,Icorr and Rp are:');
writeln(Ecorr:6:2,ba:10:2,bc:10:2,Icorr:12:6,Rp:12:0);
rms  :=rmserr(Ecorr,ba,bc,Icorr);
writeln('Initial relative RMS error is: ',rms:8:6);
writeln('Enter 1 if acceptable. ');
readln;read(ans);
WHILE ans <> 1 DO
  BEGIN
    writeln('Enter ba bc Rp *in mvolts/decade and ohms*');
    readln;read(ba,bc,Rp);
    Icorr :=((ba*bc)/(ba+bc))/(L*Rp);
    rms   :=rmserr(Ecorr,ba,bc,Icorr);
    writeln('Relative RMS error = ',rms:8:6);
    writeln('Enter 1 if acceptable. ');
    readln;read(ans);
  END;
  iterations := 0;
  ans := 1;
  REPEAT
    improve(Ecorr,ba,bc,Icorr);
    iterations := iterations + 1;
    rms := newrms;
    if iterations = 25 then
      begin
        iterations := 0;
        writeln('25 iterations have been done. Do you wish
        to do 25 more? (1=YES)'); readln;read(ans);
        if ans <> 1 then
          ans := 99;
        end;
      if detailed then
        writeln('Relative RMS error now = ',rms:8:6);

```

```

UNTIL ans=99;
stats;
writeln('Do you want results on the printer ?(Y = yes)');
readln;read(prin);
if prin='Y' THEN
    ASSIGN(OUT,'LPT1')
ELSE
    ASSIGN(OUT,'CON');
append(OUT);
writeln;
writeln(OUT);
writeln(OUT,'-----');
writeln(OUT,'File ',infile);
writeln(OUT,'relative RMS error = ',rms:8:6);
writeln(OUT,'Ecorr = ',Ecorr:7:2,' millivolts');
writeln(OUT,'Icorr = ',Icorr*1E3:7:5,'
+/-','sdevIcorr*1E3:7:5,' microamps/cm^2'); writeln(OUT,'ba
= ',ba:6:2,' +/- ','sdevba:6:2,' millivolts');
writeln(OUT,'bc      = ',bc:6:2,' +/- ','sdevbc:6:2,'
millivolts');
writeln(OUT,'Rp      = ',Rp*1E-3:6:2,' +/-
',sdevRp*1E-3:5:2,' kohms');
writeln(OUT,'-----');
writeln(OUT);
CLOSE(OUT);
repeat
    writeln('Results FILE name ?');
    readln;read(results);
until results <> '';
assign(LIST,'a:\'+results+'.res');
{$I-}
append(LIST);
{$I+}
if IOResult <> 0 then
    rewrite(LIST);
writeln(LIST);
writeln(LIST,'-----');
writeln(LIST,'File ',infile);
writeln(LIST,'relative RMS error = ',rms:8:6);
writeln(LIST,'Ecorr = ',Ecorr:7:2,' millivolts');
writeln(LIST,'Icorr = ',Icorr*1E3:7:5,'
+/-','sdevIcorr*1E3:7:5,' microamps/cm^2');
writeln(LIST,'ba = ',ba:6:2,' +/- ','sdevba:6:2,'
millivolts');
writeln(LIST,'bc      = ',bc:6:2,' +/- ','sdevbc:6:2,'
millivolts');
writeln(LIST,'Rp      = ',Rp*1E-3:6:2,' +/-
',sdevRp*1E-3:5:2,' kohms');
writeln(LIST,'-----');
writeln(LIST);

```

```

close(LIST);

ASSIGN(PLOTS, 'A:\'+INFILE+'.DAT');
ASSIGN(LIST, 'A:\'+INFILE+'.FIT');
REWRITE(PLOTS);
REWRITE(LIST);
FOR I := 1 TO COUNT DO
    BEGIN
        WRITELN(PLOTS, VOLTDATA[I]:15, ', ', CURRDATA[I]*1E3:15);
        WRITELN(LIST, VOLTDATA[I]:15, ', ', FITCURRENT
(VOLTDATA[I], Ecorr, ba, bc, Icorr)*1E3:15);
    END;
CLOSE(PLOTS);
CLOSE(LIST);
END;{datafit}

BEGIN {main}

    dataheader;
    {Opens the data file and reads in the M342 data file name. }
    {Displays the instructions and sets up a simplified or      }
    {detailed run.                                             }

    datagenerator;
    {Reads in raw data in mVolts and uAmps and stores it in    }
    {arrays POTENTIAL and CURRENT in mVolts and mAmps. POTENTIAL}
    {is checked to ensure it is in ascending order, then an    }
    {interpolating cubic spline is passed through the data.    }

    datafit;
    {Determines constants Ecorr, ba, bc, Icorr and Rp by first }
    {making substitutions for the constants then separating the}
    {equation into parts, each with one or two constants. Then}
    {solves each equation for approximations to its constant(s).}
    {These are then used as the initial parameters to a non-    }
    {linear least squares fitting routine which calculates the }
    {gradient and the Jacobian matrix to the sum of squared    }
    {errors and generates a correction to each parameter. The }
    {iteration continues until the size of the corrections      }
    {become small enough that no further improvement can be    }
    {made. The constants are then output with their estimated }
    {error and the predicted data are tabulated with the actual}
    {data.                                                       }

END.{main}

```

APPENDIX F

PCCORSUB.TPU: TURBOPASCAL UNIT USED BY PCCOR.EXE

Contains subroutines SOLVE⁷, DECOMP⁷, SEVAL⁷ and SPLINE⁷.

```

UNIT PCCORSUB;{$N+}
INTERFACE
CONST  numdata = 200;
        order = 4;
TYPE    index = 1..numdata;
        sindex = 1..order;
        svector = ARRAY[sindex] of real;
        isvector = ARRAY[sindex] of integer;
        vector = ARRAY[index] of real;
        matrix = ARRAY[sindex,sindex] of real;

PROCEDURE SPLINE(N:integer;X,Y:vector;VAR B,C,D:vector);
PROCEDURE DECOMP(NDIM,N:integer;VAR A:matrix;VAR COND:real;
VAR IPVT:isvector;VAR WORK:svector);
PROCEDURE SEVAL(N:integer;U:real;X,Y,B,C,D:vector;VAR VALU,
DVAL:real);
PROCEDURE SOLVE(NDIM,N:integer;VAR A:matrix;VAR B:svector;VAR
IPVT: isvector);

```

```

IMPLEMENTATION
PROCEDURE SOLVE;
{Solution of linear system,  $A \cdot X = B$ . Not used if DECOMP}
{has detected singularity.}
{INPUT:}
{NDIM= Declared row dimension of array containing A.}
{N = Order of matrix.}
{A = Triangularized matrix obtained from DECOMP.}
{B = Right hand side vector.}
{IPVT= Pivot vector obtained from DECOMP.}
{OUTPUT:}
{B = Solution vector, X.}

```

```

VAR
    KB,KM1,NM1,KP1,I,K,M : INTEGER;
    T                      : real;

```

```

BEGIN
IF (N <> 1) THEN {Forward elimination}
BEGIN
    NM1 := N - 1;
    FOR K := 1 TO NM1 DO
    BEGIN
        KP1 := K + 1;

```

```

        M := IPVT[K];
        T := B[M];
        B[M] := B[K];
        B[K] := T;
        FOR I := KP1 TO N DO
            B[I] := B[I] + A[I, K] * T;
        END;
    {Back substitution}
    FOR KB := 1 TO NM1 DO
        BEGIN
            KM1 := N - KB;
            K := KM1 + 1;
            B[K] := B[K] / A[K, K];
            T := -B[K];
            FOR I := 1 TO KM1 DO
                B[I] := B[I] + A[I, K] * T;
            END;
        END;
    B[1] := B[1] / A[1, 1];
END;

PROCEDURE DECOMP;
{Decomposes a real matrix by Gaussian elimination and
{estimates the condition of the matrix.
{Uses SOLVE to compute solutions to linear systems.
{
{INPUT:
{NDIM = Declared row dimension of the array containing A.
{N = Order of the matrix.
{A = Matrix to be triangularized.
{
{OUTPUT:
{A contains an upper triangular matrix U and a permuted
{version of a lower triangular matrix I-L so that:
{(permutation matrix)*A = L*U.
{
{COND = An estimate of the condition of A.
{For the linear system A*X=B, changes in A and B may cause
{changes COND times as large in X. If COND+1.0 = COND, A
{is singular to working precision. COND=1.0+32 if exact
{singularity is detected.
{
{IPVT = The pivot vector.
{IPVT(K) = The index of the K-th pivot row.
{IPVT(N) = (-1)^(number of interchanges)
{
{Work space: The vector work must be declared and included
{in the call. Its input contents are ignored. Its output
{contents are usually unimportant.
{

```

```

{The determinant of A can be obtained on output by      }
{DET(A) = IPVT(N)*A(1,1)*A(2,2)*...*A(N,N).             }
}

VAR
  NM1, I, J, K, KP1, KB, KM1, M : INTEGER;
  EK, ANORM, YNORM, ZNORM, T      : EXTENDED;
  AT : ARRAY[1..4,1..4] OF EXTENDED;
  CONDT : EXTENDED;
  WORKT : ARRAY[1..4] OF EXTENDED;

PROCEDURE CHANGES;
VAR I, J : INTEGER;
{CHANGE EXTENDED VARIABLES TO REAL}
BEGIN
  COND := CONDT;
  FOR I := 1 TO N DO
    BEGIN
      FOR J := 1 TO N DO
        A[I, J] := AT[I, J];
      WORK[I] := WORKT[I];
    END;
  END;
{END OF CHANGES}

BEGIN {CHANGE REAL VARIABLES TO EXTENDED}
  CONDT := COND;
  FOR I := 1 TO N DO
    BEGIN
      FOR J := 1 TO N DO
        AT[I, J] := A[I, J];
      WORKT[I] := WORK[I];
    END; {END OF CHANGES}
  IPVT[N] := 1;
  IF (N <> 1) THEN
    BEGIN {Compute 1-norm of A}
      NM1 := N - 1;
      ANORM := 0.0;
      FOR J := 1 TO N DO
        BEGIN
          T := 0;
          FOR I := 1 TO N DO
            T := T + ABS(AT[I, J]);
          IF (T > ANORM) THEN ANORM := T;
        END;
      {Gaussian elimination with partial pivoting}
      FOR K := 1 TO NM1 DO
        BEGIN
          KP1 := K + 1;
          M := K;
          {Find pivot}

```

```

FOR I := KP1 TO N DO
BEGIN
  IF (ABS(AT[I, K]) > ABS(AT[M, K])) THEN M := I;
END;
IPVT[K] := M;
IF (M <> K) THEN IPVT[N] := -IPVT[N];
T := AT[M, K];
AT[M, K] := AT[K, K];
AT[K, K] := T;
{Skip step if pivot is zero.}
IF (ABS(T) > 1E-9) THEN
BEGIN
  {Compute multipliers.}
  FOR I := KP1 TO N DO
    AT[I, K] := -AT[I, K] / T;
  {Interchange and eliminate by columns.}
  FOR J := KP1 TO N DO
  BEGIN
    T := AT[M, J];
    AT[M, J] := AT[K, J];
    AT[K, J] := T;
    IF (ABS(T) > 1E-9) THEN
    BEGIN
      FOR I := KP1 TO N DO
        AT[I, J] := AT[I, J] + AT[I, K] * T;
    END;
  END;
END;
END;
END;
{COND = (1-NORM of A)*(an estimate of 1-NORM of A-inverse) }
{Estimate obtained by one step of inverse iteration for the}
{small singular vector. This involves solving two systems }
{of equations, (A-transpose)*Y=E and A*Z=Y where E is a }
{vector of +1 or -1 chosen to cause growth in Y. }
{Estimate = (1-NORM of Z)/(1-NORM of Y) }
{Solve(A-TRANSPPOSE)*Y=E }

FOR K := 1 TO N DO
BEGIN
  T := 0.0;
  IF (K > 1) THEN
  BEGIN
    KM1 := K - 1;
    FOR I := 1 TO KM1 DO
      T := T + AT[I, K] * WORKT[I];
    END;
    EK := 1;
    IF (T < 0) THEN EK := -1.0;
    IF (ABS(AT[K, K]) < 1E-9) THEN
    BEGIN

```

```

        CONDT := 1.0+32;
        CHANGES;
        EXIT;
    END;
    WORKT[K] := -(EK+T) / AT[K,K];
END;
FOR KB := 1 TO NM1 DO
BEGIN
    K := N - KB;
    T := 0;
    KP1 := K + 1;
    FOR I := KP1 TO N DO
        T := T + AT[I, K] * WORKT[I];
    WORKT[K] := T;
    M := IPVT[K];
    IF (M <> K) THEN
    BEGIN
        T := WORKT[M];
        WORKT[M] := WORKT[K];
        WORKT[K] := T;
    END;
END;
YNORM := 0;
FOR I := 1 TO N DO
BEGIN
    YNORM := YNORM + ABS(WORKT[I]);
END;
{Solve A*Z=Y}
CHANGES;
SOLVE(ndim,n,A,work,ipvt);
FOR I := 1 TO N DO
BEGIN
    FOR J := 1 TO N DO
        AT[I,J] := A[I,J];
    WORKT[I] := WORK[I];
END;
ZNORM := 0;
FOR I := 1 TO N DO
BEGIN
    ZNORM := ZNORM + ABS(WORKT[I]);
END;
{Estimate condition}
CONDT := ANORM * ZNORM / YNORM;
IF (CONDT < 1.0) THEN CONDT := 1.0;
CHANGES;
EXIT;
END;
{1-BY-1}
CONDT := 1;
IF (ABS(AT[1, 1]) > 1E-9) THEN

```

```

BEGIN
    CHANGES;
    EXIT;
END;
{Exact singularity.}
CONDT := 1.0+32;
CHANGES;
END;

PROCEDURE SEVAL;
{This subroutine evaluates the cubic spline function and }
{its derivative and returns VAL and DVAL.}
{VAL =  $Y(I)+B(I)*(U-X(I))+C(I)*(U-X(I))^2+D(I)*(U-X(I))^3$ }
{DVAL =  $B(I)+2*C(I)*(U-X(I))+3*D(I)*(U-X(I))^2$ }
{Where  $X(I) < U < X(I+1)$ , using Horner's rule.}
{If  $U < X(1)$  then  $I=1$  is used.}
{If  $U \geq X(N)$  then  $I=N$  is used.}
{
{INPUT:
{N = The number of data points.}
{U = The abscissa at which the spline is to be evaluated.}
{X,Y = The arrays of data abscissas and ordinates.}
{B,C,D = Arrays of spline coefficients computed by spline.}
{
{If U is not in the same interval as the previous call,}
{then a binary search is performed to determine the proper }
{interval.}

VAR
    I, J, K : INTEGER;
    DX : real;

BEGIN
    I := 1;
    IF (U >= X[I]) THEN
        IF (U <= X[I+1]) THEN
            BEGIN
                DX := U-X[I];
                VALU := Y[I]+DX*(B[I]+DX*(C[I]+DX*D[I]));
                DVAL := B[I]+DX*(2*C[I]+DX*(3*D[I]));
                EXIT;
            END;
        I := 1;
        J := N+1;
        {Binary search.}
        REPEAT
            K:=(I+J) DIV 2;
            IF (U < X[K]) THEN J:=K;
            IF (U >= X[K]) THEN I:=K;
        UNTIL (J <= (I+1));

```

```

    {Evaluate spline and derivative.}
    DX := U - X[I];
    VALU := Y[I] + DX * (B[I] + DX * (C[I] + DX * D[I]));
    DVAL := B[I] + DX * (2 * C[I] + DX * (3 * D[I]));
END;

PROCEDURE SPLINE;
{The coefficients B(I), C(I), and D(I), I=1,2,...,N are }
{computed for a cubic interpolating spline.}
{S(X) = Y(I)+B(I)*(X-X(I))+C(I)*(X-X(I))^2+D(I)*(X-X(I))^3}
{for X(I) <= X <= X(I+1)}
{
}
{INPUT:
}
{N = The number of data points or knots (N >= 2)}
{X = The abscissas of knots in strictly increasing order}
{Y = The ordinates of the knots}
{
}
{OUTPUT:
}
{B,C,D = Arrays of spline coefficients as defined above}
{Using P to denote differentiation,}
{Y(I) = S(X(I))}
{B(I) = SP(X(I))}
{C(I) = SPP(X(I))/2}
{D(I) = SPPP(X(I))/6 (Derivative from the right.)}
{The procedure SEVAL is used to evaluate the spline and}
{its derivative.}

VAR
    NM1, IB, I : INTEGER;
    T           :real;
BEGIN
    NM1 := N - 1;
    IF (N < 2) THEN EXIT;
    IF (N >= 3) THEN
        BEGIN
            {Set up tridiagonal system.}
            {B=Diagonal, D=Offdiagonal, C=Right hand side}
            D[1] := X[2] - X[1];
            C[2] := (Y[2] - Y[1]) / D[1];
            FOR I := 2 TO NM1 DO
                BEGIN
                    D[I] := X[I + 1] - X[I];
                    B[I] := 2 * (D[I - 1] + D[I]);
                    C[I + 1] := (Y[I + 1] - Y[I]) / D[I];
                    C[I] := C[I + 1] - C[I];
                END;
            {End conditions. Third derivative at X(1) and X(N)}
            {obtained from divided differences.}
            B[1] := -D[1];
            B[N] := -D[N - 1];
        END
    END

```

```

C[1] := 0;
C[N] := 0;
IF (N <> 3) THEN
BEGIN
  C[1] := C[3] / (X[4] - X[2]) - C[2] / (X[3] - X[1]);
  C[N] := C[N - 1] / (X[N] - X[N - 2]) - C[N - 2] /
(X[N - 1] - X[N - 3]);
  C[1] := C[1] * SQR(D[1]) / (X[4] - X[1]);
  C[N] := -C[N] * SQR(D[N - 1]) / (X[N] - X[N - 3]);
END;
{Forward elimination}
FOR I := 2 TO N DO
BEGIN
  T := D[I - 1] / B[I - 1];
  B[I] := B[I] - T * D[I - 1];
  C[I] := C[I] - T * C[I - 1];
END;
{Back substitution}
C[N] := C[N] / B[N];
FOR IB := 1 TO NM1 DO
BEGIN
  I := N - IB;
  C[I] := (C[I] - D[I] * C[I + 1]) / B[I];
END;
{Compute polynomial coefficients.}
B[N] := (Y[N] - Y[NM1]) / D[NM1] + D[NM1] * (C[NM1] + 2
* C[N]);
FOR I := 1 TO NM1 DO
BEGIN
  B[I] := (Y[I + 1] - Y[I]) / D[I] - D[I] * (C[I+1]
+ 2 * C[I]);
  D[I] := (C[I + 1] - C[I]) / D[I];
  C[I] := 3 * C[I];
END;
C[N] := 3 * C[N];
D[N] := D[N - 1];
EXIT;
END;
B[1] := (Y[2] - Y[1]) / (X[2] - X[1]);
C[1] := 0;
D[1] := 0
END;
END.

```

APPENDIX G
SIMPLIFIED PCCORROS RUN

Would you like to read the introduction? yes = 1
2

Do you want a detailed run? yes = 1
2

100 data points read in

Do you want to see the data tabulated ? yes = 1
2

Estimated Ecorr is: -237.69

Range around Ecorr reduced to: 15.3

62points in range

at oP= 5.0	a = -0.008587	at oP= 5.5	a = -0.005321
at oP= 6.0	a = -0.002811	at oP= 6.5	a = -0.002065
at oP= 7.0	a = -0.003319	at oP= 7.5	a = -0.006285
at oP= 8.0	a = -0.008199	at oP= 8.5	a = -0.006307
at oP= 9.0	a = -0.006264	at oP= 9.5	a = -0.006371
at oP= 10.0	a = -0.007122	at oP= 10.5	a = -0.004228
at oP= 11.0	a = -0.002421	at oP= 11.5	a = -0.003676
at oP= 12.0	a = -0.005147	at oP= 12.5	a = -0.005323
at oP= 13.0	a = -0.003477	at oP= 13.5	a = -0.003513
at oP= 14.0	a = -0.003755	at oP= 14.5	a = -0.003211
at oP= 15.0	a = -0.003721	Average a is: -0.004815	

Enter starting oP: minimum oP where a becomes reasonably constant

5

Data too scattered at 5.0 to give a w.

Data too scattered at 8.0 to give a w.

Data too scattered at 8.5 to give a w.

Data too scattered at 9.0 to give a w.

Average w is: 0.054312

Re-estimate of a is: -0.0048 Average Rp is: 3072

Estimated Icorr is: 0.00299712

Re-estimate of w is: 0.05433495

Initial Ecorr,ba,bc,Icorr and Rp are:

-237.69	46.50	38.93	0.002996	3072
---------	-------	-------	----------	------

Initial relative RMS error is: 0.026588

Enter 1 if acceptable.

1

No further improvement available.

Do you want results on the printer ?(Y = yes)

N

File FE551
relative RMS error = 0.020926
Ecorr = -237.56 millivolts
Icorr = 3.69377 +/- 0.08267 microamps/cm²
ba = 55.47 +/- 1.81 millivolts
bc = 47.97 +/- 1.40 millivolts
Rp = 3.02 +/- 0.07 kohms

Results FILE name ?
TEST

APPENDIX H

DATA FILE FE551.DAT

POTENTIAL (mV)	CURRENT (mA/cm ²)
-2.530000E+0002,	-5.991200E+0000
-2.525000E+0002,	-5.591800E+0000
-2.520000E+0002,	-5.297500E+0000
-2.515000E+0002,	-5.066200E+0000
-2.510000E+0002,	-4.814000E+0000
-2.505000E+0002,	-4.624800E+0000
-2.500000E+0002,	-4.456600E+0000
-2.495000E+0002,	-4.267400E+0000
-2.490000E+0002,	-4.057200E+0000
-2.485000E+0002,	-3.868000E+0000
-2.480000E+0002,	-3.741900E+0000
-2.475000E+0002,	-3.552700E+0000
-2.470000E+0002,	-3.384500E+0000
-2.465000E+0002,	-3.258400E+0000
-2.460000E+0002,	-3.048100E+0000
-2.455000E+0002,	-2.863100E+0000
-2.450000E+0002,	-2.495300E+0000
-2.445000E+0002,	-2.308200E+0000
-2.440000E+0002,	-2.144200E+0000
-2.435000E+0002,	-2.009700E+0000
-2.430000E+0002,	-1.866700E+0000
-2.425000E+0002,	-1.713300E+0000
-2.420000E+0002,	-1.503000E+0000
-2.415000E+0002,	-1.311800E+0000
-2.410000E+0002,	-1.156200E+0000
-2.405000E+0002,	-9.838000E-0001
-2.400000E+0002,	-8.829000E-0001
-2.395000E+0002,	-7.105000E-0001
-2.390000E+0002,	-4.436000E-0001
-2.385000E+0002,	-2.733000E-0001
-2.380000E+0002,	-9.520000E-0002
-2.375000E+0002,	4.370000E-0002
-2.370000E+0002,	1.308000E-0001
-2.365000E+0002,	2.674000E-0001
-2.360000E+0002,	3.597000E-0001
-2.355000E+0002,	4.303000E-0001
-2.350000E+0002,	6.243000E-0001
-2.345000E+0002,	1.082600E+0000
-2.340000E+0002,	1.259200E+0000
-2.335000E+0002,	1.400000E+0000
-2.330000E+0002,	1.530400E+0000

-2.325000E+0002,	1.698500E+0000
-2.320000E+0002,	1.881400E+0000
-2.315000E+0002,	2.053800E+0000
-2.310000E+0002,	2.194700E+0000
-2.305000E+0002,	2.297700E+0000
-2.300000E+0002,	2.465800E+0000
-2.295000E+0002,	2.667600E+0000
-2.290000E+0002,	2.882100E+0000
-2.285000E+0002,	2.993500E+0000
-2.280000E+0002,	3.079700E+0000
-2.275000E+0002,	3.233100E+0000
-2.270000E+0002,	3.607300E+0000
-2.265000E+0002,	3.760800E+0000
-2.260000E+0002,	3.819600E+0000
-2.255000E+0002,	3.861700E+0000
-2.250000E+0002,	4.061400E+0000
-2.245000E+0002,	4.393500E+0000
-2.240000E+0002,	4.498600E+0000
-2.235000E+0002,	4.750900E+0000
-2.230000E+0002,	5.003200E+0000
-2.225000E+0002,	5.213400E+0000

APPENDIX I

PRINTOUT OF A PCCORROS RESULTS FILE

File FE551
relative RMS error = 0.020926
Ecorr = -237.56 millivolts
Icorr = 3.69377 +/- 0.08267 microamps/cm²
ba = 55.47 +/- 1.81 millivolts
bc = 47.97 +/- 1.40 millivolts
Rp = 3.02 +/- 0.07 kohms

File FE552
relative RMS error = 0.030113
Ecorr = -244.75 millivolts
Icorr = 1.74461 +/- 0.06352 microamps/cm²
ba = 37.89 +/- 1.20 millivolts
bc = 40.86 +/- 2.23 millivolts
Rp = 4.89 +/- 0.17 kohms

File FE553
relative RMS error = 0.087937
Ecorr = -238.68 millivolts
Icorr = 1.99252 +/- 0.11613 microamps/cm²
ba = 33.01 +/- 1.67 millivolts
bc = 54.15 +/- 3.65 millivolts
Rp = 4.47 +/- 0.26 kohms

File FE554
relative RMS error = 0.034270
Ecorr = -235.64 millivolts
Icorr = 1.79764 +/- 0.08619 microamps/cm²
ba = 33.65 +/- 1.24 millivolts
bc = 37.62 +/- 2.59 millivolts
Rp = 4.29 +/- 0.19 kohms

File FE555
relative RMS error = 0.027763
Ecorr = -233.08 millivolts
Icorr = 1.84006 +/- 0.06822 microamps/cm²
ba = 33.49 +/- 1.29 millivolts
bc = 36.24 +/- 1.69 millivolts
Rp = 4.11 +/- 0.14 kohms

File FE556
relative RMS error = 0.030861
Ecorr = -228.06 millivolts
Icorr = 2.00665 +/- 0.05716 microamps/cm²
ba = 34.05 +/- 0.64 millivolts
bc = 37.37 +/- 1.42 millivolts
Rp = 3.86 +/- 0.11 kohms

File FE557
relative RMS error = 0.033995
Ecorr = -223.22 millivolts
Icorr = 2.31465 +/- 0.07973 microamps/cm²
ba = 36.55 +/- 1.11 millivolts
bc = 39.10 +/- 1.79 millivolts
Rp = 3.54 +/- 0.12 kohms

File FE558
relative RMS error = 0.032829
Ecorr = -219.41 millivolts
Icorr = 2.57045 +/- 0.08475 microamps/cm²
ba = 33.28 +/- 1.04 millivolts
bc = 35.85 +/- 1.42 millivolts
Rp = 2.92 +/- 0.09 kohms

File FE559
relative RMS error = 0.036933
Ecorr = -213.04 millivolts
Icorr = 3.80187 +/- 0.15673 microamps/cm²
ba = 36.98 +/- 1.95 millivolts
bc = 42.86 +/- 2.09 millivolts
Rp = 2.27 +/- 0.09 kohms

File FE5510
relative RMS error = 0.034996
Ecorr = -206.91 millivolts
Icorr = 3.48532 +/- 0.13455 microamps/cm²
ba = 35.82 +/- 1.59 millivolts
bc = 35.87 +/- 1.66 millivolts
Rp = 2.23 +/- 0.08 kohms

File FE5511
relative RMS error = 0.033866
Ecorr = -199.15 millivolts
Icorr = 2.66925 +/- 0.10185 microamps/cm²
ba = 30.41 +/- 0.98 millivolts
bc = 31.05 +/- 1.43 millivolts
Rp = 2.50 +/- 0.09 kohms

File FE5512
relative RMS error = 0.033131
Ecorr = -193.85 millivolts
Icorr = 2.68506 +/- 0.09301 microamps/cm²
ba = 33.46 +/- 0.76 millivolts
bc = 32.35 +/- 1.49 millivolts
Rp = 2.66 +/- 0.09 kohms

APPENDIX J

INSTALL.BAT: BATCH FILE THAT INSTALLS PCCORROS

```
@ECHO OFF
ECHO This batch file will install PCCORROS on drive C from
any other drive.
ECHO The subdirectory PCCORROS will be created and all the
files copied to it.
ECHO The batch file PCCORROS.BAT will be copied to the root
directory. To run
ECHO PCCORROS move to the root directory of drive C and type
in "PCCORROS".
PAUSE
COPY \PCCORROS\PCCORROS.BAT C:\
MD C:\PCCORROS
COPY \PCCORROS\*.* C:\PCCORROS
C:
CD\
```

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An IBM PC has been set up to control an EG&G PARC M273 potentiostat to perform electrochemical corrosion experiments using PARC'S M342 corrosion measurement software. Modifications to the software permit the measurement of corrosion current over long periods of time using the Polarization Resistance measurement technique. A computer program, PCCORROS, is used to analyze the polarization resistance data to determine the polarization resistance, corrosion current, anodic and cathodic tafel constants, and the corrosion potential.

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