

Hewlett-Packard

Laser Metrology Package

OPERATING NOTE and Program LISTINGS

*HP 5526A

*HP 9825A

*HP 9872A

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Introduction

The 9825A Laser Metrology Package provides data acquisition, reduction, and graphic display of several common error measurements performed by the HP 5526A Laser Measurement System. The programs were adapted to the 9825A Desktop Computer because of its flexibility and programming ease. These programs can be modified or new ones created by the user to solve unique problems.

Hardware Description

The following hardware is needed to run the 9825A Metrology Program:

9825A	Programmable Calculator
98216A	9872A Plotter/General I/O, Extended I/O ROM
98210A	String Advanced Programming ROM
98034A	HP-IB Cable
9872A	Plotter
K76-59995A	98033A BCD Input Interface Cable

Before connecting the entire system together, turn off all instruments and connect the system as shown in Figure 1.

Always cut off power before installing or removing the interface cables.

Basic software description and operation

The 9825A Metrology Program Package has eight metrology programs and 28 data storage files. The available programs are described in later sections. Data storage files 1 thru 19 are available for storing user-generated data. Any data storage file may be reused by storing the new data over the old, previously stored data. However, the old data will be lost in this operation.

It is suggested that the user duplicate the 9825A Metrology Program following the procedure in V. and keep the master copy in a safe place as a backup for the future. Eventually, after heavy usage, the cartridge will wear out to the extent that the calculator will not be able to read a file. At this point, take out the master tape and a new tape can be copied.

To read a number from the Laser Display over the interface, the following sequence has to be performed:

red 3, X, Y

$X + \text{sgn}(X) (Y \cdot 10^8) \rightarrow X$

X will be the 9 digits on the display. X must then be multiplied by a power of ten dependent upon the display switch settings.

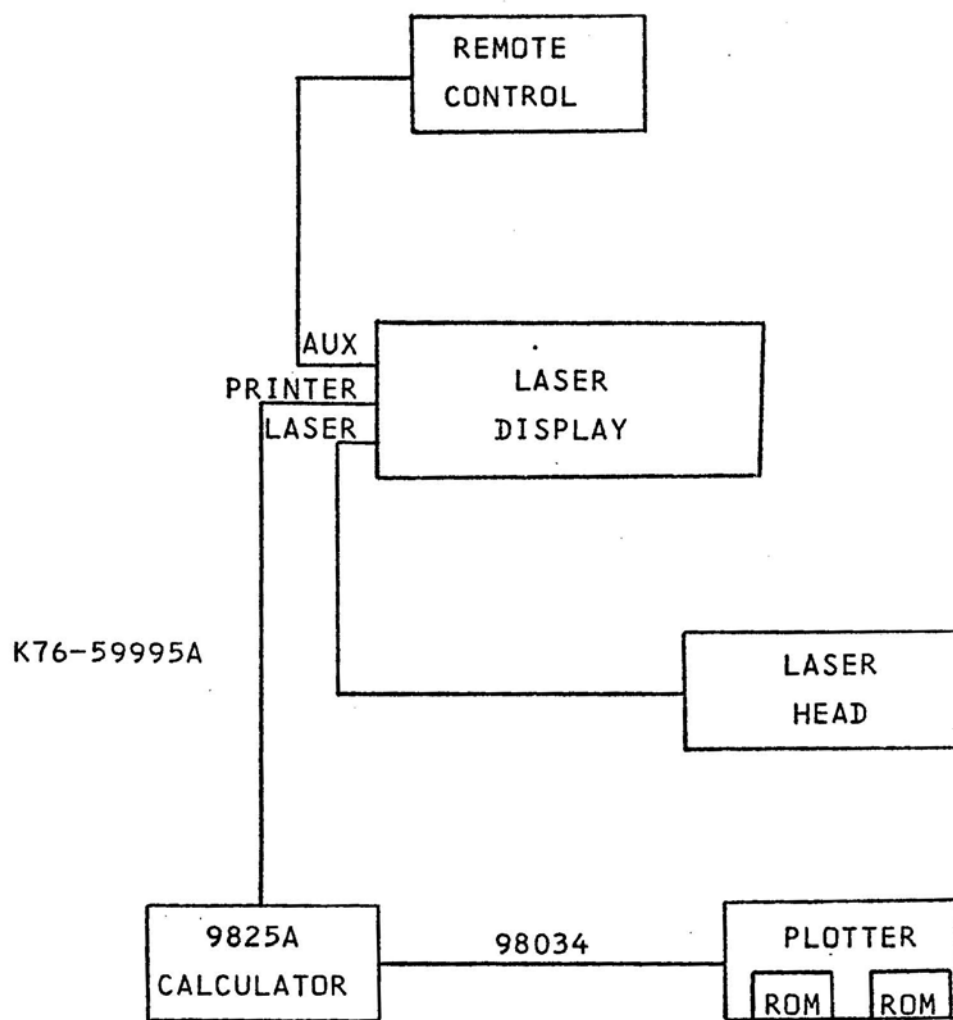


Figure 1 System configuration

For a linear measurement, this correction factor is:

Display Mode	Units		
	English	Metric	$\lambda/4$
x10	10^{-6}	10^{-5}	.1
NORMAL	10^{-5}	10^{-4}	1

A thorough familiarity with the 9825A is required before any program modifications should be attempted.

Individual Software Programs

Initialization Program (Program 0)

The first program located on the 9825A Metrology Program Cartridge is the Initialization Program. This program is read into the 9825A Calculator when the calculator is turned on. The purpose of the initialization program is to set up specific measurement and data presentation conditions inside the 9825A Calculator before a metrology program is run.

The soft keys, f1 through f8, located on the 9825A Calculator keyboard define the specific metrology program being used.

f1 Used to select the Surface Plate calibration program.

f2 Used to select the Surface Plate Isoplot program.

f3 Used to select the Surface Plate Numeric plot program.

f4 Used to select the LARGE ANGLE CORRECTION program.

f5 Used to select the Velocity of light compensation calculation program.

f6 Used to select the STANDARD ERROR MEASUREMENT and PLOT program.

f7 Used to select the Straightness, Squareness and Parallelism program.

f8 Used to select the STATISTICAL PACKAGE program to perform statistical error analysis.

Surface Plate Calibration (Program 1)

(Used with Angular Optics)

Introduction

This program accepts data from the 5526A Angular Optics and computes the flatness contours of a surface plate. Once the calculations have been-made, the results can be listed on the calculator printer and/or stored on the data cartridge for future use by Programs II and III. These programs provide graphics display of results stored on the tape. Data can be entered directly from the Laser Display or via the calculator keyboard in either English or Metric units. The inspection lines can be entered in any order and any line can be edited or replaced during the calibration.

Application Note 156-2 describes the complete surface plate calibration procedure and should be referred to before making the measurement.

CAUTION: Care should be taken when inputting the data for the inspection lines or when editing a previously input line of data. When editing, the new number of points must equal the number of points in the original data line. Otherwise, lines of data may overlap and yield erroneous results.

Operation

1. English (0) or Metric (1) units?

Answer this question according to the switch setting on the Laser Display or in whatever units the data is to be entered. For example, if data is English units (inches), respond with "0". (Default = English).

2. CREATE (0) or EDIT File #) data?

If a new surface plate is to be measured in entirety, answer "0". If a previously stored data file is to be modified or edited, respond with the file # that is to be modified. (Default = CREATE).

3. Data via 5526 (0) or Keyboard (1)?

Indicate how data is to be sent to calculator. If transfer is over the interface direct from the Laser Display, answer "0". If data is hand entered into the calculator keyboard, answer (1). (Default = 5526).

4. Foot Spacing?

Distance between measurement points if different from the standard spacing provided by the angular optics bracket (2.0625 inches). (Default = 2.0625 inches).

NOTE: At this point, we are ready to input the data. Step 5 will occur before each new inspection line is begun. Step 6 or Step 7 will occur for each point that is input on the current inspection line. Step 8 will be reached after all lines have been entered.

5. (+/-) line # ? (+: Away) (-: Toward)

As explained in Application Note 156-2, the line # identifies the inspection line which is to be measured or edited next. The positive or negative sign indicates the reference direction of the angular mount with respect to the interferometer. All lines should be measured with the same reference direction. A line can be re-measured simply by re-entering its line # when this question is asked. Press CONTINUE with no line entry when all lines are completed. This exits this section. (Default = end of data acquisition).

6. Break Beam and Push PRINT to End.

This message is displayed when data entry directly from the Laser was selected. When a line has been completed, break the alignment by passing hand through beam (flashing RESET indicator on display) and press the "PRINT" switch an additional time on the display. This will return to Step #5 (new line #). If the beam is broken accidentally during a line, press the "PRINT" switch and re-enter the same line # in response to Step 5.

7. Data?

This question is asked for each data point to be entered on the calculator keyboard during hand entry. Press CONTINUE after each data point is entered. Return to Step #7. When a line is complete, press CONTINUE with no data entered. Return to Step #5. (Default = end of line).

NOTE: For either Laser or Keyboard data entry, the first point of each inspection line is always 0. The calculator assumes this. Do not enter the first zero measurement point of each line. Increment the angular optics and begin data entry with the second position.

8. Data Printout? NO (0) or YES (1)

This question occurs after all calculations are complete. If a listing of the calculated points is desired, then answer "1". If not, answer "0". (Default = No).

9. Month? (1-12)

Enter the month in numerics, 1 through 12.

Day? (1-31)

Enter the date in numerics, 1 through 31.

Year? (0-99)

Enter the year in numerics, 0 through 99.

10. Surface Plate ID #?

Enter a numeric identifier for the plate measured. (This will be printed on all plots).

11. Data to be stored on File #?

Enter the file # to store the results. Data must be stored before programs II and III can be used to display results.

Example

- A. Insert **9825A** Metrology Program cartridge into **9825A** calculator.
- B. Power on calculator.
- C. When <<<SELECT Program KEY>>> is displayed, press f1.
- D. Want:
 - 1. English units
 - 2. Create data
 - 3. Data via keyboard
 - 4. Foot spacing = 2.0625 inches
 - 5. + line numbers
 - 6. Data - input data from Application Note 156-2, p. B-3 and B-4, column 1. Always start with data from station 2 of each line.
 - 7. Answer YES to Data Printout
 - 8. Month, date and year 0,0,0
 - 9. Surface Plate ID #? 999
 - 10. Data to be stored on file 4

The data is now stored in file 4 and ready to be used in **Program II**, Isometric Plot or **Program III**, Numeric Plot.

Isometric Data Plot (Program 2)

(For Surface Plate Calibration Data)

Introduction

This program takes data generated and saved in a data file by Program I and plots it isometrically on the **HP 9872A** Four Color Graphics Plotter.

It features variable tilt and rotation of axes which allow different perspective views of the surface plate profile. This type of data presentation is very useful for determining areas needing rework, or those particularly flat areas which should be used for critical work.

NOTE: Turn on **9872A** Plotter before answering the following questions.

Operation

1. **Which data file?**
Specify the file in which the data to be plotted was stored by Program I.
2. **Tilt Angle?**
Specify (in degrees) the angle the surface plate should be tilted towards you. (Default is 350).
3. **Rotation Angle?**
Specify the angle (in degrees) the surface plate image should be twisted left or right. (Default is 100).

The default values for both of these yields a comfortable viewing angle. Simply press **CONTINUE** with no entries to activate default values.

Example

Recall data saved in file #4. Use a tilt angle of 35° and a rotation angle of 10°.

Resulting Isometric Plot is shown on Figure 2.1.

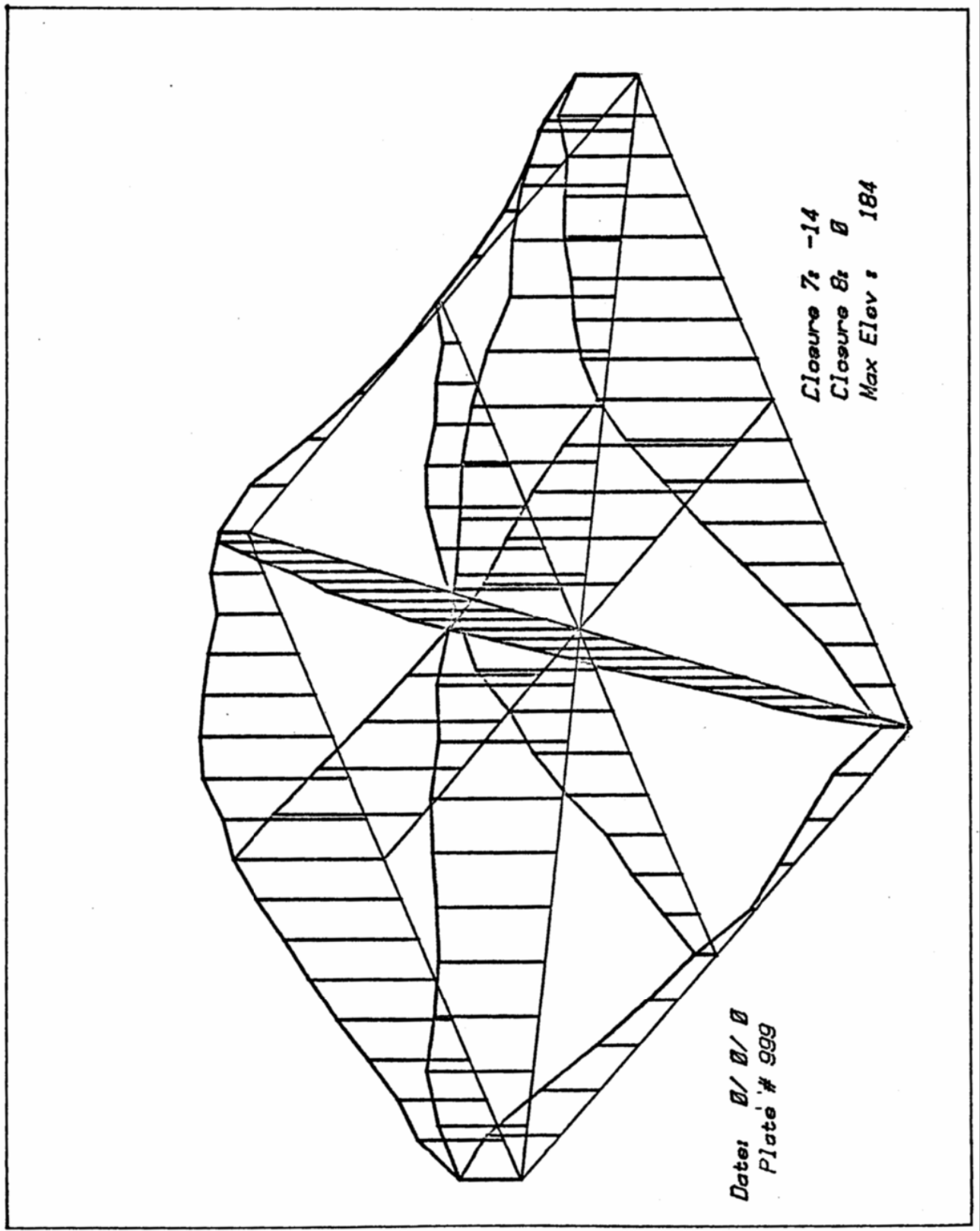


Figure 2.1 Isometric Plot

Numeric Data Plot (Program 3)

(For Surface Plate Calibration Data)

Introduction

This program takes the data generated and saved on the data cartridge by Program I and plots it in numeric form on the HP 9872A Graphics Plotter. This is the presentation format commonly used for surface plate certification certificates.

Operation

1. Which data file #?

Specify the tape file in which the data has been stored in Program I.

2. Positive (0) or Relative (1) data?

Positive will calculate a reference plane such that all deviations will be positive. Relative calculates the best flat surface including the most measured points. All deviations are shown as relative (positive or negative) to this plane.

3. Grid Lines: None (0) Line (1) Dash (2)

If the measurement grid lines are desired, they can be solid lines or dashed.

The following examples show the same data presented isometrically before with dashed grid lines. The first plot is printed in absolute form while the second is in relative form.

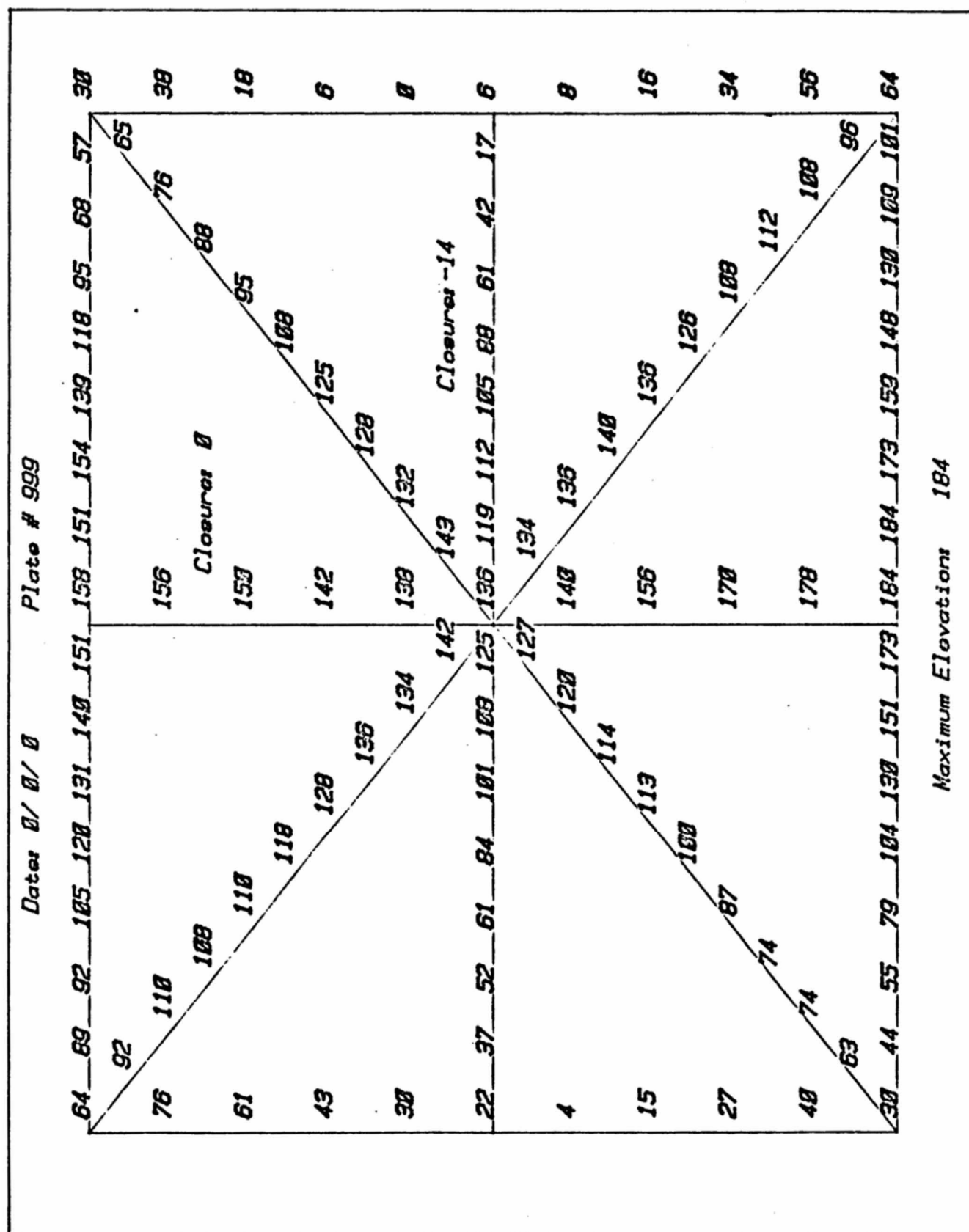


Figure 3.1 Numeric data in absolute form

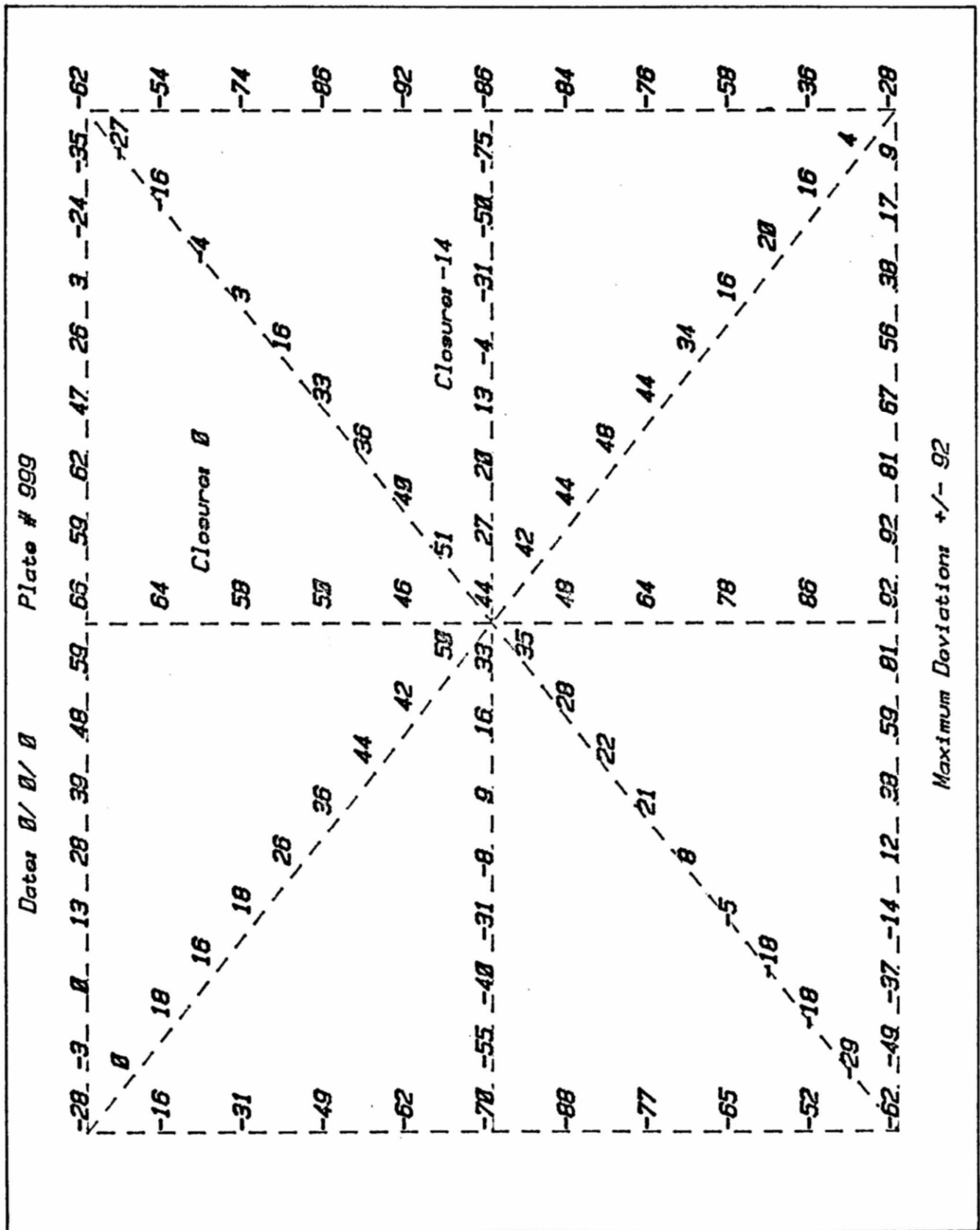


Figure 3.2 Numeric data in relative form

Large angle correction (Program 4)

(For use with Angular Optics)

Introduction

This program is used to supplement the Angular/Flatness optics to extend their measurement capabilities beyond 3000 arc-seconds.

When angles measured are less than 3000 arc-seconds in magnitude, the value read from the Laser Display is linear and correct. But, for angles larger than 3000 arc-seconds, the reading must be corrected by the following formula:

$$\theta = \arcsin \frac{(\text{Laser Reading}) (\text{Mode Correction})}{2.0625 \text{ inches}}$$

θ is the corrected angle. The mode correction is derived from the Laser setup state (X10 Normal Mode). Program IV can take data directly from the display or via keyboard entry. The data is corrected by the above formula and printed in milliradians, arc-seconds, or degrees as specified by the user.

NOTE: Input θ is always in arcsecs.

Example

LARGE ANGLE ERROR CORRECTION

Arcsecs 0.0
Correct 0.0
 arcseconds

Arcsecs 3600.0
Correct 3600.4
 arcseconds

Arcsecs -3600.0
Correct -3600.4
 arcseconds

LARGE ANGLE ERROR CORRECTION

Arcsecs 3600.0
Correct 1.00012
 degrees

LARGE ANGLE ERROR CORRECTION

Arcsecs 3600.0 ← Keyboard
Correct 3600.4 Entry
 arcseconds

Arcsecs -3600.0
Correct -3600.4
 arcseconds

Corrected
Large Angle

LARGE ANGLE ERROR CORRECTION

Arcsecs 3600.0
Correct 1.00012
 degrees

LARGE ANGLE ERROR CORRECTION

Arcsecs 3600.0
Correct 17.4554
 milliradians

Arcsecs -3600.0
Correct -17.4554
 milliradians

Velocity of Light Compensation (Program 5)

Introduction

This program calculates the compensation factor to be dialed into the thumbwheel switches on the Laser Display. The factor takes into account the effects of ambient temperature, barometric pressure, humidity, and material temperature(s). The data can be entered in either English or Metric units.

Operation

1. English (0) or Metric (1) units?

Specify the units in which the remaining questions will be answered.

2. Air Temperature?

Specify in degrees (C or F).

3. Air Pressure?

Specify in inches or mm of mercury.

4. Humidity (%)?

Specify percent relative humidity.

5. Material Expansion Coefficient (PPM/F)?

Specify the expansion coefficient of the material comprising the machine or part. (In parts per million per degree C or F). If not to be used, push CONTINUE with no entry. If to be used, enter temperature of part. (Up to three temperatures can be averaged).

The thumbwheel setting will then be displayed.

Example

V.O.L. COMPENSATION

English Units

Air:
Temperature 72.0
Pressure 30.0
Humidity(%) 20.0

Material:
Exp Coeff 6.5
Temp #1 71.6
Temp #2 71.8
TEMP #3 71.9

THUMBWHEEL 705.5

English units selected

User input

Calculator output

Metric Units

Air:
Temperature 20.0
Pressure 760.0
Humidity(%) 50.0

Material:
Exp Coeff 5.0
Temp #1 18.0
Temp #2 19.0
TEMP #3 17.0

THUMBWHEEL 738.8

Metric units selected

User input

Calculator output

Standard Error Plotting (Program 6)

(Used with 5526A Linear Optics)

Introduction

This program prints and/or plots linear positioning error versus position. The data can be entered directly from the Laser Display or from the calculator keyboard.

The input format for this program is freeform. The machine tool command position does not need to be known. This is possible due to an assumption of maximum possible error by the calculator. The display can then be read and both the intended position and the actual error derived. The only restriction on the operator commands is that all commands be a multiple of twice the maximum allowed error.

	Max. Error Assumed		Least Significant Digit of Command	
	English	Metric	English	Metric
NORMAL	$\pm .005$ in.	$\pm .05$ mm	.01 in.	.1 mm
X10	$\pm .0005$ in.	$\pm .005$ mm	.001 in.	.01 mm

The last column indicates the minimum resolution of the command to position the machine. This is the least significant digit allowed to be specified.

Operation

1. English (0) or Metric (1) units?

If data will be in inches answer (0) or if data will be in mm, answer (1). Response should correspond to switch setting on Laser Display. (Default = English).

2. Maximum machine travel?

Respond with the maximum command position that will be used during the test. The plot axis will be drawn from zero to this number.

3. Error Plot? (Yes = (1), No = (0))

If a plot of the error is desired, answer "1". If not "0". (Default = yes).

4. Printout? (Yes = (1), No = (0))

If a printout of the intended destinations and errors is desired, answer "1". If not, answer "0". (Default = yes).

5. Data via Laser (0) or Keyboard (1)?

Specify the method of data entry into the calculator. If data is to be sent over the interface directly from the display unit, answer "0". If entered by hand on the calculator, answer "1". (Default = Laser).

6. NORMAL (1) or x10 (10) mode?

This specifies the switch setting on the Laser Display and picks the command position resolution and maximum error. (Refer to previous table.) If the Laser is NORMAL mode, answer "1". If it is x10 mode, answer "10". Default = NORMAL mode).

7. Data?

- a. Actual position should be input onto the keyboard of calculator. This will repeat until CONTINUE is pressed with no data entry. The program is exited.
- b. Data via Laser... Push Print
Data is ready to be read from Laser display. Each time PRINT is pushed, the display position is sent to the calculator. This step repeats until the beam is broken. If PRINT is pressed after alignment is lost, the program exits.

Example

For a machine travel of 10 inches in .5 inch Increments, the position error is printed below with the standard error plot shown on the next page.

Standard Error Plotting

Command 0.000000	User input → 0.500051, calculator outputs error	Command 6.000000
Error 0.000000		Error 0.000830
Command 0.500000		Command 6.500000
Error 0.000051 ←		Error 0.000990
Command 1.000000		Command 7.000000
Error 0.000620		Error 0.001000
Command 1.500000		Command 7.500000
Error 0.000480		Error 0.000960
Command 2.000000		Command 8.000000
Error 0.000450		Error 0.000710
Command 2.500000		Command 8.500000
Error 0.000560		Error 0.000640
Command 3.000000		Command 9.000000
Error 0.000660		Error 0.000470
Command 3.500000		Command 9.500000
Error 0.000540		Error 0.000330
Command 4.000000		Command
Error 0.000470		10.000000
Command 4.500000		Error 0.000560
Error 0.000590		
Command 5.000000		
Error 0.000670		
Command 5.500000		
Error 0.000750		

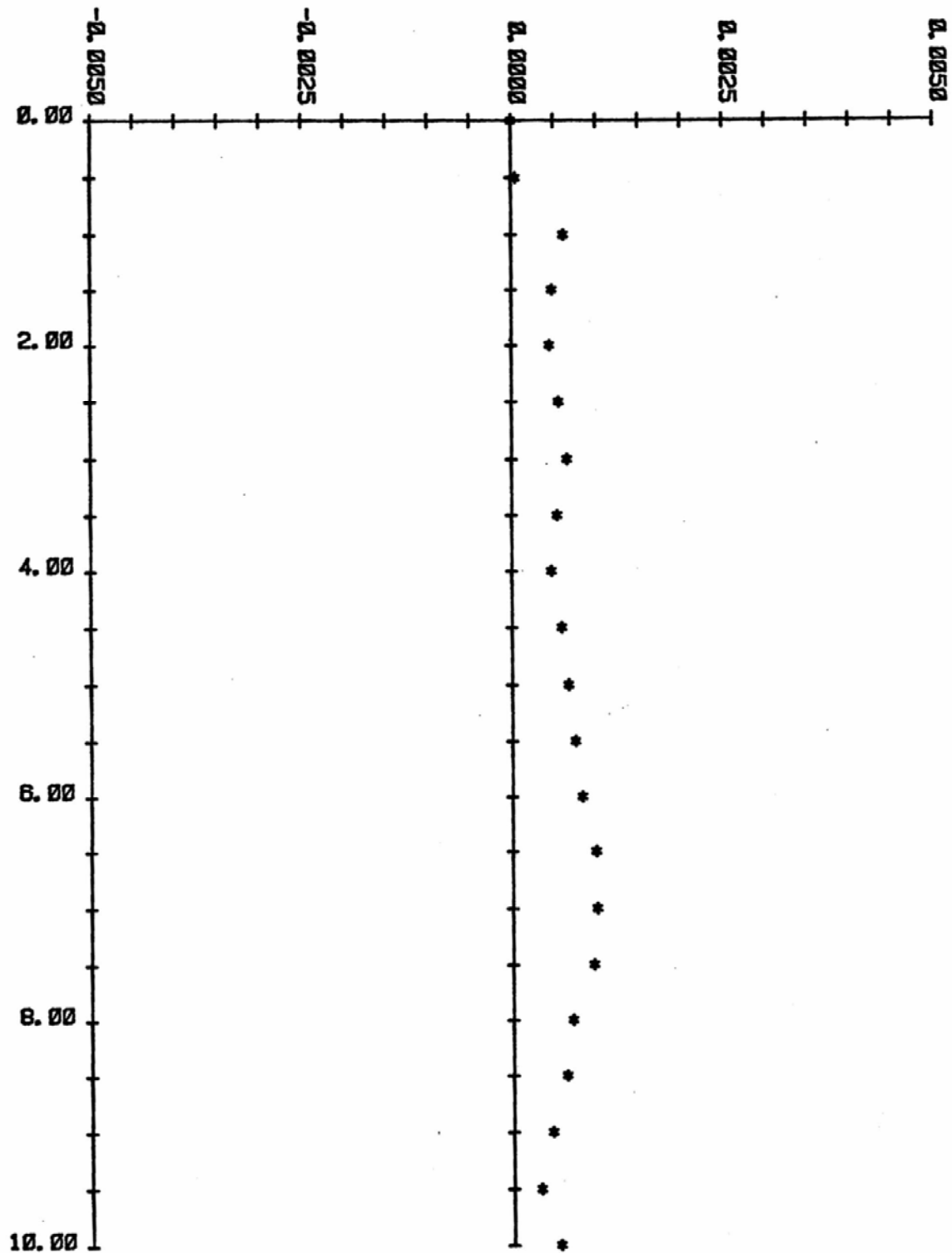


Figure 6.1 Standard Error Plot

Straightness, Squareness, and Parallelism (Program 7)

(Used with Straightness Optics)

This program accepts straightness deviations from the 5526A Straightness Optics and offers a choice of line fitting: either least-squares fit or a straight line through the end points. The data are then presented as deviations from this selected straight line. The data can be printed and/or plotted.

Multiple runs of data may be taken on any axis with the average of all runs being used to determine the straightness error. This feature is particularly useful for averaging out non-repeatable fluctuations.

If a measurement of out-of-parallelism between a spindle axis and a collinear axis of motion is to be made, input the first line of data with the Straightness Reflector and spindle rotated through 180 degrees. The Calculator will ask whether the second line of data is for a parallelism or squareness measurement. For parallelism it will look at the difference in slopes of the two lines and will print and/or plot one half the angle between the two input lines as a parallelism error. (See Figure 7.1)

Because of the sign convention used with the program, the parallelism measurement should be made with both runs starting from the same point. For the second run, after the reflector and spindle have been rotated 180°, change the direction sense of the data *by* either rotating the straightness interferometer 180° or by changing the direction sense switch on the 5505A Laser/Display.

It is possible to configure the straightness/squareness equipment several different ways and still obtain a squareness error of the correct sign and magnitude. Figure 7.2 provides a sign convention guide which covers all the possible straightness/squareness setups. By following this guide the squareness value will be correct in both sign and magnitude.

Equation for straight line

$$Y = mX + b$$

where m = slope and b = intercept of the line.

Straight line through end points of N data points

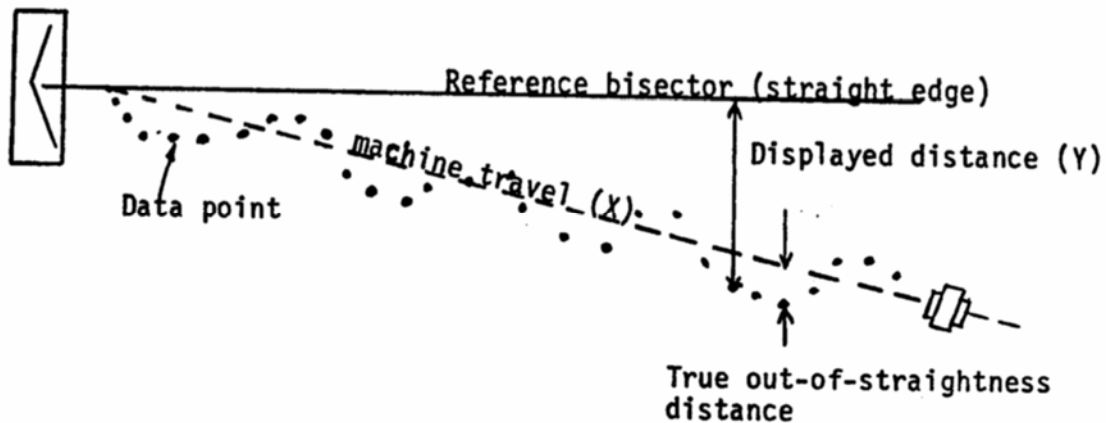
$$m = \frac{Y_N - Y_1}{X_N - X_1}$$

$$b = Y_1$$

Least-squares best fit line to N data points

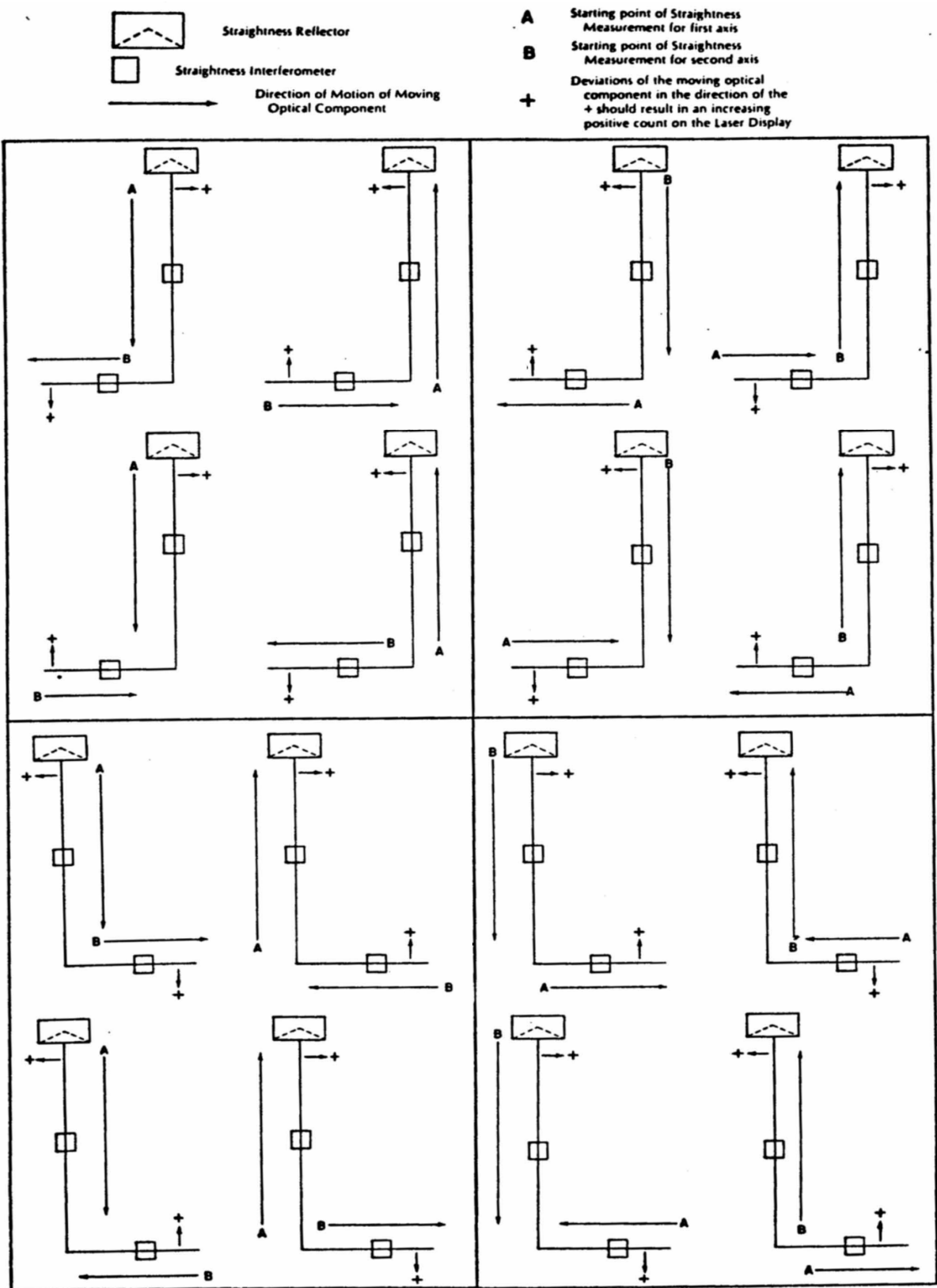
$$m = \frac{\sum Y * \sum X - N * \sum XY}{(\sum X)^2 - N * \sum X^2}$$

$$b = \frac{\sum X * \sum XY - \sum Y \sum X^2}{(\sum X)^2 - N * \sum X^2}$$

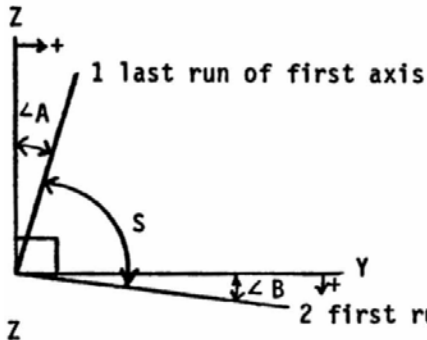


$$m = \text{data slope} = \frac{Y}{X}$$

Squareness sign convention guide



Squareness

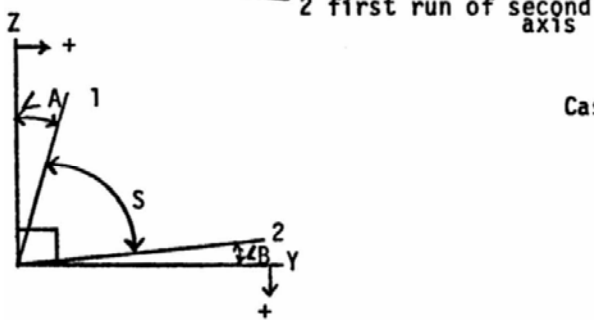


Case One:

Data taken away from
Optical square in both axis
Data positive in both axis
 $\angle A$ = Slope of data in Axis 1
 $\angle B$ = Slope of data in Axis 2

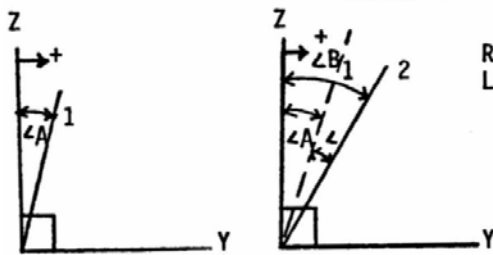
Squareness:

$$S = \angle B - \angle A + \text{Prism Error}$$



Case Two:

Data negative in second Axis

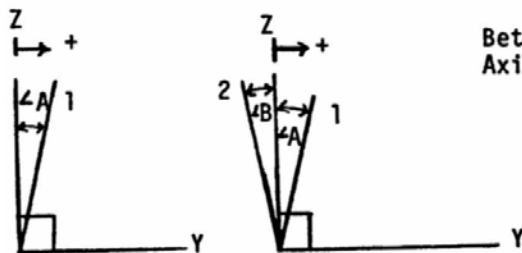


PARALLELISM

Rotational Axis to
Linear Axis

Data taken from same point
Data positive in both runs

$$\angle/2 = (\angle B - \angle A)/2$$



PARALLELISM

Between two Linear
Axis

Data taken from same point
Data negative in second axis
Parallelism = squareness = $\angle = S$
 $\angle = \angle A - \angle B$

Operation

1. Straightness Calibration Number?

Enter the calibration number engraved on the straightness reflector. If Long Range Straightness is being used, divide this number by 10. (Default = 1).

2. Axis Number?

Enter a numeric value referencing the axis on which straightness is to be measured.

3. Number of points on axis?

Enter the number of measurement points to be made on this axis.

4. Distance between points?

Enter the increment of travel between the measurement points in either inches or mm.

5. Plot? (Yes = 1, No = 0)

If a plot is desired enter a "1". If not, enter "0". (Default = yes).

6. Data via Laser (0) or Keyboard (1)?

If data is to be transmitted over the interface direct from the Laser Display, answer "0". If data is to be entered by hand, answer "1". (Default = Laser).

7. Data?

If automatic data transfer was selected, go to Step 9.

8. Enter the data point as an integer value as it appears on the 5505A Laser/Display with sign but without the decimal point. (i.e., in X10, Inch units two hundred and one micro inches should be entered as 201.)
9. For automatic data input, move the equipment to the desired position. When the data are ready to be transmitted between the 5505A Laser/ Display and the calculator, press the manual print switch on the 5505A Laser/Display, or actuate this function through the AUX connector on the 5505A. The data will be transmitted.

10. More Data? (Yes = 1, No = 0)

If another set of data points is to be averaged with previous sets, answer "1". Go to Step 11. If not, answer "0". Go to Step 12. (Default = yes).

11. Direction? +1 = Same, -1 = Oppos

This refers to the direction in which the data is taken. The program assigns a positive sense to the direction in which the first set of data is taken on a given axis. The correct entry is +1 if the additional data is to be taken in the same direction as the first set of data was taken, and -1 if the additional data is to be taken in the opposite direction as the first set of data was taken. When the correct response has been entered, press the CONTINUE key. Return to Step 7.

12. Type of Line Fit? (0 or 1)

Press 0 if data is to be fitted by least-squares, best-fit line. Press 1 to fit a straight line through the end points of the data.

13. If a printout was selected, the calculator will print out the average of the current set of runs or maximum and minimum deviations.

14. Max Error? (for plot scaling)

If a plot was selected, the average of the current set of runs will be plotted. If a scaling maximum is desired other than the max and min values already printed, enter that maximum value. This will become the top of the vertical axis on the plot. (Default = MAX dev).

15. Parallelism? (Yes = 1, No = 0)

If the next axis to be measured will be a parallelism measurement relative to the first, answer "1". Go to Step #2. If not, answer "0". (Default = yes).

When the measurement axis has been completed for parallelism, the parallelism deviation in arc-seconds will be printed and plotted.

NOTE: Can only get to squareness if answer No for this question.

16. Squareness? (Yes = 1, No = 0)

For determination of out-of-squareness between the two axes, press 1 and CONTINUE key. Return to Step 2. Or, press "0" if not desired.

17. Pentaprism Error?

Enter the optical square calibration number shown on the optical square in arcsecond units and press CONTINUE key. Go to Step 17. If squareness is not desired, press "0" and CONTINUE key.

18. The INITIALIZATION Program will be reread into the calculator and run. Another program can now be selected.

Example

Given the following raw data, use Program VII to calculate 1) out-of-straightness using least-squares fit, 2) parallelism in axis 1, 3) squareness between axis 1 and 2.

Set-up

5505A Display in X10 mode

Straightness calibration no. = 1 Prism error = 2 arcseconds

Raw Data

Axis 1

Display reading = -3 9 15 25 29 36 42 51 59 72 (pinches)

Machine travel = 0 1 2 3 4 5 6 7 8 9 (inches)

Number of points = 10

Axis 2

Display reading = 5 -12 -25 -38 -40 -48 -59 -62 -74 -88 (pinches)

Machine travel = 0 .5 1 1.5 2 2.5 3 3.5 4 4.5

Number of points = 10

Figure 7.1 shows the out-of-straightness of axis 1 and Figure 7.2 shows the out of straightness of axis 2. Parallelism between axis 1 and axis 2 is displayed between the two figures.

Squareness between axis 1 and 2 is displayed between Figure 7.3 and 7.4.

Parallelism

STRAIGHTNESS,
SQUARENESS,
& PARALLELISM

ENTER
CALIBRATION
NUMBER OF
STRAIGHTNESS
INTERFEROMETER

AXIS 1

Input Data

-3.0
9.0
15.0
25.0
29.0
36.0
42.0
51.0
59.0
72.0

User input
raw data.

Line Fit:
0: Least Square
1: Zero End Pts

STRAIGHTNESS

0.0
3.7
1.3
3.0
-1.3
-2.7
-5.0
-4.3
-4.7
0.0

True out-of-
straightness
distance
calculated
using least-
squares-fit

MAX Dev= 3.7
MIN Dev= -5.0

Calculator
outputs
max & min.
deviations.

AXIS 2

Input Data

5.0
-12.0
-25.0
-38.0
-40.0
-48.0
-59.0
-62.0
-74.0
-88.0

User input
raw data

Line Fit:
0: Least Square
1: Zero End Pts

STRAIGHTNESS

0.0
-6.7
-9.3
-12.0
-3.7
-1.3
-2.0
5.3
3.7
0.0

True out-of-
straightness
distance calculated
using least-
squares fit.

MAX Dev= 5.3
MIN Dev= -12.0

Calculator output
max. & min.
deviations of axis
2.

PARALLELISM=-3.0
ARCSECONDS

Calculator output
parallelism between
axis 1 & axis 2.

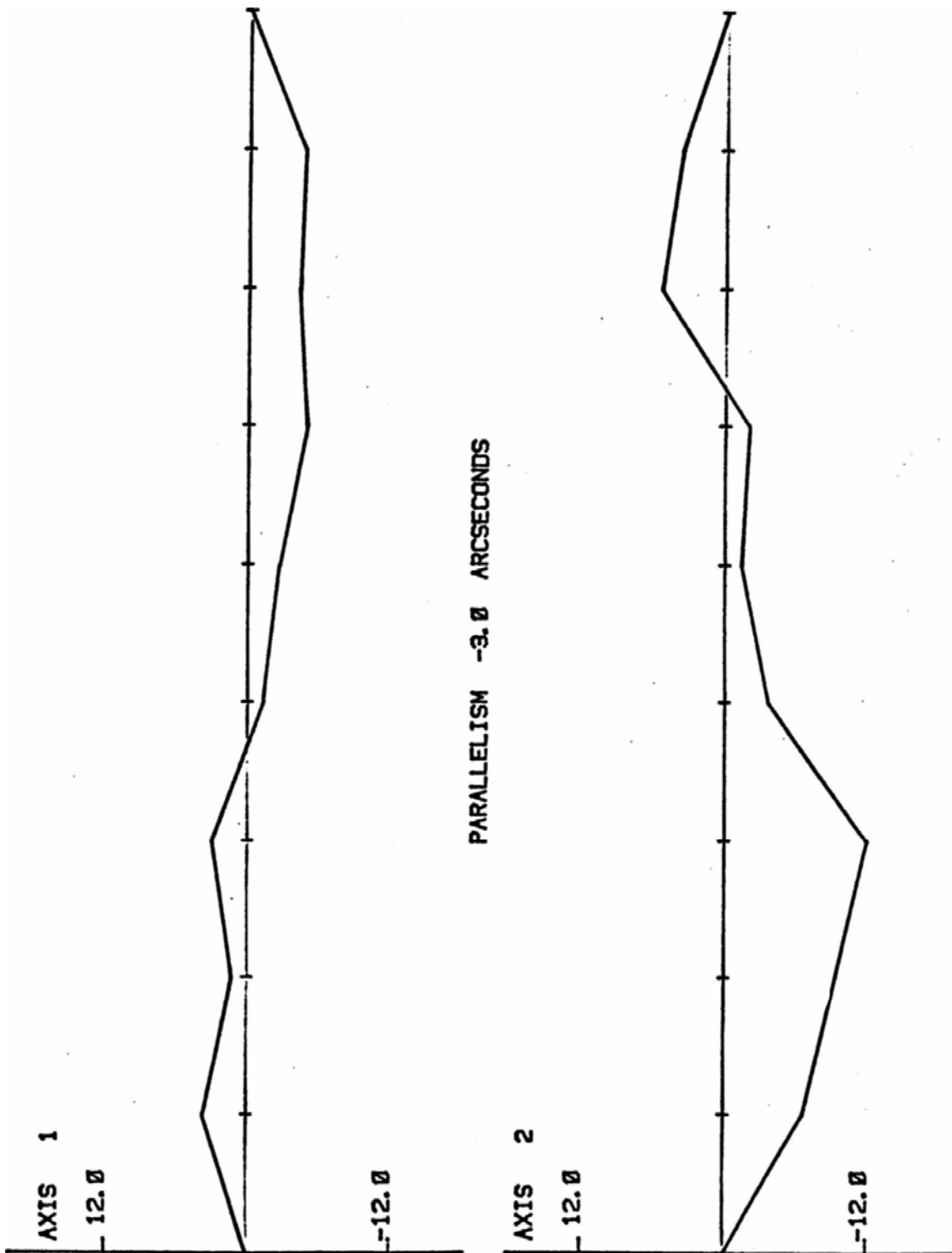


Figure 7.1 Out-of-straightness of axis 1

Figure 7.2 Out-of-straightness of axis 2

Squareness

STRAIGHTNESS,
SQUARENESS,
& PARALLELISM

ENTER
CALIBRATION
NUMBER OF
STRAIGHTNESS
INTERFEROMETER

AXIS 1

Input Data

-3.0	}	User input raw data
9.0		
15.0		
25.0		
29.0		
36.0		
42.0		
51.0		
59.0		
72.0		

Line Fit:
0: Least Square
1: Zero End Pts

STRAIGHTNESS

0.0	True out-of straightness distance calculated using least- squares-fit.
3.7	
1.3	
3.0	
-1.3	
-2.7	
-5.0	
-4.3	
-4.7	
0.0	

MAX Dev= 3.7
MIN Dev= -5.0

AXIS 2

Input Data

5.0	}	User input raw data.
-12.0		
-25.0		
-38.0		
-40.0		
-48.0		
-59.0		
-62.0		
-74.0		
-88.0		

Answer no to
parallelism.
Yes to Squareness.

Line Fit:
0: Least Square
1: Zero End Pts

STRAIGHTNESS

0.0
-6.7
-9.3
-12.0
-3.7
-1.3
-2.0
5.3
3.7
0.0

MAX Dev= 5.3
MIN Dev= -12.0

Input pentaprism
error in arcsecond

SQUARENESS= -4.0
ARCSCDS

Calculator outputs
0, squareness
between axis 1 and
axis 2.

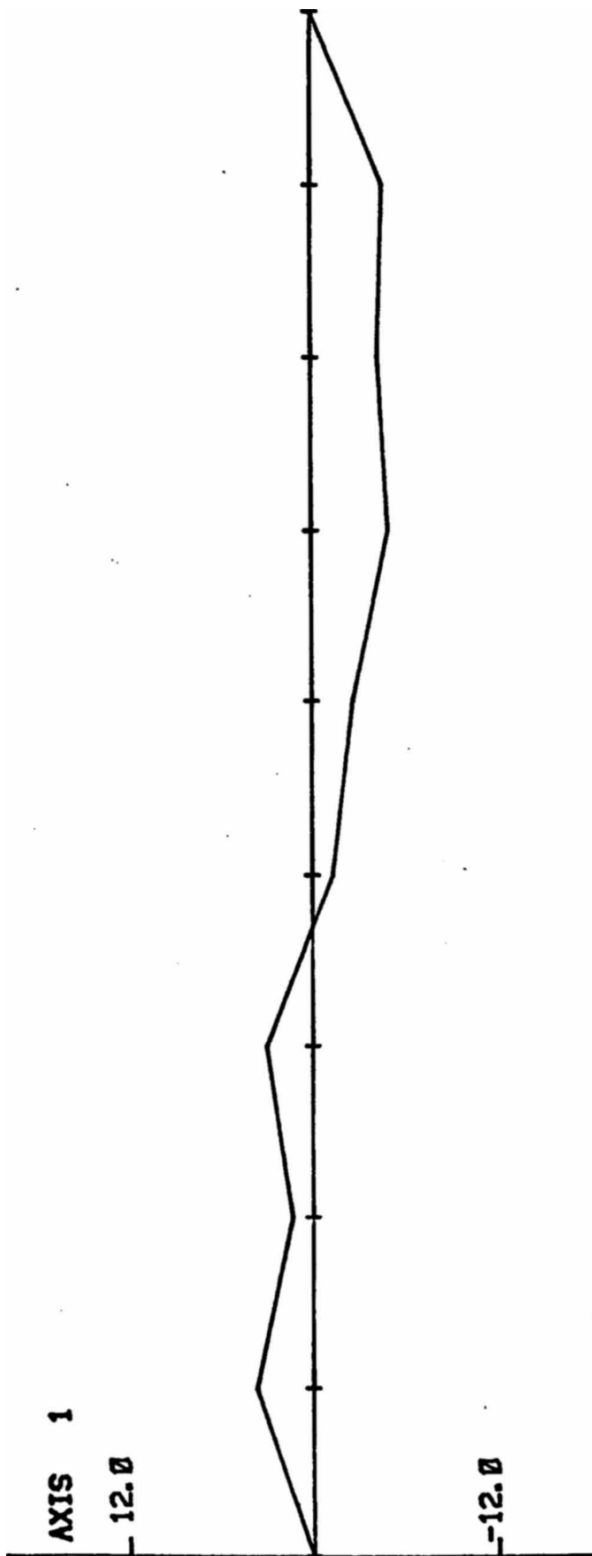


Figure 7.3 Out-of-straightness of axis 1

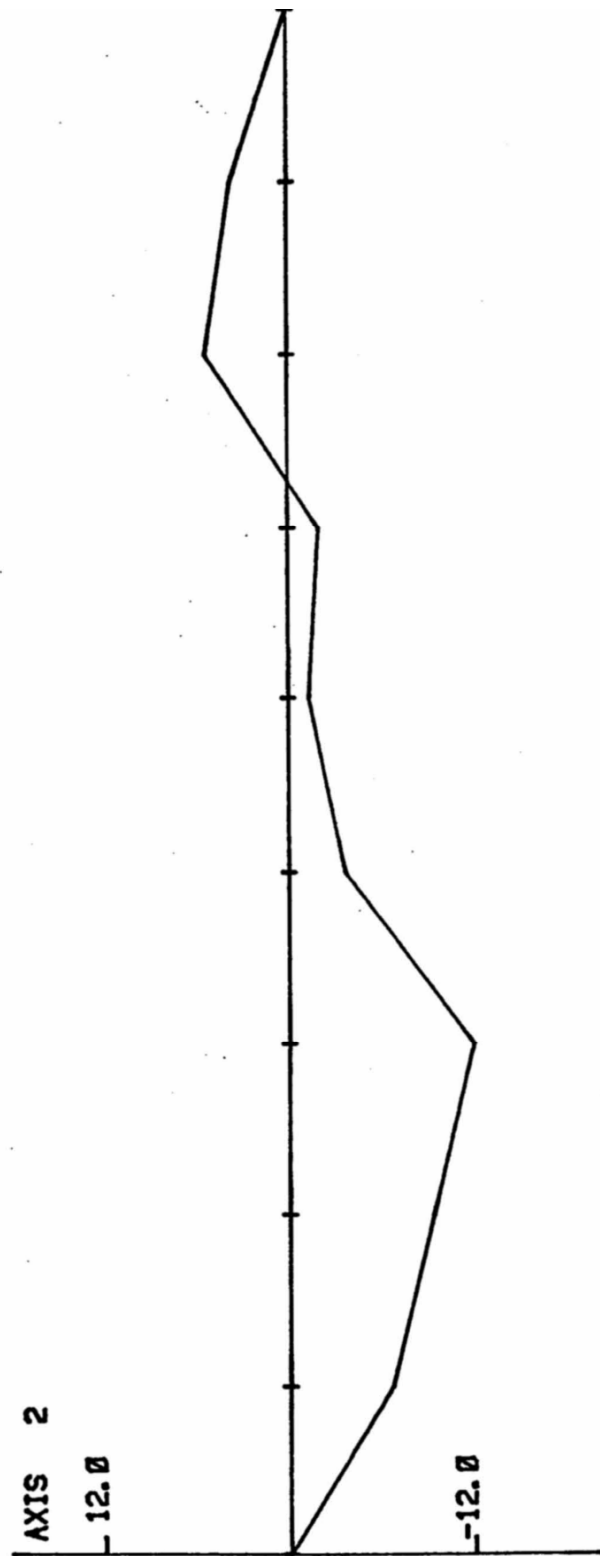


Figure 7.4 Out-of-straightness of axis 2

Statistical Package (Program 8)

(Linear Error with Linear Optics) (Angular Error with Angular Optics)

Introduction

This program provides graphic and numeric analysis of linear or angular error versus command position. The command positions are conveniently derived by specifying the total machine travel and an increment of travel.

Multiple unidirectional or bidirectional runs can be made to provide statistical analysis at each command position. The mean average and + 3 sigma limits are calculated and plotted along with the individual measurements.

The sorted printout lists the individual measurements, mean average, and standard deviation data for each position.

All data can be stored on the data cartridge for future reference if desired.

Software notes

The Statistical Error Package is segmented into 2 files: The measurement routine is in file #7 and the plot/list is in file #8. Interaction between these two programs is controlled internal to the software, invisible to the user.

As configured, the maximum number of allowed measurements is 7 runs of 51 points per run. The subscripted variable E contains the measured errors as well as the statistical information. If more memory (Option 001,002,003) has been added to the 9825A than the standard 6500 bytes, the subscript may be reallocated to increase the number of measurement points.

NOTE: During the setup for a measurement, any calculator questions are answered by typing the prompt associated with the preferred response and pressing CONTINUE. Simply pressing CONTINUE without an entry defaults to the first listed response.

Operation

1. Measurement (0) or Post Plot (1)?

To perform a new measurement, enter "0". To list and/or plot data previously stored on the cartridge, enter "1" and go to operating step #17.

Default = Measurement

2. Linear (0) or Angular (1)?

If linear error analysis is to be performed (Option 010 Optics), enter "0". If angular error analysis is to be performed (Option 020 Optics), enter "1". Default = Linear

3. Date:

Enter the date of the test in any form. (Alphanumeric's are allowed.)

Example: "April 3, 1979"

Default = blank

4. Machine ID Code:

Enter an alphanumeric identification code to represent the machine being tested. Example: "Lucas #123"

Default = Blank

5. Plot on the fly? (Yes = 1 and No = 0)

If error data is to be plotted while measurements made, answer yes ("1"). If not, answer no ("0").

Default = yes

6. Print on the fly? (Yes = 1 and No = 0) If printout of error is desired

while measurements are being made, answer yes ("1").

If not, answer no ("0"). Default = yes

7. Increment of travel?

Enter the increment of travel that will occur between each positioning command. No Default

8. Total machine travel?

Enter the distance the machine will be moved total for each run in inches or mm for linear and arcseconds for angular. (The number of measurements per run will be the starting point. Zero plus the total travel divided by the increment of travel.)
No Default

9. Maximum expected error?

What is the maximum positioning error (for linear) or maximum angular error in arc-seconds (for angular) that should be encountered. (This is used to set the scales of the plot, only.)
No Default

10. Number of runs?

Enter the number of times the machine is to traverse the total travel during the measurement. (Maximum of 7 runs as configured). If bi-directional has been selected, going from zero to the end and back to zero is considered 2 runs.
No Default

11. Uni (1) or Bi (2) directional?

This asks whether the runs to be made in one direction (1) or in alternate directions (2)?
Default = unidirectional

12. At this time, the plotter will draw grids and prepare for the measurement if plot on the fly has been selected.

13. Data via Laser (0) or Keyboard (1)?

If data is to be read from the 5505A Laser Display directly, enter a "0" and go to operation step #14. If data is to be entered by hand on the calculator keyboard, enter a "1" and go to operation step #16.

Default = Laser entry

14. English (0) or Metric (1)?

Question #14 and #15 refer to the setup of the Laser Display since this is the method of data entry chosen. If the display is in English units (inches), enter "0". If it is in Metric units (mm.), enter "1".

15. NORMAL (1) or X10 (10) mode?

Enter "1" if the display is in NORMAL or SMOOTH mode. Enter "10" if it is in X10 mode.

Default = NORMAL

16. Position X.XXXXXX Data?

Enter the actual position (or angular error) for the command position indicated by pressing the toggle switch on the Laser or by the keyboard (as selected earlier).

Repeat this step until all runs are completed. Then continue to step #17.

17. Store on which file #? (0 = NO)

If the data is to be stored for future use, enter a file # (1 or above) that the data can be stored on. (Data files are independent of program file numbers). No entry or a zero entry retains the data in memory only as no tape file copy will be made.

Go to step #19.

18. If Post Plot was selected in step #1, the calculator will request the file # of the data to be plotted.

19. **Sorted printout?** (Yes = 1 or No = 0)

If a sorted printout is desired, answer yes ("1") and a listing of all error values, the mean average, standard deviation, and 3 sigma bounds will be printed for each command position. If not wanted, answer no ("0").

Default = yes

20. **Statistical Plot?** (Yes = 1 and No = 0)

Answering no ("0") will end the program at this point. A yes ("1") will add the statistical information to the plot in progress (plot on fly) or plot all data if a tape file has just been specified for a post plot.

21. For copy, change paper..... CONT.

For additional copies of the same data, change paper on plotter and press CONTINUE.

Metrology program cartridge duplication

To duplicate the metrology program, follow the procedure outlined below.

Hardware

- 9825A Calculator
- 98216A General I/O - Extended I/O ROM
- 98210A String - Adv. Programming ROM

Procedure

1. Insert master tape into 9825A.
2. Power on 9825A.
3. Soft keys are automatically loaded. When calculator reads "SELECT Program KEY", remove master tape.
4. Insert new tape with tab in record position. Press (shift) (f10) The tape will be marked in approximately 3 minutes.
5. The new tape is marked when the round red light on the calculator display goes off. Remove new tape.
6. Insert master tape. Press shift (f5). This will read the next file. Display will read "ORIGINAL LOADED 0.00"
7. Insert new tape. Press shift (f11). The file will be recorded. If copying more than one tape, insert other marked new tapes and press shift (f11)
8. Go back to step 7. Repeat till 0-9 is copied.
9. when display reads "DUPLICATE 9.00", all programs are copied. To copy key files and numeric data,
10. Insert master tape, press **trk 1; ldk 0 (execute)**
11. when display reads r, remove master tape, insert new tape, press **trk 1; rck 0, (execute)**
12. Remove new tape, insert master tape, press **trk; ldf1, r 0 (execute)**
13. when display reads r, insert new tape, press **trk 1; rcf 1, r 0 (execute)**
14. Canned surface place data are stored on file 4. Insert master tape, press **trk 1; ldf 4, r 0 (execute)**
15. Insert new tape, press **trk 1; rcf 4, r 0, r 14 6 (execute)**

This concludes tape duplication

Program Listings

Program 0 (Metrology package directory)

```
1:  "*****":
2:  "** Program Zero ** Metrology package directory **":
3:  "*****":
4:  dsp "HP 5526A/9825A Metrology Package"
5:  spc 2
6:  prt "*****"
7:  prt "HEWLETT-PACKARD","LASER METROLOGY"," PACKAGE";spc
8:  prt " %%%%%%%%%% % HP 5526A % % HP 9825A % % HP
5872A %
9:  prt " %%%%%%%%%%"
10: spc 2
11: prt " Directory:";spc
12: prt "f1:Surface Plate","Calibration";spc
13: prt "f2:Surface Plate","Isoplot";spc
14: prt "f3:Surface Plate","Numeric Plot";spc
15: prt "f4:Large Angle","Error Correct";spc
16: prt "f5:Vel. of Light","Compensation";spc
17: prt "f6:Standrd Error","Meas and Plot"; spc
18: prt "f7:Straightness","& Squareness"; spc
19: prt "f8:LinearAngular","Stat Pack"
20: spc
21: prt "*****"
22: spc 5
23: trk 1;ldk 0;trk 0
24: "wait":beep;wait 100;beep;wait 100;beep
25: fmt 1,6b," SELECT Program KEY ",6b
26: wrt .1,160,160,160,160,160,160,160,160,160,160,160,160
27: stp
28: dsp "YOU MUST SELECT Program KEY!!!!";beep;wait 2000
29: gto "wait"
30: end
```

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Program 1 (Surface Plate calibration)

```
1:  "*****":
2:  "*** Program One *** Surface Plate calibration ***":
3:  "*****":
4:  "START":cfg ;fxd 0;dsp "    Surface Plate calibration"
5:  spc 5;prt " SURFACE PLATE"," CALIBRATION";spc 2
6:  wait 2000
7:  ent "ENGLISH(0) or METRIC(1) units?",Z
8:  if flg13+(Z=0);sfg 2;dsp "ENGLISH units selected.";jmp 2
9:  dsp "METRIC units selected.";prt "METRIC Units"
10: wait 1500
11: 0}F;ent "CREATE(0) or EDIT(file#) data?",F
12: if F;trk 1;ldf F,r0;trk 0
13: r9}J;r10}K;r19}L;r20}M
14: if F=0;jmp 4
15: dsp "Date:",J,K,L,"    Plate#",M
16: prt "File #",F,"Plate #",M;spc ;prt
    "Month",J,"Day",K,"Year",L;spc 2
17: wait 2000
18: 21}B;2.0625}Y
19: ent "Data via 5526(0) or KEYBOARD(1)?",Z
20: if flg13+(Z=0);sfg 1;dsp "Data entry direct from Laser.";wait
    2000;jmp 2
21: dsp "Data entry via KEYBOARD";wait 2000
22: ent "Foot spacing?",Y
23: if flg1=0;gto "NEXT"
24: prt " Laser Display","MUST be in X10","    Mode.";spc 3
25: dsp "Set Laser to X10 MODE CONT";beep;stp
26: "NEXT":ent "(+/->line#?    (+:Away)(-:Toward)",Z;if flg13;gto
    "Done"
27: if Z=0;beep;dsp "LINE # FIRST !!!!!";wait 2000;gto "NEXT"
28: abs(2)}X;X/Z}r19
29: if X>8;beep;dsp "Line# must be between 1 & 8.";wait 2000;gto
    "NEXT"
30: X+10}R;if rA=0;gto +3
31: gsb "A"
32: A}B;X+10}A
33: r19*Y/2.0625}r19
34: if flg2;jmp 2
35: r19/25.4}r19
36: B}rA}r5;0}rB;-1}Z
37: "NEXTPOS":if flg1;gto "LASER"
38: "KEYBOARD":ent "Data ?",r(B+1}B);if flg13;B-1}B;gto "LAST" 36:
    gto "PRINT"
39: "LASER":dsp "Break Beam and Push PRINT to end."
40: red 3,W,V
```

```

41:  if v>=80;dsp "BEAM has been BROKEN!!!";beep;wait 4000;gto "LAST"
42:  w+sgn(w)(v*1e8)}r(B+1}B)
43:  "PRINT":prt rB
44:  rE*r19}rE
45:  gto "NEXTPOS"
46:  "LAST":(B-r5+1)*1e3+rA}rA
47:  spc 2;r5}A;0}Z
48:  rA+Z}rA}Z;jmp (A+1}A)>B
49:  r5}A
50:  rB*(B-A)}r1
51:  0}Z
52:  rA-Z*r1}rA;Z+1}Z;jmp (A+1}A)>B
53:  r5}A;B-A+1}C
54:  8}Z;gsb "L"
55:  B+1}B;gto "NEXT"
56:  "Done":1}X}r20
57:  qsb "M"
58:  rA-r1}rA;jmp (A+1}A)>B
59:  if x=1;2}X;jmp -2
60:  1}X
61:  gsb "A"
62:  rA}r(X*2-1)
63:  rB}r(X*2)
64:  if x=1;2}X;imp -3
65:  3}X;r3}Y;r1}Z;gsb "E"
66:  4}X;r3}Y;r2}Z;gsb "E"
67:  5}X;r2}Y;r4}Z;gsb "E"
68:  6}X;r1}Y;r4}2;gsb "E"
69:  3}X
70:  gsb "M"
71:  r1}rX;if (X+1}X)<=6;jmp -1
72:  7}X;r4}Y;r6}Z;gsb "E"
73:  8}X;r3}Y;r5}Z;gsb "E"
74:  7}X
75:  gsb "M"
76:  r1}rX;if x=7;8}X;jmp -1
77:  21}A;rA}X}Y;r20}B
78:  if x>rA;rA}X
79:  if rR>Y;rA}Y
80:  if (A+1}F1)<=E;jmp -2
81:  abs(X-Y)}r1
82:  prt "CLOSURE ERROR","LINE 7",r7,"LINE 8",r8,"MAX ELEV",r1;spc 8
83:  21}A
84:  rA-X}rA;jmp (A+1}A)>B
85:  1}X}Z
86:  ent "Data Printout?    NO(0) or YES(1)",2;if (Z=0)+flg13;gto
    "STORE"
87:  gsb "A"

```

```

88:  gsb "L"
89:  if (X+1}X)<=8;jmp -2
90:  spc 10
91:  "STORE":dsp "Enter date of Calibration      ";wait 1000
92:  ent "Month?  (1-12)?",J;if flg13;gto "ID"
93:  ent "Day?    (1-31)",K;if flg13;gto "ID"
94:  ent "Year?   (00-99)",L
95:  "ID":ent "Surface Plate ID# ?",M
96:  r20}B
97:  J}r9;K}r10;L}r19;M}r20
98:  ent "Data to be stored on FILE#?",F;if (F=0)+flg13;gto "END"
99:  trk 1;rcf F,r0,rB;trk 0
100: prt "Data stored in File #",F
101: "END":beep;wait 100;beep;wait 100;beep
102: dsp "SURFACE PLATE CAL. COMPLETED";wait 3000;beep
103: dsp "Press CONT for more Calibration";stp
104: gto "START"
105: "A":
106: X+10}B;int(rB/1e3)}C
107: rB-C*1e3}A
108: if (A+C-1}B)>r20;B}r20
109: ret
110: "L":
111: spc 2
112: prt "LINE NUMBER",X,""
113: prt rA;jmp (A+1}A)>B
114: prt "",C;spc Z
115: ret
116: "E":
117: 0}r7;gsb "A"
118: Y-rA}r9
119: (Z-rB-r9)/(C-1)}r8
120: rA+r9+r7*r8}rA;r7+1}r7;jmp (A+1}A)>B
121: ret
122: "M":
123: qsb "A"
124: (A+B)/2}Z;rZ}r1
125: if Z-int(Z)>0;(rZ+r(Z+1))/2}r1
126: ret
127: end

```

Program 2 (Surface Plate Isoplot)

```
1:  "*****":
2:  "*** Program TWO *** Surface Plate Isoplot ***":
3:  "*****":
4:  "START":dsp "      Surface Plate Isoplot";wait 2000
5:  ent "which data file?",F
6:  trk 1;ldf F,r0;trk 0
7:  r9}J;r10}K;r19}L;r20}M
8:  fxd 0;pclr
9:  35}r2;ent "TILT ANGLE?",r2
10: cos(r2)}r19;sin(r2)}r20
11: 10}r2;ent "ROTATION ANGLE?",r2;cos(r2)}X;sin(-r2)}Y
12: X+Y}r9;X-Y}r10
13: pen# 1
14: scl -110r9,110r10,-10,(110r9+110r10)r20+30;plt 0,0,1
15: 0}X}Y}Z;gsb "P"
16: 100}X;gsb "P"
17: 100}Y;gsb "P"
18: 0}X;gsb "P"
19: 0}Y;gsb "P"
20: 100}X}Y;gsb "P"
21: pen;50}Y;gsb "P"
22: 0}X;gsb "P"
23: pen;100}Y;gsb "P"
24: 100}X;0}Y;gsb "P"
25: pen;50}X;gsb "P"
26: 100}Y;gsb "P"
27: pen# 3;pen;0}X;50}Y;gsb "P"
28: fxd 3;wrt 705,"SL",tan(20);fxd 0
29: pen;cplt -18,-1;lbl "Date: ",J,"/",K,"/",L;cplt
30: cplt -16,0;lbl "Plate #",M
31: pen;50}X;0}Y;-r1/4}Z;gsb "P"
32: pen# 2
33: lbl "Closure 7: ",r7;cplt
34: lbl "Closure 8: ",r8;cplt
35: lbl "Max Elev : ",r1
36: pen# 4;plt 1000,1000,1
37: pen;1}X;0}r3;100}r4
38: 100}r5;0}r6;gsb "L"
39: pen;2}X;100}r3}r4
40: 0}r5>r6;gsb "L"
41: pen;3}X;100}r3}r4
42: 0}r5;100}r6;gsb "L"
43: pen;4}X;100}r3}r4
44: 100}r5;0}r6;gsb "L"
45: pen;5}X;100}r3;0}r4
```



```

46:  0}r5}r6;gsb "L"
47:  pen;6}X;0}r3;100)r4
48:  0}r5}r6;gsb "L"
49:  pen;7}X;100}r3;50}r4
50:  0}r5;50}r6;gsb "L"
51:  pen;8}X;50}r3;100}r4
52:  50}r5;0}r6;gsb "L"
53:  pen# ;pit 140,175,1
54:  beep;wait 100;beep;wait 100;beep
55:  dsp "Press CONT for additional plots!";stp
56:  gto "START"
57:  "P":if r1=0;1}r1
58:  plt X*r10-Y*r9,(X*r9+Y*r10)*r20+Z*30/r1
59:  ret
60:  "L":gsb "A"
61:  (r5-r3)/(C-1)}r0
62:  (r6-r4)/(C-1)}r2
63:  rA}Z;r3}X;r4>Y
64:  qsb "P"
65:  0}Z;qsb "P"
66:  rA}Z;gsb "P"
67:  r3+r0}r3
68:  r4+r2}r4
69:  A+1}A;if A<=B;jmp -6
70:  ret
71:  "R":X+10}r0
72:  int(rr0/1000)}C;rr0-C*1000}A;A+C-1}B
73:  ret
74:  end

```

*30021

Program 3 (Surface Plate Numeric plot)

```
1:  "*****":
2:  "**** Program THREE *** Surface Plate Numeric plot ***":
3:  "*****":
4:  "START":cfq ;fxd 0;pc1r
5:  dsp "  Surface Plate Numeric plot";wait 2000
6:  ent "which data file# ?",F
7:  if flgl3;beep;dsp "Enter File* to be plotted!!";wait 1000;jmp -1
8:  trk 1;ldf F,r0;trk 0
9:  r9/J;r10}K;r19)L;r20)M
10:  0}Z;ent "POSITIVE(0) or RELATIVE(1) data?",Z
11:  if Z;sfg 1;r1/2/r3}r4;jmp 2
12:  0}r3;r1}r4
13:  scl -10,110,-10,110
14:  0}G;ent "GRIDS: None(0)      Line(1)      Dash(2)•",G
15:  dsp "Date:",J,K,L,"      Plate#",M
16:  pen# wine
17:  xax -10,0;yax 110,0;yax -10,0;xax 110,0
18:  pen# 2;fxd 3;wrt 705,"SL",tan(20);fxd 0
19:  plt 50,110,1;cp1t -21,-1
20:  1b1 "Date:",J,"/",K,"/",L," Plate #",M
21:  if G=0;gto "PRINT"
22:  if G=1;line ;jmp 2
23:  line G,2
24:  pen# 3
25:  pen;pit 0,0;pit 100,0;plt 100,100;plt 0,100;plt 0,0;plt
    100,100,-1
26:  pit 0,100;plt 100,0,-1;plt 100,50;plt 0,50,-1;plt.50,0;plt
    50,100,-1
27:  "PRINT":pen# 4
28:  1}X;gsb "A"
29:  0}X;100}Y;100/C}Z;A-1}A
30:  plt X,Y,1;1b1 rA-r3;X+Z}X;Y-Z}Y;jmp (A+1}A)>L+1
31:  2}X;gsb "A"
32:  100}X}Y;100/C}Z;A-1/8
33:  plt X,Y,1;1b1 rA-r3;X-Z}X;Y-Z}Y;jmp (A+1}A)>B+1
34:  3}X;gsb "A"
35:  100/C}Z;(100}Y)-Z}X
36:  plt X,Y,1;1b1 rA-r3;X-Z}X;jmp (A+1}A)>B
37:  4}X;gsb "A"
38:  100/C};(100}X)-Z}Y
39:  plt X,Y,1;1b1 rA-r3;Y-Z}Y;jmp (A+1}A)>B
40:  5}X;gsb "A"
41:  0}Y:100-(100/C}Z)}X
```

```

42: plt X,Y,1;lbl rA-r3;X-Z}X;jmp (A+1}A)>B
43: 6};gsb "A"
44: 0};100-(100/C}Z)/Y
45: plt X,Y,1;lbl rA-r3;Y-Z}Y;jmp (A+1}A)>B
46: 7};gsb "M"
47: 50};100-(100/C/Z)/X
48: plt X,Y,1;lbl rA-r3;X-Z}X;if A+1=r2;A+1}R;X-Z}X
49: A+1}A;if A<=B;jmp -1
50: 8};gsb "M"
51: 50}X;100-(100/C}Z)}Y
52: plt X,Y,1;lbl rA-r3;Y-Z}Y;if A+1=r2;A+1}A;Y-Z}Y
53: R+1}A;if A<=B;jmp -1
54: pen# 2;plt 70,55,1;lbl " Closure:",r7;plt 55,85,1;lbl
    "Closure:",r8
55: plt 50,-10,1;cplt -12,1
56: if flg1;lbl "Maximum Deviation: +/-",r4;jmp 2
57: lbl "Maximum Elevation: ",r4
58: pen# ;pit 125,125,1
59: beep;wait 100;beep;wait 100;beep
60: dsp "Press CONT for additional plots!";stp
61: qto "START"
62: "M":gsb "A"
63: (A+B)/2}r2
64: if r2-int(r2)>0;0)r2;ret
65: ret
66: "A":X+10}r0
67: int(rr0/1000)}C;(rr0-C*1000+1}A)+(C-1}C)-2}B
68: ret
69: end

```

*11766

Program 4 (Large angle error correction)

```
1:  "*****":
2:  "* Program FOUR *** Large angle error correction *":
3:  "*****":
4:  "START":dsp " Large Angle Error Correction"
5:  spc 3;prt " LARGE ANGLE","ERROR CORRECTION";spc 3
6:  wait 2000
7:  cfg ;2.0625}Y;1e-5}M
8:  0}Z;ent "INPUT: 5526(0) or Keyboard(1) ?",Z;if Z;gto "SKIP"
9:  sfg 1;spc 2;prt "LASER MUST BE in INCHES MODE!";spc 3
10: dsp "LASER MUST BE IN INCHES MODE !!!";beep;wait 3000
11: 0}Z;ent "Laser: NORMAL(0) or X10(1) Mode?",Z
12: if Z;1e-6}M
13: "SKIP":0}T;ent "OUTPUT?: Arcsec(0) Deg(1) Rad(2)",T
14: if T=2;rad;jmp 2
15: deg
16: "loop":if flg1=0;gto "KEY"
17: "LASER":dsp " Enter data from Laser Display."
18: red 3,X,Y
19: if Y>=80;beep;dsp " BEAM is BROKEN !!!";gto "loop"
20: X+sgn(X)(Y*1e8)}X
21: "KEY":ent "ANGLE (arcseconds)?",X;if flg13;gto "exit"
22: "CORR":X*M}X;asn(X/Y)}C
23: if T=0;C*3600)C
24: fxd 1;prt "Arcsecs",X*1e5
25: if T=2;C*1000}C;fxd 4
26: if T=1;fxd 5
27: prt "Correct",C
28: if T=0;prt " arcseconds";jmp 3
29: if T=2;prt " milliradians";jmp 2
30: prt " degrees"
31: spc 2;gto "loop"
32: "exit":dsp "Press CONT for more corrections."
33: stp
34: gto "START"
35: end
```

*2359

Program 5 (Velocity of light compensation)

```
1:  "*****":
2:  "* Program FIVE *** Velocity of light compensation *":
3:  "*****":
4:  fxd 1;spc 3
5:  dsp " Velocity of light compensation"
6:  prt "  V.O.L.", " COMPENSATION"
7:  spc 3;wait 1000
8:  71 "STAFT":cfg ;20}T}r8;0}Z;ent "ENGLISH(0) or METRIC(1)
   units?",Z
9:  if Z=0;sfg 1;68)T)r8
10: if abs(Z)>1;beep;jmp -2
11: if flg1;prt "English Units";jmp 2
12: prt "Metric Units"
13: spc
14: 0)r1}r2}r3}r4}r5}r6}r7
15: prt "Air:"
16: ent "Air Temperature?",r1;if flg13;beep;jmp 0
17: ent "Air Pressure?",r2;if flg13;beep;jmp 0
18: ent "Relative Humidity 00 ?",r3;if flq13;beep;jmp 0
19: prt "Temperature",r1
20: prt "Pressure",r2
21: prt "Humidity(%)",r3;spc
22: prt "Material:"
23: if flg1;gto "PPMF"
24: ent "Mat'l Expansion Coeff. (PPM/C)?",r4
25: if r4=0;sfg 2;gto "MET"
26: jmp 3
27: "PPMF":ent "Mat'l Expansion Coeff. (PPM/F)?",r4
28: if r4=0;sfg 2;gto "ENG"
29: prt "Exp Coeff",r4
30: ent "Material Temp #1 ?",r5;if flg13=0;prt "Temp #1",r5;gto "T2"
31: sfq 2
32: if flg1;gto "ENG"
33: gto "MET"
34: "T2":ent "Material Temp #2?",Z;if flg13;1}X;gto "AVG"
35: prt "Temp #2",Z}r6
36: ent "Material Temp #3?",Z;if flg13;2}X;gto "AVG"
37: prt "TEMP #3",2}r7;3}X
38: "AVG":(r5+r6+r7)/X}r8
39: if flg1=0;gto "MET"
40: "ENG":9.7443*r2*(1+1e-6*r2*(26.7-.187*r1))/(.934915+.0020388*
   r1}r9
41: r9-1.089*(.001*r3)*exp(.032015*r1)}r11
42: jmp 3
43: "MET":.3836391*r2*(1+1e-6*r2*(.817-.0133*r1))/(1+.003661*r1)}
```

```

r9
44: r9-3.033*(.001*r3>exp(.057627*r1)}r11
45: 1e12/(r11+1e6)-999000)r12
46: r12-r4*(r8-T)}r13
47: if flg2;prt "Not used."
48: spc 2;prt "THUMBWHEEL",r13
49: dap "THUMBWHEEL SETTING: ",r13
50: spc 5;stp
51: gto "START"
52: end

```

*14709

Program 6 (Standard error plotting)

```
1:  "*****":
2:  "*** Program SIX *** Standard error plotting ***":
3:  "*****":
4:  "START":fxd 6;cfg
5:  spc 3;prt "Standard Error","      Plotting";spc 2
6:  .01}r1;.005}r2;.001}r4;.0005}r5;.00001}r6
7:  0}Z;ent "English(0) or Metric(1) units ?",Z;if
   Z;10r1}r1;10r2}r2;10r6}r6
8:  ent "Maximum machine travel ?",r0
9:  1}Z;ent "Error Plot ? (Yes=1      No=0]",Z;if Z;sfg 1
10:  1}Z;ent "Printout ?      (Yes=1      No=0)",Z;if Z;sfg 2
11:  0}Z;ent "Data via Laser(0) or Keyboard(1)",Z;if Z=0;sfg 3
12:  1}Z;ent "NORMAL(1) or X10(10) mode ?",Z;r1/Z}r1;r2/Z}r2;r6/Z}r6
13:  if flg1=0;gto "SKIP"
14:  pclr;pen# 4
15:  scl -r0/10,r0,-5r2/4,r2
16:  fxd abs(log(r2))+2;yax 0,r2/10,-r2,r2,5
17:  fxd abs(log(r2));xax -r2,r0/20,0,r0,4
18:  xax 0,r0/20,0,r0
19:  line 0;pen# 1;plt 0,0,1;wrt 705,"SM*"
20:  fxd 6
21:  "SKIP":-1}Z
22:  "LOOP":if flg3=0;gto "KEYBOARD"
23:  "LASER":dsp "Data via Laser Press PRINT"
24:  red 3,X,Y
25:  if Y>=80;dsp "BEAM has been BROKEN !!!";beep;wait 3000;gto "END"
26:  r6*(X+sgn(X)(Y*1e8))}X
27:  gto "ERROR"
28:  "KEYBOARD":ent "Data ?",X;if flg13;gto "END"
29:  "ERROR":r1*int(X/r1)}Y
30:  X-Y}B;if B>r2;B-r1}B;Y+r1}Y
31:  if flg1;plt Y,B,2;pen
32:  if flg2;prt "Command",Y,"Error",B;spc
33:  gto "LOOP"
34:  "END":pen# ;spc 5;plt r0,r2,1
35:  beep;dsp "Press CONT to restart.";beep;stp
36:  gto "START"
37:  end
```

*20783

Program 7 (Straightness and Squareness)

```
1:  "*****":
2:  "*** Program SEVEN *** Straightness and Squareness ***":
3:  "*****":
4:  prt " Straightness"," Squareness"," & Parallelism";spc 2
5:  pclr;0}r10)r2)r1}r0;sfg 3;fxd 1;1}r9
6:  prt "ENTER";prt "CALIBRATION";prt "NUMBER OF ";prt
   "Straightness"
7:  1}r9;prt "INTERFEROMETOR";spc 2;ent "Straightness Calibration
   Number?",r9
8:  cfg 1;cfg 2;ent "Axis Number?",r10
9:  ent "Number of points on axis?",r1,"Distance between points?",r2
10:  1}Z;ent "Plot?   [Yes=1   No=0]",Z;if Z;sfg 1
11:  0}Z;ent "Data via Laser(0) or Keyboard(1)",Z;if Z=0;sfg 2
12:  -1}11}E;1>r0;fxd 0;prt "AXIS",r10;fxd 1;spc 1;prt "Input Data"
13:  0}Z;if flg2;gto 17
14:  if Z=r1;gto 23
15:  ent "Data?",A;Z+1}Z
16:  A'r9>A;prt A;A+rB}rB;if Y<=0;B+1}B;gto 13
17:  E-1}B;gto 13
18:  if Z=r1;gto 23
19:  red 3,X,Q;if Q>=80;dsr "BEAM is BROKEN !!!";beep;wait 4000;gto
   "AGAIN"
20:  (X+sgn(X)(Q*1e8))/r9}X
21:  Z+1>Z
22:  prt X;X+rB}rB;if Y<=0;B+1}B;gto 17
23:  B-1}B;gto 17
24:  1}Z;spc 4;ent "More Data?   [Yes=1   No=0]",Z;if Z=0;gto 28
25:  1}Z;ent "Direction?   +1=Same -1=Oppos",Z
26:  if Z<=0;if Y<=0;1}Y;B-1}B;gto 27
27:  11}B;-1}Y
28:  r0+1}r0;gto 12
29:  11}B
30:  rB/r0)rB;B+1}B;if B-11=r1;gto 31
31:  gto 29
32:  gsb "L"
33:  11}E;prt "Straightness"
34:  prt rB;B+1}B;if 8-11=r1;gto 35
35:  gto 33
36:  spc 2;gsb "S"
37:  if flg1;qsb "P"
38:  if flg3;cfg 3;gto 40
39:  gsb "SO"
40:  gto 46
41:  1}Z;ent "Parallelism? [Yes=1   No=0]",Z;if Z=0;gto 42
42:  sfg 4;gto 43
```



```

43: 1}Z;ent "Squareness? [Yes=1 No=0]",Z;if Z=0;gto 46
44: 11}B
45: 0}rB;B+1}B;if B>140;gto 7
46: gto 44
47: pen;ldp 0
48: "L":spc 2;prt "Line Fit:", "0: Least Square", "1: Zero End
Pts";spc 2
49: 0}Z;ent "Type of Line Fit ? C0 or 17",Z;if 2=0;gto 62
50: 0}r3}r4}r5}r6;11}B
51: r4+rE}r4;r5+rB*r2*(B-11)}r5;(B-11)*r2+r3}r3
52: (B-11)*(B-11)*r2*r2+r6}r6;B+1}B
53: if B-11=r1;gto 54
54: gto 50
55: (r4*r3-r1*r5)/(r3*r3-r1*r6)}r7
56: (r4-r7*r3)/r1}C
57: if flg3;r7}r8
58: 11}B;0}A
59: rB-(r7*A+C)}rB
60: A+r2}R;B+1}B
61: if B-11=r1;ret
62: gto 58
63: (r(r1+10)-r11)/(r1*r2-r2)}r7;r11}C
64: gto 56
65: "S":
66: 11}B;rB}A}C
67: if rB>A;rB}A
68: if rB<=C;rB}C
69: B+1}E;if B-11=r1;gto 70
70: gto 66
71: prt "MAX Dev=",A;spc 1;prt "MIN Dev=",C;spc 8;if flg1;gto 72
72: ret
73: if abs(C)>A;-C}A
74: ent "Max Error?.... (for plot scaling)",A
75: scl 0,r1*r2-r2,-A,A
76: if flg3;gto 77
77: gto 87
78: pen* 1;pen;plt 0,-A;plt 0,-.05*A;pen;plt 0,.05*A;plt 0,A;pen
79: xax A/2,r2,0
80: xax -A/2,r2,0
81: plt 0,.8A;plt .01*r1*r2,.8A;pen
82: plt 0,.2A;plt .01*r1*r2,.2A;pen
83: plt 0,-.2A;plt .01*r1*r2,-.2A;pen
84: plt 0,-.8A;plt .01*r1*r2,-.6A;pen
85: pen# 2;plt .01*r1*r2,.8A,1;lbl A
86: plt .01*r1*r2,.2A;lbl -A
87: pen* 3;pit .01*r1*r2,.9*A;fxd 0;lbl "AXIS ",r10;fxd 2
88: if flg3;gto 91
89: pen# 2;plt .01*r1*r2,-.2A;lbl A

```

```

90:  plt .01*r1*r2,-.8A;lbl -A
91:  pen# 3;plt .01*r1*r2,-.1R;fxd 0;lbl "AXIS ",r10;fxd 1
92:  ret
93:  "P":
94:  11}E;0}X;A/2}A
95:  if flg3;-A}A
96:  pen# 4;pit X,.6*rB/2-A;X+r2}X;E+1}B;if D-11=r ;gto 97
97:  gto 95
98:  pen;plt 0,0,1
99:  ret
100: "SQ":atn(r7*1e-6)}A;atn(r8*1e-6)}C;(A-C)*3600}X;fxd 1
101: if flg4;gto 106
102: 0}Z;ent "Pentaprism Error?",Z
103: X+Z}X
104: prt "Squareness=",X,"ARCSCDS";spc 8
105: if flg1;plt .3*r1*r2,0;lbl "Squareness ",X
106: gto 108
107: prt "Parallelism=",X/2,"ARCSECONDS";spc 8
108: if flg1;plt .3*r1*r2,0;lbl "Parallelism ",X/2
109: if flg1;lbl " ARCSECONDS";pit r1*r2,A,1
110: ret
111: end
*3766

```

Program 8/1 (Linear/Angular Statistical)

```
1: "*****":
2: "*** Program EIGHT/1 *** Linear/Angular Statistical analysis
   package ***":
3: "*****":
4: "START":dim G,H,V,D$(25),I$(25),I,T,E,R,E[7+2}G,0:(49}H)];cfg
5: spc 3;prt " Incremental","Error Analysis";spc 2
6: "START2":
7: 0}Z;ent "Measurement[0] or Post Plot[1] ?",Z;if Z;sfg 5;gto
   "LOADPLOT"
8: "MEASURE":1e-5}M
9: 0}V;ent "Linear[0] or Angular[1] Error ?",V;if V;sfg 7
10: 6}S;if flg7;2}S
11: enp "Date:",D$;spc
12: enp "Machine ID Code:",1$;spc 3
13: 1}Z;ent "Plot on fly? [Yes=1    No=0]",Z;if Z;sfg 1
14: 1}Z;ent "Print on fly? [Yes=1    No=0]",Z;if Z;sfg 2
15: "INFO":ent "Increment of travel ?",I
16: ent "Total machine travel ?",T
17: ent "Maximum expected error ?",E
18: ent "Number of Runs ?",R;R+1}A;R+2}B
19: if (B<=G)*(int(T/I)<=H);gto "OK"
20: "TOOBIG":beep;dsp "WARNING: ARRAY SIZE EXCEEDED !";wait
   4000;fxd 0
21: beep;dsp "Max: ",G-2," Runs and",H," Pts./run";wait 5000;fxd
   S;gto "INFO"
22: "OK":1}Z;ent "Uni[1] or Bi[2] directional ?",Z;if Z=2;sfg 4
23: if flg1;gsb "AXES"
24: 0}Z;sfg 3
25: ent "Data via Laser[0] or Keyboard[1]",Z;if Z;cfg 3;gto "INPUT"
26: if flg7;beep;dsp "LASER MUST BE IN ENGLISH UNITS !";wait 3000;jmp
   2
27: 0}Z;ent "English[0]    or Metric[1] ?",Z;if Z;10M}M
28: 1}W;ent "NORMAL[1] or X10[10] mode ?",W;M/W}M
29: "INPUT":0}P;1}Q}N
30: "LOOP":fxd S;dsp "Position:",IP,"    Data?"
31: if flg3=0;gto "KEY"
32: "LASER":red 3,X,Y
33: if Y>=80;dsp "BEAM has been BROKEN!!! ReRUN";stp ;gto "START2"
34: if flg7;X/W}X}E[Q,P];gto "ERROR"
35: M(X+sgn(X)(Y*1e8))}X
36: gto "ERROR"
37: 35: "KEY":ent "",X;if flg13;dsp "Laser entry...";sfg 3; wait
   4000; gto "LOOP"
38: "ERROR":if flg7;X}Y;jmp 2
39: X-IP}Y
```

```

40: if flg1;wrt 705,"SMX";plt IP,Y,1
41: "LOOPBI":if flg2;prt "Pos:",IP,"Error:",Y;spc
42: Y}E[Q,P]
43: E[A,P]+Y}E[A,P]
44: E[B,P]+YY}E[B,P]
45: if (I(P+N)<=T)*(I(P+N)>=0);P+N}P;gto "LOOP"
46: "NEWRUN":Q+1}0
47: if Q>R;gto "CALC"
48: fxd 0;spc ;prt "RUN#",Q;spc 2
49: if flg4=0;dsp "Begin Run#",Q,"Send Machine to 0";0}P
50: if flq1;pclr;plt IP,0,1
51: if flg4;dsp "Reverse Direction..Begin Run#",Q;-N}N
52: fxd 6;beep;wait 4000;beep .
53: if flg4;gto "LOOPBI"
54: gto "LOOP"
55: "CALC":for P=0 to int(T/I)
56: if R>1;\abs((E[B,P]-E[A,P]*E[A,P]/R)/(R-1))}E[B,P]
57: E[A,P]/R}E[A,P]
58: next P
59: 0}F;ent "Store on which File#? [0=No]",F;if F=0;gto
    "LOADPLOT"
60: trk 1;rcf F,V,DS,I$,I,T,E,R,E[*];trk 0
61: "LOADPLOT":ldf 9,0,1
62: "AXES":pclr;pen# 4
63: scl -T/10,12T/10,-2.5E,2.1E
64: fxd 2;xax -2E,I,0,T,max(1,int(T/5I))
65: xax 0,I,0,T
66: fxd S;yax 0,E/5,-2E,2E,5
67: pen* 3;plt T/2,1.9E,1
68: if flg7;lbl "ANGULAR ERROR vrs. POSITION";cplt ;jmp 2
69: lbl "LINEAR ERROR vrs. POSITION";cplt
70: lbl "Date: ",DX;cplt
71: lbl "Machine ID Code: ",I$
72: pent! 1;plt 0,0,1
73: ret
74: end

```

*8802

Program 8/2 (Linear/Angular STAT-PAY)

```
1:  "START":ldp 8
2:  "*****":
3:  "*** Program EIGHT/2 *** Linear/Angular STAT-PAY.  POST TEST PLOT
   ***":
4:  "*****":
5:  "POSTPLOT":dsp "Post Measurement Documentation"
6:  spc 5;prt "Post Measurement"," Documentation";spc 3
7:  if flg5;ent "File# of data to be plotted ?",F
8:  if flg5;trk 1;ldf F,V,D$,I$,I,T,E,R,E[*];trk 0
9:  6}S;if V;sfg 7;2}S
10: R+1}A;P+2}B
11: 1}Z;ent "Sorted Printout?  [Yes=1    No=0]",Z;if Z=0;gto
   "STATPLOT"
12: spc 5;prt " Statistical"," Error Analysis"
13: spc ;prt D$;spc ;prt "Machine ID Code:",I$;spc 4
14: for P=0 to int(T/1)
15: prt "*****";spc
16: prt "COMMAND POSITION",IP;spc
17: if flg7;prt "    ANGULAR";jmp 2
18: prt "    LINEAR"
19: prt "RUN#    ERROR"
20: for 0=1 to R
21: if flg7;fmt f3.0,f13.1;wrt 16,0,E[O,P];jmp 2
22: fmt f3.0,f13.6;wrt 16,0,E[Q,P]
23: next Q
24: spc ;fxd S;prt "AVG:",E[A,P]
25: if flg7;gto "ANGLIST"
26: fmt 2x,b,":",f12.6;wrt 16,9,E[B,P]
27: spc ;fmt "+3",b,":",f12.6;wrt 16,9,E[A,P]+3E[B,P]
28: fmt "-3",b,":",f12.6;wrt 16,9,E[A,P]-3E[B,P];spc 3
29: gto "CUNT"
30: "ANGLIST":fmt 2x,b,":",f12.2;wrt 16,9,E[B,P]
31: spc ;fmt "+3",b,":",f12.2;wrt 16,9,E[A,P]+3E[B,P]
32: fmt "-3",b,":",f12.2;wrt 16,9,E[A,P]-3E[B,P];spc 3
33: "CONT":next P
34: spc 3
35: "STATPLOT":1}Z;ent "Statistical Plot? [Yes=1 No=0]",Z; if
   Z=0;gto "END"
36: if flg1;gto "MEAN"
37: ent "To rescale plot, enter NEW error",E
38: "PLOT":gsb "AXES"
39: pclr;fmt ;wrt 705,"SMX"
40: for P=0 to int(T/I)
```

```

41:  for 0=1 to R
42:  plt IP,E[Q,P],1
43:  next 0
44:  next P
45:  "MEAN":pclr;pen# 3;plt 0,0,1
46:  for P=0 to int(T/I)
47:  plt IP,E[A,P]
48:  next P
49:  lbl " Mean"
50:  "3SIGMA":pen# 2
51:  for N=-1 to 1 by 2
52:  pclr;plt 0,0,1
53:  for P=0 to int(T'I)
54:  pit IP,E[A,P]+N*3E[B,P]
55:  next P
56:  fxd 0;lbl " ",3N," Sigma";fxd S
57:  next N
58:  beep;pclr;pen#
59:  plt 1.3T,2E,1
60:  beep
61:  dsp "For Copy, change paper ..... CONT";stp
62:  goto "PLOT"
63:  "END":dsp " Complete 1!";stp odf 8
64:  "AXES":pclr;pen# 4
65:  scl -7/10,127/10,-2.5E,2.1E
66:  fxd 2;xax -2E,I,0,T,max(1,int(T/5I))
67:  xax 0,I,0,T
68:  fxd S;yax 0,E/5,-2E,2E,5
69:  pen# 3;plt T/2,1.9E,1
70:  if flg7;lbl "ANGULAR ERROR vrs. POSITION";cplt ;jrn 2
71:  lbl "LINEAR ERROR vrs. POSITION";cplt
72:  lbl "Date: ",D$;cplt
73:  lbl "Machine ID Code: ",1$
74:  pen# 1;plt 0,0,1
75:  ret
76:  end

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*11443

Appendix I

Use of 9872A Plotter

If the user is not familiar with the 9872A plotter, the following procedure is provided so the user can set up the plotter for use with 9825A calculator.

1. Insert 98034A HP-IB cable into any of the 3 slots on the back of 9825A calculator.

2. Set address code of the HP-IB cable to 7 *by* rotating the screw in the center of the circle on the cable.

3. Connect the other end of HP-IB cable to the HP-IB port on the back of the 9872A plotter.

4. To load paper:

Power on plotter

Press CHART LOAD button.

Place paper on the lower left corner of the plotter.

Press CHART HOLD button to prevent paper movement.

5. To set the margins,

Press P1 button

Press the arrows to guide the pen to the desired lower left position Press ENTER button, then P1 button.

Again, use the arrows to position the pen to the top right position. Press ENTER. button, then P2 button.

If the FAST button is pressed with the buttons with arrows simultaneously, the pen arm will move at a faster speed.

The plot generated will be drawn in the user specified area.

To unload paper, press CHART LOAD.

Note: If you want to use 1 color pen only, place the desired colored pen in the arm and remove the other 3 from the plotter.