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AUTOMATED TEXTURE DIFFRACTOMETER

T. L. Williams

**UNION
CARBIDE**

OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

*prepared for the U.S. ATOMIC ENERGY COMMISSION
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ABSTRACT

A minicomputer was interfaced to a four-circle diffractometer for preferred orientation studies of rolled sheet materials. The system scans a specimen in the reflective mode between alphas of 15 and 90 degrees, drawing its pole figure on an X-Y plotter. Additional software will provide a pole figure between alphas of 0 and 90 degrees.

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CONTENTS

SUMMARY	5
INTRODUCTION	6
AN AUTOMATED TEXTURE DIFFRACTOMETER SYSTEM	7
Procedure	7
System Description	7
Interface	7
Counting Instrumentation	11
Four-Circle Diffractometer	12
Minicomputer	17
Plotter	12
Software	12
System Operation	16
CONCLUSIONS AND RECOMMENDATIONS	18
ACKNOWLEDGEMENTS	19
APPENDIX A	20
Derivation of the Pole Figure Coordinates	20
APPENDIX B	22
Interface Schematics	22
APPENDIX C	27
Derivation of the Equation for Equal Spherical Areas	27
APPENDIX D	29
Compensation of Data for Time Errors	29
APPENDIX E	30
Intensity Correction Equation	30

SUMMARY

Standard techniques for acquiring pole figures of crystal orientation within rolled-sheet materials require that data be transferred from a strip-chart recorder to a three-dimensional stereographic net (pole figure). Since these figures contain as many as 2,000 data points, many manhours are required for their construction. In an effort to minimize this time and to provide a flexible system for orientation studies, a minicomputer was interfaced to a four-circle diffractometer, a nuclear counting instrument, and an X-Y plotter. The computer controls the diffractometer, assimilates data, and draws a pole figure with a minimum of operator effort.

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INTRODUCTION

A texture diffractometer is an instrument used for determining the preferred orientation of crystallites or of their lattice planes in polycrystalline specimens. Data are collected by directing a collimated X-ray beam on the specimen in question and counting the reflected intensity at the specimen's diffraction angle (2θ). The reflected intensity depends on the number of crystals lying in the reflecting position. Data are displayed on a stereographic projection (pole figure) as the diffractometer is moved to cover all possible angles around the specimen. These figures consume a large amount of operator time. Since they are used extensively at the Oak Ridge Y-12 Plant,^(a) an automated system was developed around a commercially available diffractometer and computer. The system controls diffractometer movement, accumulates data, and draws a pole figure on an X-Y plotter.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Atomic Energy Commission.

AN AUTOMATED TEXTURE DIFFRACTOMETER SYSTEM

PROCEDURE

Pole figure data are derived using a variation of the Schultz Geometry, as indicated in Figure 1. The diffraction angle (2θ) of the specimen is set, and data are taken over a

Figure 1. GEOMETRY OF THE REFLECTION METHOD.

spherical grid by movement of the α and β axes. Limits are placed on α because of X-ray scattering below 15 degrees. A simplified example of a typical grid would be α increments of 5 degrees and β increments of 10 degrees, giving 540 data points. These data are plotted on a plane (Figure 2) tangent to the north pole of a unit sphere by drawing a line through the south pole, through the data point, and plotting the intensity at the intersection of this plane. (See Appendix A for further details.) Orientation below 15 degrees alpha can be derived by an analysis of the other lattice planes within the specimen or by using the transmission method, as illustrated in Figure 3.

SYSTEM DESCRIPTION

The system (seen in Figures 4 and 5) was designed around a minicomputer with 8 kilowords of core memory (12-bit words). An effort was made to minimize the external electronics and provide flexibility. Software is used to control a four-circle diffractometer and an X-Y plotter. X-ray particles are detected, amplified, and differentiated by standard nuclear instrumentation. The resulting signals are counted via the computer's data-break facilities, corrected for various errors, converted to relative intensity, and plotted on a projected stereographic net.

Interface

The interface consists of electronics that allow the computer to control or monitor other equipment plus any manual controls that are necessary for initial specimen setup. Appendix B provides a block diagram of the system (Figure B-1) and complete drawings of the interface.

Motor Control - The motors are controlled through bits which are set in the computer's accumulator and fed to a motor-control register which, in turn, controls each motor

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Figure 4. AUTOMATED FOUR-CIRCLE DIFFRACTOMETER AND EXTERNAL ELECTRONICS.

interface accumulator register and enabling a motor clock (Figure 6). If a bit is set it will allow either a forward (FWD) or reverse (REV) pulse through to the ring counter which controls currents in the motor windings, causing the motor to step in the appropriate direction. Table 1 contains a list of bits and the resulting functions. The actual position of each motor is accounted for by software registers inside the computer. As each motor-clock pulse arrives, it is sensed by the computer through its interrupt facility. At this time, the computer either increments, decrements, or ignores each of these registers. Computer control commands pertaining to the control of the motors are listed in Table 2.

Manual Control - The manual control facility consists of eight switches that route 200-Hz pulses to the inputs of each of the motor controller's ring counters (Figure B-5). It also includes various other controls (clutch and the motor power control are normally controlled by the computer) that must be enabled before the motors can be manually moved.

Data Control and Memory Increment Data Break - X-ray data are counted via these circuits, as shown in Figure B-4 (Appendix B). When it is necessary to accumulate data, the computer enables the data control circuits which allow pulses (generated by reflected

Figure 5. PRINCIPAL COMPONENTS OF THE DIFFRACTOMETER SYSTEM.

Table 1
ACCUMULATOR CONTROL BITS

Control Bit	Motor Movement	Schematic Reference
0	+ Beta	Motor 1
1	- Beta	Motor 1
2	+ Alpha	Motor 2
3	- Alpha	Motor 2
4	+ 2θ	Motor 3
5	- 2θ	Motor 3
6	+ Omega	Motor 4
7	- Omega	Motor 4
8	Enable Motor Clock	

X rays) through to a memory increment data break. This circuit causes memory location 100(8) to be incremented each time a pulse arrives. When it overflows, location 101(8) is incremented giving a count capacity of 2^{24} . Computer control commands are given in Table 3.

X-Y Plotter Interface - The interface is designed to operate with a Mosley 2D plotter and G-2B null detector, a Hewlett Packard 7004 plotter and 17173A null

Figure 6. COMPONENTS OF THE MOTOR TRANSLATOR.

Table 2
MOTOR CONTROL COMMANDS

Computer Pnemonics	Octal Code	Function
DISGAG	6334	Disengage Beta Clutch
ENGAGE	6332	Engage Beta Clutch
RESINT	6312	Clear Interrupt Circuit
CLRREG	6311	Clear Motor Control Register
REDREG	6314	Load Accumulator into Motor Control Register

detector, or a Hewlett Packard 7004 plotter with a 17175A active filter on the inputs. The present system uses the latter setup with an enable/disable circuit that lifts the plotting pen. Pen position is controlled by two 9-bit digital-to-analog converters connected to the computer's accumulator bits 3-11. Table 4 lists the computer control signals that pertain to the plotter interface. Further details are included in Figure B-4.

Counting Instrumentation

Standard instruments are used for conditioning the reflected X-ray signals before being fed to the computer for counting. These com-

Table 3
DATA CONTROL COMMANDS

Computer Pnemonics	Octal Code	Function
ENACNT	6344	Enable Data Break Circuits
DIACNT	6342	Disable Data Break Circuits

Table 4
PLOTTER CONTROL COMMANDS

Computer Pnemonics	Octal Code	Function
SEEK	6324	Lower Pen
DISABL	6322	Raise Pen
CLEDAC	6331	Clear DAC's
XAXIS	6352	Load XDAC from Accumulator
YAXIS	6354	Load YDAC from Accumulator

ponents include a sealed gas proportional detector, preamplifier, amplifier, pulse height analyzer, high-voltage supply for the detector, and a rate meter for instrument alignment.

Four-Circle Diffractometer

This instrument consists of a standard Siemen's diffractometer base on which an E & A goniometer ring is mounted. The ring has Slo-Syn HS25 stepper motors for movement of α and β . Each pulse of these motors represents 0.005 degree of movement. These motors were also mounted on the base, replacing the AC motors that were standard equipment for movement of 2θ and ω . Resulting base movement per step was 0.0025 degree.

Minicomputer

An 8-kiloword (12-bit word) Digital Equipment Corporation (DEC) PDP-8/I computer is used as the basic system component. The computer controls movement of the diffractometer to mathematically derived positions, accumulates data through its data break facilities, calculates the projected coordinates of these positions, corrects the data, calculates the relative intensities, and draws a symbol representing these intensities on a polar stereographic net using an X-Y plotter.

Plotter

A Hewlett Packard 7004B X-Y plotter is used for drawing the pole figure. The instrument is controlled by the computer and interface through two 9-bit digital-to-analog converters that accept computer data and various other control parameters. Relative intensity (represented by symbols and numbers) is drawn at projected Cartesian coordinates that are calculated from the α and β of the data point in question (Appendix A).

Software

Software for the system is written in machine language and uses the advanced floating-point package supplied with the computer. Further information can be found in manuals supplied with the DEC PDP-8/I computer.

Executive Subroutine (EXECU) - The executive subroutine calls all the subroutines listed in Table 5 as well as initializing both software and hardware before calling these routines.

Input Control Constants (CONTAN) - This subroutine allows entry of all control parameters via the teletypewriter. A list of these parameters is given in Table 6. In order to save memory space, no arguments are presented before these parameters are inputted.

Background Data (BAKGND) - Data are taken at two 2θ locations (defined by

Table 5
MAJOR SUBROUTINES

Subroutine	Function
CONTAN	Input All Control Constants
BACGND	Take Background Data at Selected Points
SCARAN	Scan Random Sample Storing Data in Upper Memory of Computer
DATASA	Scan Specimen and Draw Pole Figure from Resulting Data

Table 6
CONTROL PARAMETERS

Parameter	Parameter Description	Dimension
1	Alpha at Which Background is Taken	Degrees
2	Specimen Thickness	Inches
3	Number of Desired Data Points	None
4	Alpha at Which Scan is to Begin	Degrees
5	Alpha at Which Scan is to End	Degrees
6	Specimen Density	gm/cm ³
7	Specimen Absorption Factor	cm ² /gm
8	Alpha Increment	Degrees
9	2 θ for First Background	Degrees
10	2 θ for Second Background	Degrees
11	Diffraction Angle of Specimen	Degrees

control parameters that were initially inserted). At each of these locations, ten readings are taken and averaged. These two numbers are again averaged and the result is stored for later use when finding the actual reflected intensity:

$$I_R = I_T - I_{BK},$$

where:

I_R represents the actual reflected intensity,

I_T the total reflected intensity,

I_{BK} the intensity other than that desired.

Scan Random Specimen (SCARAN) - In order to compare one specimen with another, it is necessary to have some reference. This comparison is accomplished by using a specimen whose crystals have no orientation (reflected intensities are equal at all points around the sphere). It is necessary to take data from the random specimens at each position where actual specimen data are desired. This subroutine takes data between alpha limits established by the parameters of Table 6. Alpha and beta positions are calculated by subroutine CALAB whose criteria are detailed in Appendix C. The objective is to take data over equal spherical areas to prevent the crowding of data when the projected points approach the center of the pole figure. Since the alpha increment is always constant, this is accomplished by varying the degrees between beta. The sequence of subroutine operations is listed in Table 7. Table 8 lists the additional subroutines used by SCARAN and their functions.

Table 7
SUBROUTINE SCARAN OPERATIONS

1. Initialize software for the first α , β , and 2θ .
2. Skip the next command.
3. Calculate α and β for the next data point using the criteria set in Appendix C.
4. Move all axes to the required positions.
5. Accumulate data.
6. Correct the data for timing errors introduced by the data break (Appendix D).
7. Correct the data for absorption (Appendix E).
8. Store data in the upper memory as two 12-bit binary numbers.
9. Go back to Operation 3.

Scan Specimen (DATASA) - This subroutine scans the specimen at the same positions where data were taken from the random specimen. As data are taken, a pole figure is drawn on an X-Y plotter. Table 9 lists the sequence of subroutine operations. These operations are continued until subroutine CALAB detects that the last data point is taken. At this time, program flow returns to EXECU where the system is shut down. A typical pole figure is presented in Figure 7.

Table 8
SUBROUTINES USED BY SCARAN

CALAB - Calculate the position of the next β by using the following formula:

$$\beta = \text{last } \beta + \Delta\beta,$$

$$\Delta\beta = \sqrt{\frac{2\pi/N}{\cos \alpha}} \quad (N \text{ represents number of required data points}).$$

If β is greater than $360^\circ - 1/4 \Delta\beta$, then add $\Delta\alpha$ to the last alpha, set β to zero; and, if α is not equal to the maximum value of Table 6, return to calling the subroutine. If this is the case, return to the Executive (EXECU) subroutine.

MOTORS - Sets all motors to positions defined by their destination registers. Entered via the motor clock interrupt.

CORRECT - Correct the motor status registers for an initially induced one-pulse error.

TAKDAT - Correct the data for errors and store in the upper memory.

Figure 7. POLE FIGURE FOR NIOBIUM. (Each Complete Circle Represents an Alpha Increment of 2.5 Degrees)

Table 9
SUBROUTINE DATASA OPERATIONS

1. Initialize software for the first α , β , and 2θ .
2. Set 2θ destination register to defined location of 1.
3. Skip the next command.
4. Calculate α and β for the next data point. Refer to CALAB (Table 8).
5. Set α and β destination registers to the defined position.
6. Correct all motor status registers for the initial one-pulse error.
7. Calculate the Cartesian coordinates of the projected data point from the present value of α and β . Refer to Appendix A for the derivation of the formulas:

$$X = 256 + 256 \left[\tan \left(\frac{90 - \alpha}{2} \right) \right] \left[\cos (90 - \beta) \right], \text{ and}$$

$$Y = 256 + 256 \left[\tan \left(\frac{90 - \alpha}{2} \right) \right] \left[\sin (90 - \beta) \right].$$

8. Move the plotter to these coordinates.
9. Move the motors to the positions defined by the destination registers.
10. Accumulate data using the data break.
11. Correct data for the time error. Refer to Appendix D for formula derivation:

$$I_c = I \cdot [T + I \cdot 4.5 \times 10^{-6}] [I] [4.5 \times 10^{-6}].$$

12. Correct the data for the absorption error. Refer to Appendix E for the formula.
13. Subtract the background from the corrected data.
14. Retrieve the corresponding random data from the upper memory.
15. $I = I(\text{specimen}) \div I(\text{random})$.
16. Plot this rounded number at the present position of the X-Y plotter:

Symbol	Intensity Range (I)
□	0 - 0.12499...
▽	0.125 - 0.2499...
.	0.25 - 0.499...
1	0.5 - 1.499...
2	1.5 - 2.499...
3	2.5 - 3.499...
4	3.5 - 4.499...
5	4.5 - 5.499...
6	5.5 - 6.499...
7	6.5 - 7.499...
8	7.5 - 8.499...
9	8.5 - 9.499...
0	> 9.5

17. Return to Operation 4.

Motor Control Subroutine (MOTORS) - In order to minimize hardware, the stepper motors are controlled via software. Each motor has two registers. A motor status register is used to define the actual motor position, and a motor destination register is used to define the final position of the motor. Subroutine MOTORS monitors these registers and allows clock pulses to drive the motors until the status register is equal to the destination register. This software insures that each position is approached in the same direction to eliminate backlash and prevents simultaneous movement of α and β . This control is

necessitated by the goniometer ring design where α movement induces an error in β unless its clutch is disengaged. A typical movement sequence is outlined in Table 10.

SYSTEM OPERATION

Before the system can be operated, the program must first be loaded in the computer. This step consists of the "operate program" plus Floating Point Package 4 with EAE option. (For loading details

refer to the *DEC PDP-8/I System User's Guide*.) The system is started by setting the switch register to 0600(8), depressing the "load address" switch, and then depressing the "start" switch. The computer immediately goes into an input routine where experiment constraints are entered. A typical list is presented in Table 11 with the function of each entry. The titles are not written out in actual operation in order to conserve computer memory.

Table 11
TYPICAL INPUT PARAMETERS

45	Alpha at Which Background is Taken
0.1	Thickness of Specimen
1000	Number of Data Points
15	Alpha at Which Scan Begins
90	Alpha at Which Scan Ends
16.6	Specimen Density
166	Specimen Absorption Coefficient
2.5	Angle between Alpha Scans
35.6	2θ Angle for First Background
41.6	2θ Angle for Second Background
38.6	Diffraction Angle of Random Specimen
38.6	Diffraction Angle of Specimen

intervals such that the spherical area covered by each data point is always equal. When β is greater than $360^\circ - 1/4 \Delta\beta$, a value of 2.5 degrees is added to α and the scan is repeated. As each data point is taken, the corrected reflected intensity minus the average background is stored in the upper memory. This procedure is continued until α is equal to 90 degrees. At this time the computer stops and the operator loads the specimen to be analyzed.

Most of the time the operator will start the experiment at this point. It is not necessary to scan a random specimen for each analysis. The operator may enter new constraint parameters at this point by typing in the required constraints after depressing the "load address" switch with 0600(8) in the switch register, then the "start" switch. When the

Table 10
AXIS POSITIONING SEQUENCE

1. Set α , β , and 2θ destination registers to the desired position.
2. Correct for the initial one-pulse error. (When the clock is first turned on, no motor movement will be enabled on the first clock pulse. Sub-routine MOTORS does not know this and treats each status register as though it moved.)
3. Set memory location 0166(8) to the memory location where program flow is to return after all destinations are attained.
4. Set accumulator to 0010(8) [enables clock] and read the accumulator into the interface motor control register with a 6314(8) I/O command.
5. Enter a wait loop until the clock pulse causes a motor movement and a program interrupt.
6. The clock will remain enabled and all motors will continue to move until each is at its destination. At this time the clock is disabled and the program flow moves to the memory location defined in 0166(8).

After the last parameter is entered, the computer halts for loading of the random specimen. When this operation is accomplished, the operator manually sets each diffractometer axis to zero and depresses the computer's "continue" switch. Assuming the input constraints are those of Table 11, the computer takes background at 2θ equal to 35.6 and 41.6 degrees, averages the two, and stores the results for later use. When this program is finished, the system makes a random scan with 2θ equal to 38.6 and initial α and β of 15 and 0 degrees. A scan is made by rotating β at

computer halts, the switch register is set to 637(8), "load address", and "start", bypassing the random specimen routines. The system now takes specimen background at 2θ 's of 35.6 and 41.6 degrees and repeats the same scan that was performed on the random specimen. As each data point is examined, a relative intensity is plotted on a polar stereographic net (pole figure) by retrieving its corresponding random data from upper memory for the following comparison:

$$\text{Plotted Intensity} = \frac{\text{Specimen Intensity} - \text{Specimen Background}}{\text{Random Intensity} - \text{Random Background}}$$

CONCLUSIONS AND RECOMMENDATIONS

The system provides a means for acquiring pole figures using three axes of movement between alphas of 15 and 90 degrees in the reflection mode of analysis. However, this operation does not portray the entire capability of the system. Hardware is available for the fourth axis of movement (omega). By adding software for its control and data normalization, specimens may be analyzed over the full alpha range between 0 and 90 degrees. This analysis is accomplished by taking data in the transmission mode between alphas 0 and 25 degrees, in the reflection mode between 15 and 90 degrees, and normalizing the data. (Normalization is necessary because of smaller intensities encountered in the transmission mode due to the beam traveling through the specimen.)

The computer provides a flexibility that is not available with hardware systems. By changing, rearrangement, or adding software, the system may be configured to allow new experimental techniques that often occur because of new materials.

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$$\Delta X = N'P' \cos \theta ,$$

$$\Delta Y = N'P' \sin \theta ,$$

$$\theta = 90 - \beta ,$$

$$\Delta X = \left[2R \tan \left(\frac{90 - \alpha}{2} \right) \right] \left[\cos (90 - \beta) \right] , \text{ and} \quad (1)$$

$$\Delta Y = \left[2R \tan \left(\frac{90 - \alpha}{2} \right) \right] \left[\sin (90 - \beta) \right] . \quad (2)$$

Equations 1 and 2 will give the projected Cartesian coordinates for each combination of alpha and beta. The results of these equations are converted to 9-bit digital numbers and fed to two digital-to-analog converters whose outputs drive the two inputs of an X-Y plotter. The 9-bit system presents a resolution of 1 in 512, or approximately 0.02 volt in 10.00 volts. So:

$$\Delta Y \text{ (max) occurs at } \alpha = 0^\circ \quad \beta = 0^\circ \text{ and}$$

$$\Delta X \text{ (max) occurs at } \alpha = 0^\circ \quad \beta = 90^\circ .$$

Since the center of the X-Y plotter is at X = +5 volts and Y = +5 volts with outer limits of +10 volts, both axes must be offset one half of full scale which is 5 volts and represents 256 at the input of the DAC's with a maximum equation result of 5 volts or 256.

Using Equation 1:

$$\Delta X = 5 \text{ volts} = 256 = [2R \tan 45^\circ] [\cos 0^\circ] , \text{ or}$$

$$256 = 2R [1] [1] .$$

The constant, 2R, must equal 256 for correct results. With the desired offset, the resulting equation for X is:

$$X = 256 + 256 \left[\tan \left(\frac{90 - \alpha}{2} \right) \right] \left[\cos (90 - \beta) \right] .$$

Using Equation 2:

$$\Delta Y = 5 \text{ volts} = 256 = [2R \tan 45^\circ] [\sin 90^\circ] , \text{ or}$$

$$256 = 2R [1] [1] .$$

The constant, 2R, must equal 256 for correct results. With the desired offset, the resulting equation for Y is:

$$Y = 256 + 256 \left[\tan \left(\frac{90 - \alpha}{2} \right) \right] \left[\sin (90 - \beta) \right] .$$

APPENDIX B

INTERFACE SCHEMATICS

Figure B-1. AUTOMATED TEXTURE CONIOMETER. (Block Diagram)

Figure-B-2. AUTOMATED TEXTURE GONIOMETER. (Interface Electronics, Sheet 1)

Figure B-4. AUTOMATED TEXTURE GONIOMETER. (Interface Electronics, Sheet 3)

Figure B-5. AUTOMATED TEXTURE GONIOMETER. (Power Supply-Card and Connector Layout)

APPENDIX C

DERIVATION OF THE EQUATION FOR EQUAL SPHERICAL AREAS

Figure C-1. DERIVATION OF FORMULA FOR TAKING DATA OVER EQUAL SPHERICAL AREAS.

Equation 1:

$$b = r\Delta\beta \text{ (Figure C-1)}$$

$$a = R\Delta a$$

$$r = R \sin (90 - a)$$

$$r = R \cos a$$

Equation 2:

$$b = R\Delta\beta \cos a$$

$$a = b = \frac{2\pi R^2}{N} \text{ and is constant (N represents the number of required data points)}$$

$$(R\Delta a)(R\Delta\beta \cos a) = \frac{2\pi R^2}{N}$$

Equation 3:

$$\Delta a \Delta\beta \cos a = \frac{2\pi}{N}$$

For simplification purposes, assume $a = b$.

Equation 4:

$$R\Delta a = R\Delta\beta \cos a$$

$$\Delta a = \Delta\beta \cos a$$

Substituting Equation 4 into Equation 3:

$$(\Delta\beta \cos a)(\Delta\beta \cos a) = \frac{2\pi}{N}$$

$$(\Delta\beta \cos a)^2 = \frac{2\pi}{N}$$

$$\Delta\beta \cos a = \sqrt{\frac{2\pi}{N}}$$

Equation 5:

$$\Delta\beta = \frac{\sqrt{\frac{2\pi}{N}}}{\cos a}$$

Equation 5 is used by keeping Δa constant and calculating $\Delta\beta$ as a varies.

APPENDIX D

COMPENSATION OF DATA FOR TIME ERRORS

X-ray data are accumulated by using a delay subroutine on a preset timer. The subroutine counts computer cycles to acquire a specific time delay. Each reflected particle is counted by means of a memory increment data break during the time delay. The data break operates by stealing three computer cycles each time a particle is encountered, presenting a 4.5 microsecond error for each count.

The following technique is used to correct for this timing error:

$$\text{Preset Time} = T$$

$$\text{Time Error} = \Delta t = \text{Data} \times 4.5 \text{ Microseconds } (4.5 \times 10^{-6} \text{ seconds})$$

$$\text{Actual Time} = T + \Delta t = \text{Preset Time} + \text{Time Error}$$

$$\text{Count Rate} = CR = \frac{\text{Data}}{T + \Delta t}$$

$$\text{Additional Counts Due to Time Error} = AC = CR \times \Delta t.$$

$$AC = \left(\frac{\text{Data}}{T + \Delta t} \right) (\text{Data} \times 4.5 \times 10^{-6})$$

$$\text{Corrected Data} = CD = \text{Data} - [(CR)(\Delta t)]$$

$$\text{Corrected Data} = CD = \text{Data} - \left[\left(\frac{\text{Data}}{T + \text{Data} \times 4.5 \times 10^{-6}} \right) \times (\text{Data}) (4.5 \times 10^{-6}) \right]$$

APPENDIX E

INTENSITY CORRECTION EQUATION

$$I = \frac{I_0 DWS_2}{2} \left[1 - e^{-\frac{2\mu T}{\sin \theta} \cos \alpha} \right] \quad \text{(from Schulz), (b)} \quad (1)$$

where:

- I_0 represents the observed intensity (above background),
- D the scattering efficiency of the material at a given angle θ ,
- W the horizontal width of the incident X-ray beam,
- S_2 the vertical width of the incident X-ray beam,
- T the thickness of the plate specimen,
- μ the absorption coefficient,
- 2θ the Bragg angle,
- α the angle that the plane of the X-ray input and diffracted beam makes with the normal to the sample, and
- I the corrected intensity.

(b) Schulz, L. G.; "A Direct Method of Determining Preferred Orientation of a Flat Reflection Sample Using a Geiger Counter X-Ray Spectrometer", *J Appl Physics*, 20, pp 1030 - 1083 (1949).

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