5526A LASER MEASUREMENT SYSTEM

# HP 10585A
# Metrology Program Package
## user's manual


HEWLETT PACKARD

*USER'S MANUAL*

# 10585A
# METROLOGY PROGRAM PACKAGE

**SERIAL PREFIX: 2008A**

This manual applies to HP 10585A Metrology Package with Series Prefix 2008A and all previous versions.


5305 STEVENS CREEK BLVD., SANTA CLARA, CALIF. 95050

**Manual Part No. 10585-90003**
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HEWLETT PACKARD

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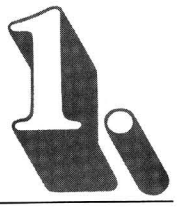

# Introduction and Hardware Description

## INTRODUCTION

The Hewlett-Packard Model 10585A consists of a BCD Input Interface Cable and a Metrology Program Package. The 10585A is intended for use with the HP 9815A Programmable Calculator and peripherals along with the 5526A Laser Measurement system. The calculator is used as a data acquisition and data reduction system which can greatly increase the efficiency of the operation and hardware of the 5526A. In addition, the calculator configured system offers standardization of procedures and an excellent visual presentation of the final data.

The manual is organized as follows:

Section I — Introduction and Hardware Description

Section II — Basic Software Description and Operation

Section III — Metrology Program Cartridge Duplication

## HARDWARE DESCRIPTION

The 10585A is used with the 5526A Laser System and the following equipment (not supplied):

- HP 9815A Programmable Calculator
- HP 9815A Option 001, 2008 Total Program Steps
- HP 9815A Option 002, 2 I/O Channels
- HP 9815A Option 003, 3 Data Cartridges
- HP 7225A Digital Plotter with 17600A Personality Module Option 001 and 015

**NOTE**

If direct input of the data from the 5505A Laser/Display into the calculator is to be used, the leading zeros in the display readout must not be blanked. If they are blanked, the display will read +0.00000. Paragraph 4-141 of the 5526A Laser Measurement Maintenance Manual should be referred to and the appropriate jumper wire must be removed. On the 5526A Laser Display, a non-blanked display will read +0000.00000.

Each individual component is described in its respective manual and diagnostics are provided with the 9815A Calculator to exercise and check out each piece of equipment. When the system is first assembled, each diagnostic should be run to ensure that all of the equipment is functioning correctly and each operating manual should be read completely. To connect the entire system together turn all of the instruments off and connect the cables as shown in Figure 1-1.

When the system has been interconnected and all the diagnostics have been run on the calculator and the peripherals, the following procedure can be used to check the 10585A Inteface Cable to ensure that data is being transferred between the 5505A Laser/Display and the 9815A Calculator.

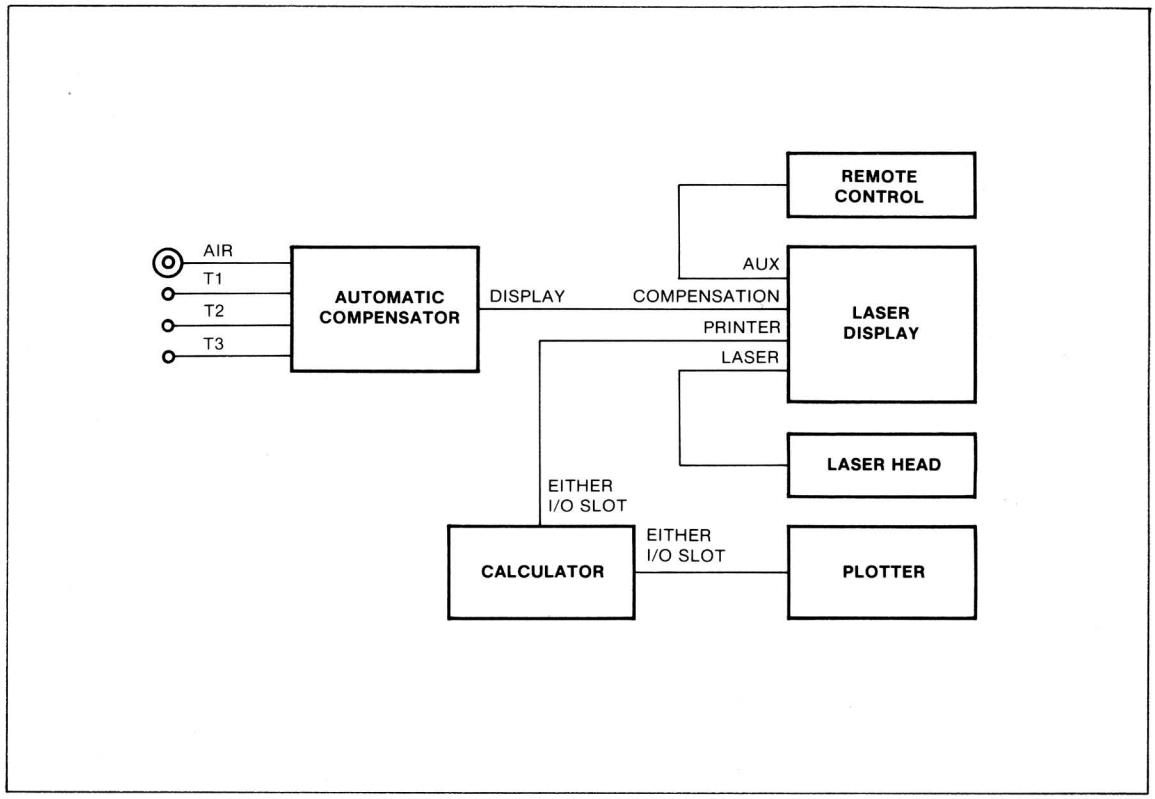


*Figure 1-1. Laser Measurement System Interconnection*

## CONNECTOR DESCRIPTIONS

See page 3 of the 5526A Laser Measurement System Operating Handbook for a complete Laser Display Connector listing.

**CAUTION**

**CONNECTORS J2 and J3 are not electrically interchangeable. Connecting the 10585A Interface Cable to J3 and subsequently applying power to the 5526A Laser Display will damage the 10585A Interface Cable.**

J1 ..... Laser Connector
J2 ..... Printer Connector
J3 ..... Compensation Connector
J4 ..... Aux Connector

The calculator and plotter interface cables will function properly in either calculator input/output connector.

Air ..... Air Temperature and Humidity Sensor
$T_1$, $T_2$, $T_3$ ..... Material Temperature Sensors

## BCD INPUT CALCULATOR INTERFACE CABLE

The Interface Cable allows BCD data from the 5505A Display to be sent to the Calculator when the manual print switch (or remote switch) is pressed. The data received by the Calculator can be processed and output to various devices including printers, plotters, the calculator display, etc. Figure 1-2 shows the interconnecting diagrams.

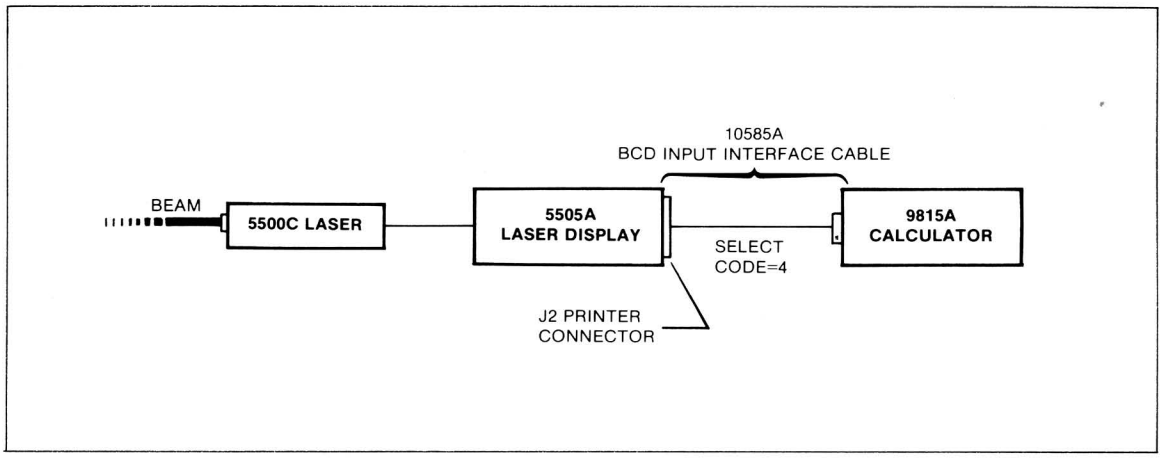


*Figure 1-2. Interconnection Diagram*

## Operational Test

**NOTES**

1. The 5505A must be turned on first, if the 9815A is turned on first, the display hangs up and none of the digits light.
2. The 9815 must be programmed in the PROGRAM mode, not RUN.
3. The RUN/STOP switch must be pressed twice to obtain data. If pressed once, MEMORY OVERFLOW is printed. If pressed twice dashes (- - - - -) appear on the calculator display, indicating the program is running.
4. 5505A Display freezes until RUN/STOP is pressed.

To run the Operational test, refer to the program on page 1-4.

## Conversion to Proper Units

It should be noted that to obtain inches or millimeters from the 5505A Display the exponent needs to be corrected for operational test.

*Table 1-1. Multiplier Factors*

| | **Inches** | **MM** | **00λ/4** |
|---|---|---|---|
| Normal | .00001 | .0001 | 1 |
| X10 | .000001 | .00001 | .1 |

*Table 1-2. Control Signals 10585A to 5505A J2 Printer Connector*

| | |
|---|---|
| (Source) 00 | Positive Print Inhibit (Destination) |
| Flag Destination | Positive Print Command (Source) |

## Diagnostics

1. Enter the following program on the Calculator keyboard (refer to the 9815A Operating and Programming Manual for basic programming procedures):

| Program Keystrokes | Description | Program Listing |
|---|---|---|
| 1 | X = 1 | 0000 1 |
| ENTER | X = Y = 1 | 0001 ENTER |
| CALL 4 K | Handshake Mode 1. Wait for flag which is positive. | 0002 HNDSK 4 |
| CALL 4 O | 1 → 5505A print inhibit. Display free to update. Wait for print command. | 0004 WBYTE 4 |
| CLEAR | PR command has occurred. X = Y = 0 | 0006 CLEAR |
| CALL 4 K | Handshake Mode 0. No waiting for flag. | 0007 HNDSK 4 |
| CALL 4 O | $\overline{0}$ → 5505A print inhibit. Display "frozen". | 0009 WBYTE 4 |
| CALL 4 A | Read data. No waiting for flag. | 0011 READ 4 |
| + → - ← | Change polarity of sign. | 0013 + → - ← |
| STORE A | Store X into A. | 0014 STO A |
| 1 | X = 1 | 0015 1 |
| ENTER | X = Y = 1 | 0016 ENTER |
| CALL 4 O | $\overline{1}$ → 5505A print inhibit. "Unfreeze" display. | 0017 WBYTE 4 |
| RECALL A | A → X | 0019 RCL A |
| PRINT | Print X | 0020 PRINT |
| GOTO 0 | Go to 0 and wait for next number. | 0021 GOTO 0000 |
| END | | 0023 END |

2. If program listing does not match that printed above ensure that the 98133A BCD Interface is correctly installed.

3. Align the Laser Head and optical components so that a number is displayed on the 5505A Laser/Display.

4. Push PRGM/AUTO START/RUN switch into RUN position, press RUN/STOP switch twice and depress the 5505A Laser/Display PRINT switch. The number being displayed on the 5505A will be transmitted, displayed, and printed on the calculator each time the PRINT switch on the 5505A is depressed. If RUN/STOP is pressed once, MEMORY OVERFLOW is printed. If pressed twice, dashes (- - - -) appear on the calculator display, indicating the program is running. (Note: The decimal point position is not transmitted.) If all zeros are printed, see NOTE on page 1-1.

5. If there is a problem with the data not being transmitted correctly, refer to the 98133A BCD Interface Service Manual for the appropriate test procedures.

*Table 1-3. BCD Interface Cable Pin List, AX2 Wire Connections*

| | Signal/Pin | Wire Color | | Signal/Pin | Wire Color |
|---|---|---|---|---|---|
| Sign Exp | A1 (50) | Wht/Orn/Vio | | H8 31 | Wht/Brn/Blu |
| Sign | A2 19 | Wht/Orn/Gry | | H4 30 | Wht/Brn/Vio |
| Logic Sign | A4 45 | +5V Wht/Yel/Grn | | H2 6 | Wht/Brn/Gry |
| Overload | A8 44 | Wht/Yel/Blu | | H1 5 | Wht/Red/Orn |
| | B1 17 | Wht/Yel/Vio | | I1 3 | Red |
| | B2 18 | Wht/Yel/Gry | | I2 4 | Orn |
| | B4 42 | Wht/Grn/Blu | | I4 28 | Yel |
| | B8 43 | Wht/Grn/Vio | | I8 29 | Grn |
| | C1 15 | Wht/Grn | | J8 27 | Blu |
| | C2 16 | Wht/Blu | | J4 26 | Vio |
| | C4 40 | Wht/Vio | | J2 2 | Gry |
| | C8 41 | Wht/Gry | | J1 1 | Wht |
| | D8 39 | Wht/Blk/Brn | Print Inhibit* | FLG1 (22) | Wht/Blk |
| | D4 38 | Wht/Blk/Red | Print Command | FLG2 23 | Wht/Brn |
| | D2 14 | Wht/Blk/Orn | CTL2 | CTL2 (NC) | Wht/Red |
| | D1 13 | Wht/Blk/Yel | | CTL1 (NC) | Wht/Orn |
| | E1 11 | Wht/Red/Yel | | I/O (NC) | Wht/Yel |
| | E2 12 | Wht/Red/Grn | | GND | — |
| | E4 36 | Wht/Red/Blu | | GND (50) | — |
| | E8 37 | Wht/Red/Vio | | GND (50) | Blk |
| | F8 35 | Wht/Red/Gry | | GND (50) | Brn |
| | F4 34 | Wht/Orn/Yel | | O7 NC | Wht/Blk/Grn |
| | F2 10 | Wht/Orn/Grn | | O6 NC | Wht/Blk/Blu |
| | F1 9 | Wht/Orn/Blu/ | | O5 NC | Wht/Blk/Vio |
| | G1 7 | Wht/Brn/Red | | O4 NC | Wht/Blk/Gry |
| | G2 8 | Wht/Brn/Orn | | O3 NC | Wht/Grn/Gry |
| | G4 32 | Wht/Brn/Yel | | O2 NC | Wht/Blu/Vio |
| | G8 33 | Wht/Brn/Grn | | O1 NC | Wht/Blu/Gry |
| | | | Print Inhibit | OØ (22) | Wht/Vio/Gry |

*FLG 1 is used on the output of OØ to provide a pull-up. The pull-up cannot be at the 5505A end as 9815A power-off would inhibit the display.

# Basic Software Description and Operation

## INTRODUCTION

The 10585A Metrology Program Package consists of two Metrology program cartridges and one set of user-definable Key Overlays. It is suggested that the user store away one metrology program package in a safe place as a backup for the future.

There is a special Key Overlay which is used for each specific metrology program. A picture of the proper Key Overlay is provided in the description of each metrology program.

The Metrology Program Tape Cartridge is used to store various metrology programs as well as user-generated data which can be recalled for future use. Table 2-1 identifies the available data storage files. 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.

The metrology programs are written such that there is an interplay between the 9815A Calculator and its cartridge reader. Therefore, often during the running of a program the cartridge reader will start up and read a new file. This operation is normal. It will also freeze the Laser Display during program entries.

Eventually, after heavy usage, the Metrology Program Cartridge will wear out and the 9815A Calculator will not be able to read a file. At this point it is best to take a new tape cartridge and copy the spare metrology cartridge according to the instructions provided in Section 3.

In writing programs for direct input of data from the 5505A Laser/Display it may be necessary to scale the data to obtain the desired numeric answer. This is required because the interface cable as wired does not include the decimal point locator.

Throughout the Metrology Program Package, a positive response to a simple yes/no question posed by the 9815A Calculator is accomplished by entering:

Ø followed by pressing the **RUN STOP** key ..... for a **YES** response.
**RUNSTOP** without an entry ..... for a **NO** response.

**NOTE**

Do not utilize the Keyboard while the Calculator Display reads dashes (----). This signifies that the Calculator is responding to the software. When the Calculator returns it may interpret the Keyboard entry as a response and either incorrectly perform the next step or futilely try to perform an errant step.

*Table 2-1. Available Data Files*

| | **Data Description** |
|---|---|
| 32 | |
| 33 | |
| 34 | |
| 35 | |
| 36 | |
| 37 | |
| 38 | |
| 39 | |
| 40 | |
| 41 | |
| 42 | |
| 43 | |
| 44 | |
| 45 | |
| 46 | |
| 47 | |
| 48 | |
| 49 | |
| 50 | |
| 51 | |
| -1 | |
| -2 | |
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| -4 | |
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| -29 | |
| -30 | |
| -31 | |
| -32 | |
| -33 | |
| -34 | |
| -35 | |
| -36 | |
| -37 | |
| -38 | |

# INDIVIDUAL SOFTWARE PROGRAMS

The Metrology Program Package includes a set of eight special Key Overlays. The Key Overlays are used in conjunction with the Initialization Program to identify the User-defined Keys and specific setup and format conditions.

The User-definable Keys (A-O) located on the 9815A Calculator keyboard are broken up into an UPPER and LOWER case. The UPPER case, which defines the specific metrology program being used, is obtained by pressing the SHIFT (E) key first. Then the key which has the metrology program desired printed above it is pressed and the calculator printer will print the name of the selected metrology program. All the UPPER case functions are color coded in red.

The LOWER case keys are used to define for the 9815A Calculator the MODE OF OPERATION of the 5526A Laser Measurement System and to set up the data presentation provided by the specific metrology program. Each key overlay has printed on it only those setup conditions which are pertinent to the particular metrology program selected. The lower case keys are color coded in black *except* the **CLEAR** *key* which is blue. The CLEAR key is used to restart the Initialization Program when an error in entry is made only during Initialization.

### Upper Case Metrology Program Keys

(Color Coded in Red and above the corresponding key on the key overlays)

*Table 2-2. Upper-Case Metrology Program Keys*

| Key | Description |
|---|---|
| (E) SHIFT<br>On all Key Overlays | Used to shift to upper-case key functions. *It must be pressed once first before an upper-case key function is executed.* |
| (A) SURFACE PLATE CALIBRATION<br>Key Overlay #1 | Used to select the Surface Plate Calibration Program. |
| (B) STANDARD ERROR<br>Key Overlay #2 | Used to select the Standard Error Analysis program for single runs of Linear displacement. |
| (C) GENERALIZED ERROR<br>Key Overlay #7 | Used to select the Generalized Error Analysis Program for Multiple runs of Linear Displacement for Accuracy, Precision and Backlash measurements. |
| (D) STATISTICAL ERROR<br>Key Overlay #8 | Used to select the Statistical Error Analysis program. To format and plot multiple runs of *Linear Displacement* gathered in *Generalized Error.* |
| (F) STR. SOR. PRLL<br>Key Overlay #2 | Used to select the Straightness, Squareness, and Parallelism program. |
| (G) ANGULAR ERROR<br>Key Overlay #2 | Used to select the Angular Error Analysis program. |
| (H) WAVELENGTH COMPENSATION - Key Overlay #5 | Used to select the wavelength Compensation Calculation program. |
| (K) ISOMETRIC PLOT<br>Key Overlay #3 | Used to select the Isometric Data Plot program. |
| (L) NUMERIC PLOT<br>Key Overlay #4 | Used to select the Numeric Data Plot program. Either all positive data or +/- data plots. |
| (M) LARGE ANGLE CORRECTION<br>Key Overlay #6 | Used to select the Large Angle Correction program. |
| (O) LIST<br>On all Key Overlays | Used to list the setup conditions selected. |

*Note: Keys are color coded in red and above the corresponding key on the key overlays.*

*Table 2-3. Lower-Case Mode of Operation Keys*

| Key | Description |
|---|---|
| (A) ENGLISH | Identifies that the measurement is being made using English units. |
| (B) METRIC | Identifies that the measurement is being made using Metric units. |
| (C) AUTO DATA TRANSFER | Specifies that the data being taken is to be transferred directly between the 5505A Laser/Display and the 9815A Calculator. |
| (D) KEYBOARD DATA ENTRY | Specifies that the data will be entered manually via the numeric keyboard on the 9815A Calculator. |
| (F) PRINTOUT | Used to select a printout of the finalized data on the 9815A Calculator printer. |
| (G) PLOT | Used to select a graphical plot of the finalized data on the 9862A or 7225A Digital Plotter. |
| (H) NORMAL | Identifies that the measurement is being made with the 5505A Laser/Display in the Normal or Smooth operating mode. |
| (I) X10 | Identifies that the measurement is being made with the 5505A Laser/Display in the X10 (times 10 resolution extended) operating mode. |
| (J) PRE-RECORDED DATA FILE | Used to input a previously recorded data file into the calculator for use in a metrology program. This function *requires* that the file number be entered via the numeric keyboard on the 9815A Calculator *before* this key is pressed. |
| (K) DEGREES | Used in conjunction with Large Angle Correction program to specify the corrected angle to be printed in degree units. |
| (L) ARCSECONDS | Used in conjunction with Large Angle Correction program to specify the corrected angle to be printed in seconds of arc units. |
| (M) RADIANS | Used in conjunction with the Large Angle Correction program to specify the corrected angle to be printed in radian units. |
| (K) POSITIVE DATA | Used in conjunction with the Numeric Plot program to specify the plot to be presented in the positive data format. |
| (L) +/- DATA | Used in conjunction with the Numeric Plot program to specify the plot to be presented in the +/- data format. |
| (M) GRID LINES | Used in conjunction with the Numeric Plot program to specify the drawing of the baseline grid pattern on the plot. |
| (O) CLEAR | *(Color Coded in Blue)*<br>Used to completely clear the selected metrology program and set-up conditions previously selected. The Initialization program will be restarted when the CLEAR key is pressed. |

*Note: Keys are color coded in black and below the corresponding key on the key overlays.*

## Auto Start

(How To Start The Calculator)

1. Insert the Metrology Program Cartridge into the 9815A Calculator cartridge reader/tape drive.

   If data is to be directly inputted from the 5505A Laser/Display into the 9815A Calculator:

   A. A jumper wire inside the 5526A Laser/Display may have to be cut. See NOTE on page 1-1.

   B. Follow the instructions on page 1-1 and connect the hardware as described in Figure 1-1.

2. Set the CALCULATOR MODE slide switch on the 9815A Calculator to AUTO START (see Figure 2-1).

3. Set the PRINTER MODE switch on the 9815A Calculator to NORM.

4. Turn the 9815A Calculator on. AUTO START will be printed and dashes will appear across the 9815A Calculator Display.

**NOTE**

Do not attempt to use the Keyboard while dashes appear on the Display. Displayed functions or key strokes may be interpreted as answers to questions the program directs the calculator to ask when it returns from performing a task. It may be necessary to start over by turning the 9815A Calculator off and on again.

INITIALIZATION PROGRAM will be printed after a short delay.

The 9815A Calculator is now ready for you to initiate a program from the Metrology Program Package. See Table of Contents for listing of programs.

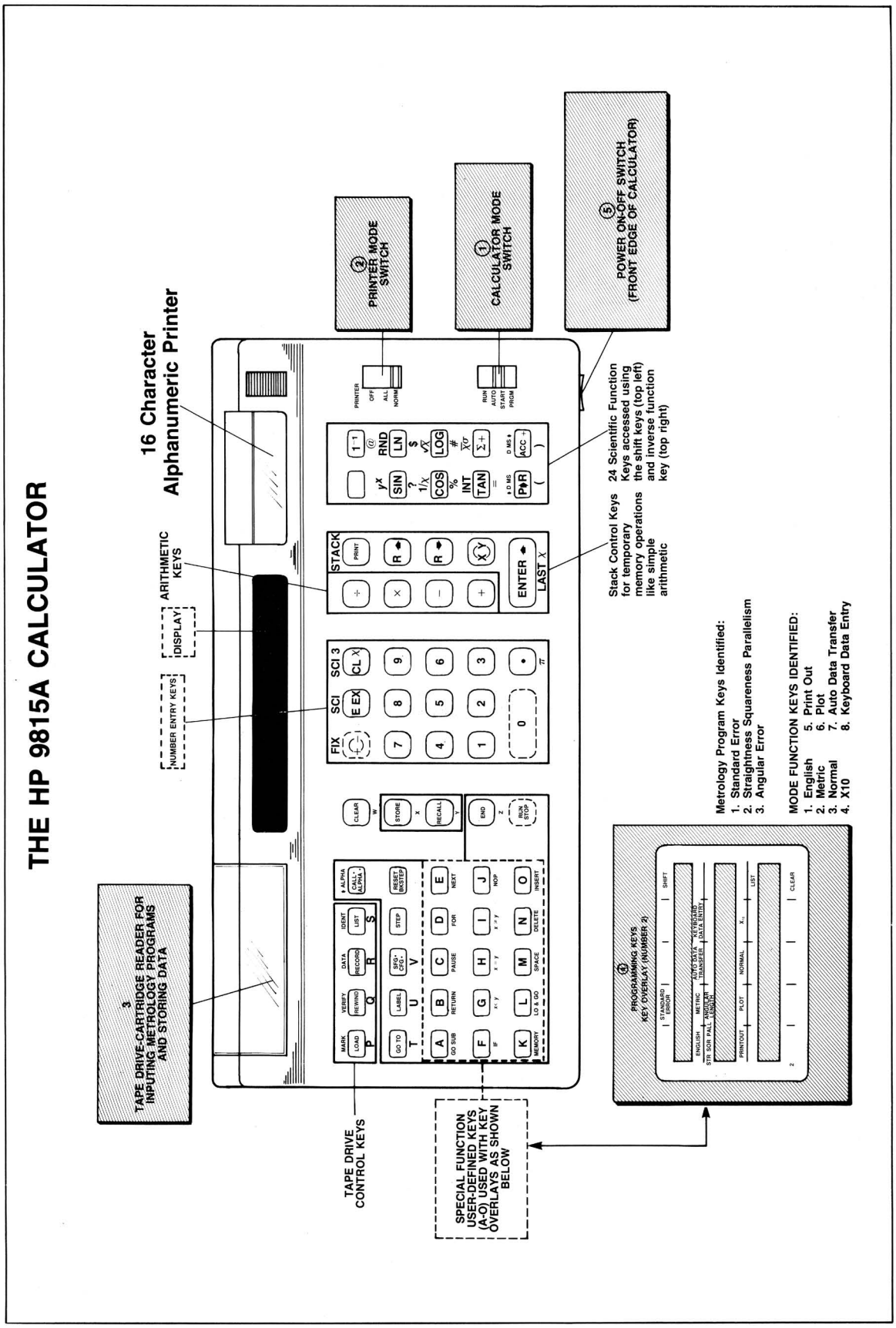



*Figure 2-1. HP 9815A Calculator*

## INITIALIZATION PROGRAM

(How To Select and Run a Program)

The first program located on the Metrology Program Cartridge is the Initialization Program. This program is read into the 9815A Calculator when the operating mode switch on the calculator is set in the AUTO START position and the calculator is turned on. The purpose of the initialization program is to set up specific measurement and data presentation conditions inside the 9815A Calculator before a metrology program is run.

1. Insert the Metrology Program Cartridge into the 9815A Cartridge Reader.

2. Set the mode switch on the 9815A Calculator keyboard to AUTO START.

3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.

4. Turn the 9815A Calculator on. AUTO START and INITIALIZATION PROGRAM will be printed.

5. Select the key overlay which contains the metrology program of interest and place it on the 9815A keyboard.

6. Press the red SHIFT (E) key and then press the key below the desired metrology program, also in red. The name of the selected metrology program will be printed on the calculator printer.

7. Select the desired or appropriate modes of operation for the particular conditions. The selectable modes are listed below the appropriate keys on each key overlay. Each function selected will be printed on the Calculator printer.

8. When a pre-recorded data file is to be entered (when available it will be listed on the key overlay), the numeric data file number must be first entered via the numeric keyboard on the calculator and displayed on the calculator's display. Press the PRE-RECORDED DATA FILE (J) key.

   If the file number entered is an illegal number (i.e., Ø through 31, or -Ø) ILLEGAL FILE # ENTER NEW FILE # will be printed. Enter a new data file number and press the PRE-RECORDED DATA FILE (J) key.

9. If an error was made during steps 6, 7, or 8, press the CLEAR(O) key on the key overlay. INITIALIZATION PROGRAM will be printed. Return to step 6.

---

**NOTE**

This is one of the few times an error can be corrected without starting over by turning the 9815A Calculator off and on again.

---

10. For a listing of the mode keys selected press the SHIFT key and then the LIST (O) function. A printout of the selected setup (functions will be provided on the calculator printer. If no setup functions were selected, QUESTIONS NOT ANSWERED will be printed. Return to step 7.

    If no program was selected in step 6 PROGRAM NOT SELECTED will be printed. Return to step 6.

11. Press the RUN STOP key and refer to the section which covers the specific metrology program selected.

---

**NOTE**

The Initialization Program will check to see if two mutually exclusive setup conditions have been selected. Any of the following printouts may occur if an error was made in the initialization process:

---

ENGLISH AND METRIC UNITS SELECTED

AUTO DATA TRANS AND KEYBOARD INPUT SELECTED

NORMAL MODE AND X10 SELECTED

NO DATA FILE SELECTED (will appear only for Isometric Data Plot, Numeric Data Plot, or Statistical Error Analysis programs)

POSITIVE AND =DATA FORMAT SELECTED (Will appear only for the Numeric Data Plot program)

PROGRAM NOT SELECTED

After the error message, INITIALIZATION PROGRAM will be printed. Return to step 6.

If a metrology program was not selected in step 6, PROGRAM NOT SELECTED will be printed. Return to step 6.

## SURFACE PLATE CALIBRATION

This program computes the flatness contours of a surface plate according to accepted practices. Once the calculations for a completed line have been made the results will be printed on the calculator printer. When all lines are completed, the user then has the choice of plotting contours or numeric flatness data with key overlays number 3 or 4. Data can be entered directly from the 5505A 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 or after a plot.

The individual components are described in their respective operation manuals and the complete surface plate calibration procedure is explained in Application Note 156-2.

- Caution should be used in certain areas of the operation of the program. These areas include the input of the data for an inspection line and the editing of a previously input line of data.

- The program automatically assigns a value of zero to the first data point on any line and Application Note 156-2 should be consulted for configurations and procedures. When editing a previously inputted line of data, the number of points may exceed the number in the original line of data. However, one must be careful so as not to exceed the upper limit on the total number of points accepted.

- This program breaks down the memory storage area of the calculator into two groups with lines 1, 2, 3, and 4 being stored on the left side of the decimal point and lines 5, 6, 7, and 8 being stored on the right-hand side of the decimal point. Therefore, the sum total of data points in lines 1, 2, 3, and 4 or lines 5, 6, 7, and 8 cannot exceed a total of 135 points.

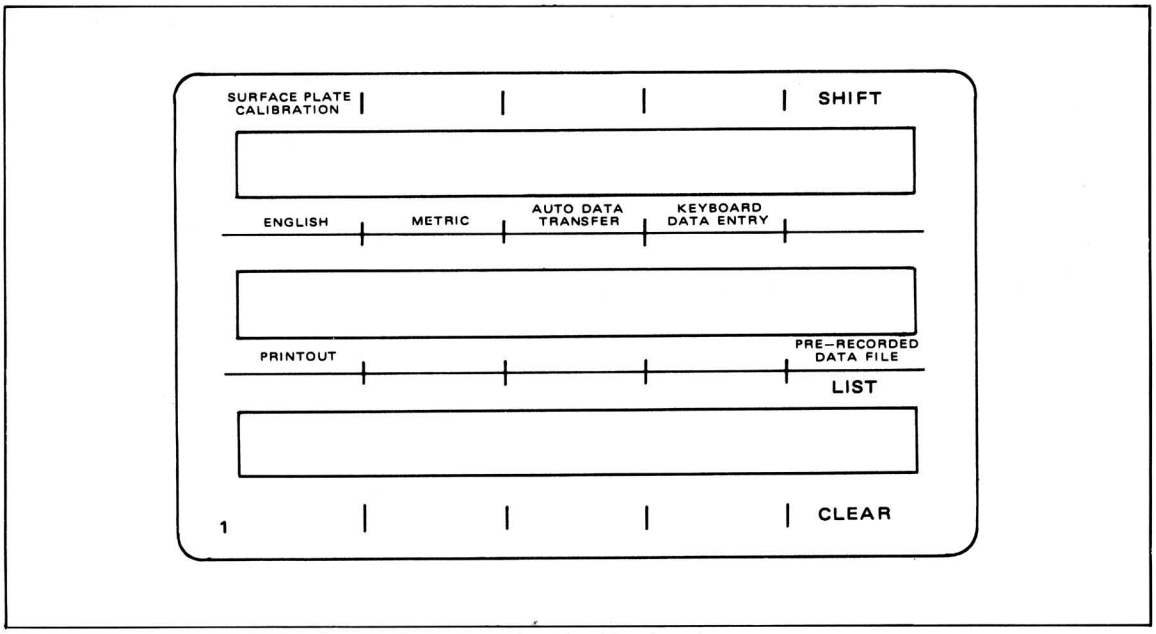



*Figure 2-2. Key Overlay Number 1*

1. Insert the Metrology Program Cartridge into the 9815A Cartridge Reader.

2. Set the operating mode switch on the 9815A Calculator Keyboard to AUTO START.

3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.

4. Turn the 9815A Calculator on. AUTO START and INITIALIZATION PROGRAM will be printed.

5. Place the Surface Plate Calibration Key Overlay #1 on the 9815A Keyboard.

6. Press the SHIFT key and then the SURFACE PLATE CALIBRATION key. SURFACE PLATE CALIB will be printed.

7. Select the appropriate or desired Modes of Operation Keys for the measurement from the Key Overlay and press the RUN STOP key. (For a better description on the key overlay and setup keys refer to the section titled INITIALIZATION PROGRAM.)

8. EDITING STORED DATA: During selection of the function keys enter the file number containing the data to be edited on the numeric keys and press PRE-RECORDED DATA FILE. Data entered in steps 14 through 20 will replace data already stored and be processed automatically.

9. SURFACE-PLATE CALIBRATION, *(X10 Mode must be used)*, and ENTER PLATE ID # will be printed after a brief pause.

10. If you wish to enter an identification number for the surface plate being calibrated, press the proper numeric keys and press the RUN STOP key.

**NOTE**

The surface plate ID # must be an integer value, i.e., 123456.

If you do not wish to enter an ID # then press the RUN STOP key with no entry and go to step 12.

11. DATE? will be printed. Enter today's date in either of the two following formats:

    Month, Decimal Point, Two-numeral Day
    and Four-numeral Year or

    Day, Decimal Point, Two-numeral Month
    and Four-numeral Year.

    (Example: June 8, 1976 can be entered as either
    6.081976 or 8.061976.)

    and press the RUN STOP key.

12. ±LINE NUMBER? will be printed. If all the data has been entered press the RUN STOP key and go to step 21. If a data line is to be entered, enter the desired LINE NUMBER (any order of 1 through 8) if the retroreflector moves away from the interferometer, enter a negative LINE NUMBER (1 through 8) if the retroreflector moves toward the interferometer.

**NOTE**

See Figure 9 of Application Note 156-2 and accompanying explanation to determine the ±LINE NUMBER.

Press the RUN STOP key.

13. FOOT SPACING? will be printed. Enter the FOOT SPACING being used in either English or Metric units and press the RUN STOP key.

    If the RUN STOP key is pressed without a foot spacing entered, the spacing of the 10559A Reflector Mount (2.0625 inches, or 52.3875 millimeters) is automatically used.

14. DATA? will be printed. If AUTOMATIC DATA ENTRY was selected go to step 18.

15. Enter the data point via the 9815A Calculator numeric keyboard and press the RUN STOP key.

**NOTE**

Input the data with the same sign as is displayed by the 5505A Laser/Display.

16. The entry will be printed. Continue to enter each data point via the procedure in step 15. When the last data point has been entered and printed press the RUN STOP key.

17. The input data will be normalized and printed. Return to step 12.

**NOTE**

Lines 3, 4, 5, 6, 7, and 8 require an even number of data points to be taken. The calculator adds a zero end point and expects the result to be an odd number of points.)

18. For automatic data input, position the equipment for the first input data point. 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, printed, and the calculator will be ready for the next data point.

19. Move the Retroreflector to the next point and repeat step 18. When the last data point has been transmitted and printed, press the RUN STOP key twice.

20. The input data will be normalized and printed. Return to step 12 if more lines are to be recorded. Go to 21 if all lines are recorded.

21. Editing a line before data is stored in a file: If a data point is entered in error the line can be repeated by first completing the line (reserves adequate memory space), and then returning to step 12 and entering the desired line again.

22. When all the data has been entered the calculator display will read ±LINE NUMBER? Press RUN STOP twice. It will take approximately 30 seconds to process the data. The closure errors and the maximum elevation will be printed. If a printout was not asked for in the initialization program, go to step 23.

    If lines 3, 4, 5, 6, 7, or 8 contain an even number of points (data points taken plus one) LINE n EVEN # OF PTS will be printed. Go to step 12.

**NOTE**

The two diagonal lines (1 and 2) are allowed to contain an even number of points.)

23 .If a printout was asked for in the Initialization Program a complete listing will be generated.

**NOTE**

If a surface plate ID # and date of calibration was entered during step 10 it will also be printed at this time.

24. ENTER FILE # FOR DATA STORAGE will be printed. Enter the available file number and press the RUN STOP key.

    If the file number entered is an illegal number (i.e., Ø through 31, or -Ø) ILLEGAL FILE # will be printed. Enter a new data file number and press the RUN STOP key.

**NOTE**

The data must be stored on a file before it can be plotted via the ISOMETRIC or NUMERIC program.

25. The data will be stored in the file # given and the Initalization Program will be reread into the calculator and run. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

    To plot the data just taken, a Data Storage File must be selected and the 9815A Calculator will store the data in that file. The available data storage files are listed on page 2-2. Once the data is stored the 9815A Calculator will be ready to enter the desired format program. You can choose Isometric Plot overlay number 3, or Numeric Plot overlay number 4 with either all positive data or + and - data. See Application Note 156-2 for instructions.

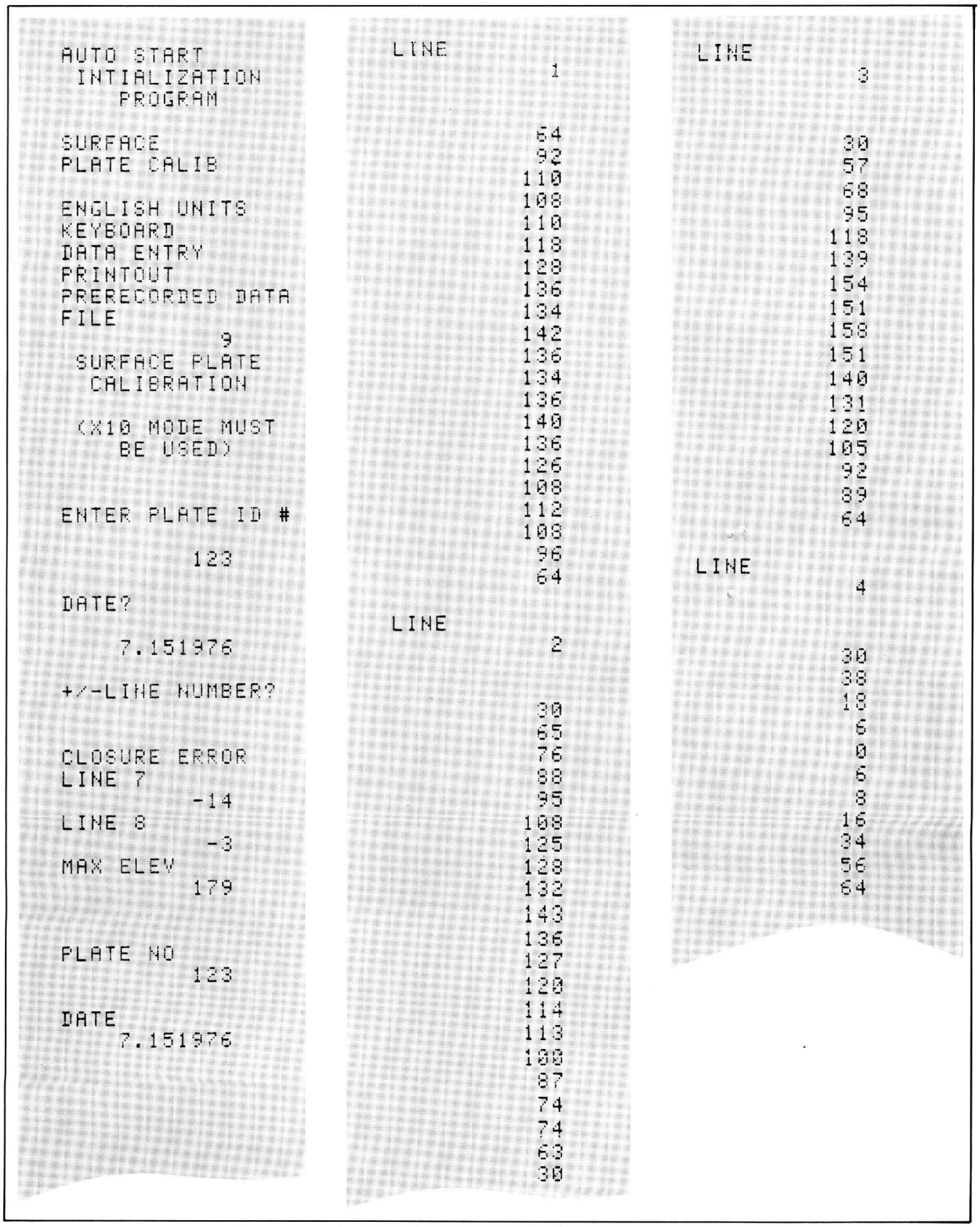



*Figure 2-3. Surface Plate Calibration Example Printout*

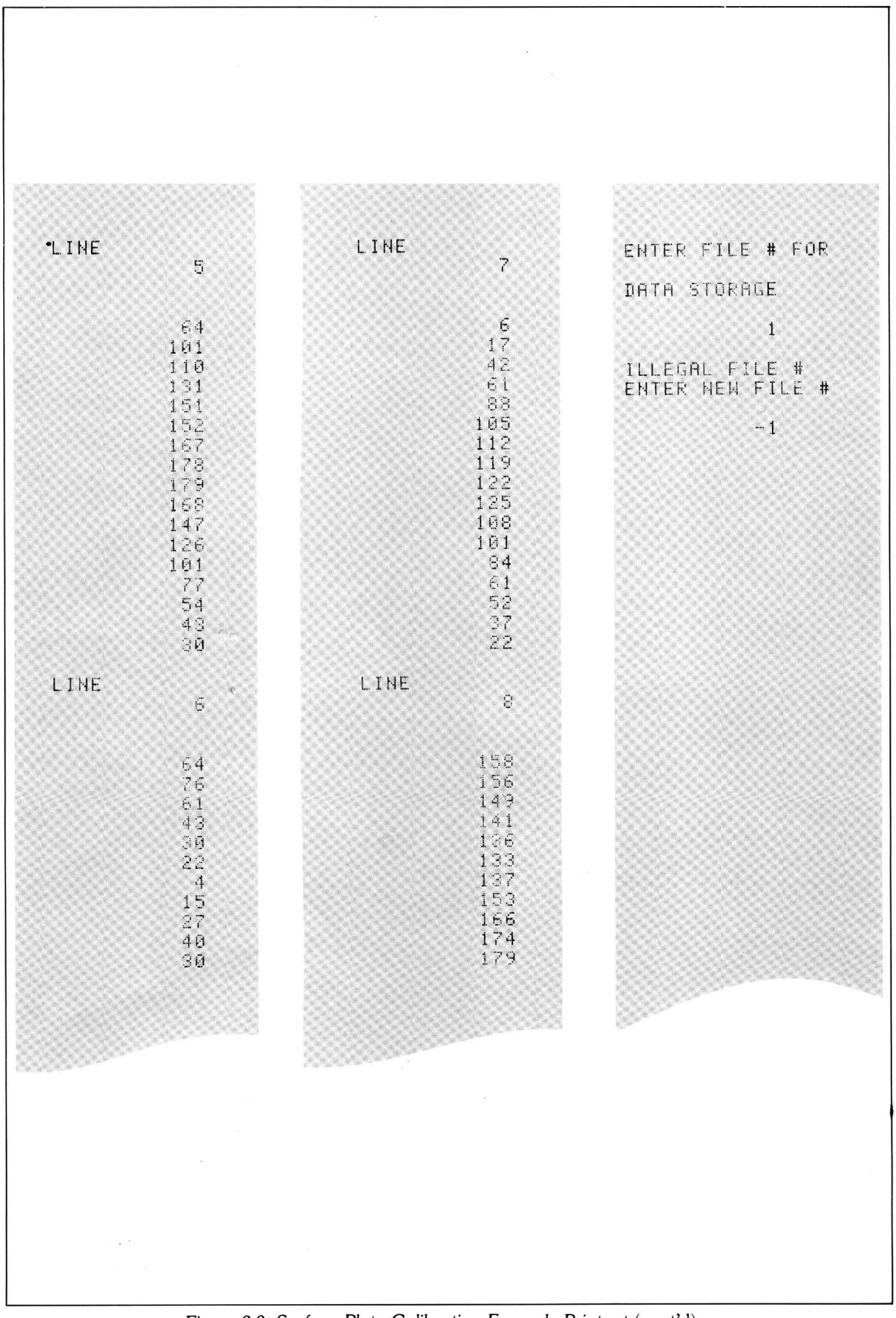



*Figure 2-3. Surface Plate Calibration Example Printout* (cont'd)

## ISOMETRIC DATA PLOT

This program takes the contour data generated by the Surface Plate Calibration Program and plots it isometrically on the 9862A or 7225A Digital Plotter. The isometric plot has variable tilt and rotational angles which allow different perspective views of the surface plate profile. This type of data presentation is very useful for determining areas needed rework, or those particularly flat areas which should be used for critical work.

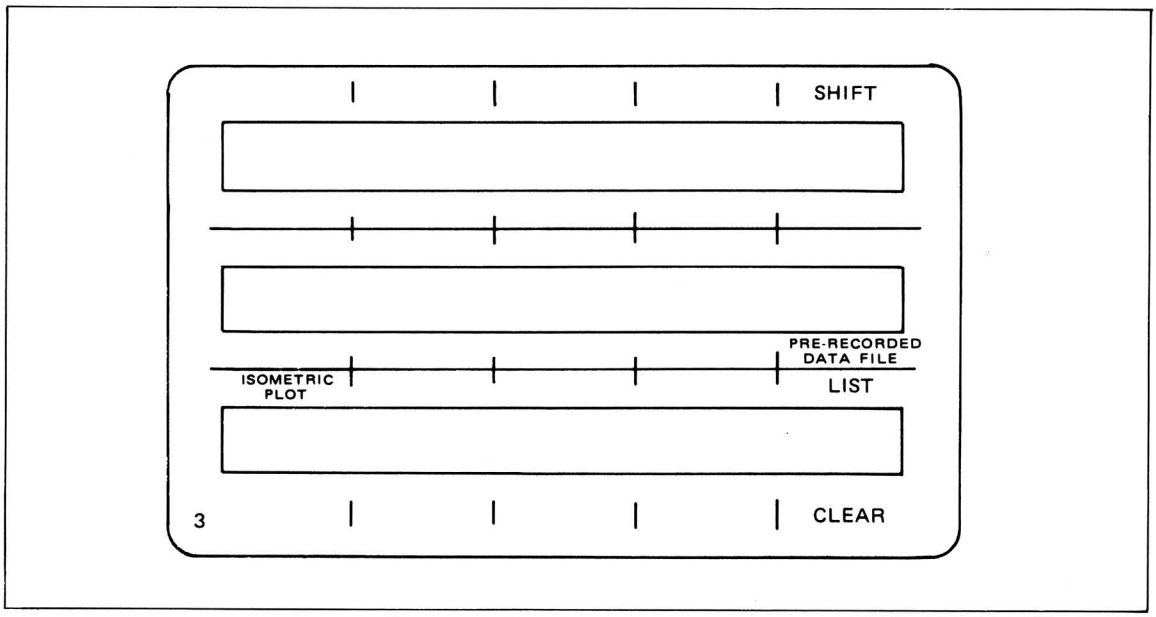



*Figure 2-4. Key Overlay Number 3*

1. Insert the Metrology Program Cartridge into the 9815A Cartridge reader.
2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.
3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.
4. Turn the 9815A Calculator on.
5. Place a new sheet of paper on the 7225A Plotter and turn the plotter on.
6. AUTO START and INITIALIZATION PROGRAM will be printed.
7. Place the ISOMETRIC PLOT key overlay on the 9815A keyboard.
8. Press the SHIFT key and then the ISOMETRIC PLOT key. ISOMETRIC PLOT will be printed.
9. Enter the file number which contains the surface plate data to be plotted via the numeric keys and press the PRE-RECORDED DATA FILE key. (A sample set of surface plate data is provided in file 9.)
10. Press the RUN STOP key and the 9815A Calculator will read the proper file on the Metrology Program Cartridge.
11. ISOMETRIC PLOT and TILT ANGLE? will be printed. If a tilt angle other than 10° is desired, enter the angle and press the RUN STOP key. If a 10° tilt angle is appropriate, do not make an entry and press the RUN STOP key.
12. ROT. ANGLE? will be printed. If a rotation angle other than 35° is desired, enter the angle and press the RUN STOP key. If a 35° rotation angle is appropriate, do not make an entry and press the RUN STOP key.

13. The baselines of the plot will be drawn and CHANGE PEN? will be printed. A different color pen can then be loaded on the plotter to give more contrast in the plot.

14. Press the RUN STOP key and the isometric plot will be generated.

15. If a surface plate ID number and data of calibration was originally given in the Surface Plate Calibration program these will be plotted. If no surface plate ID number was provided originally then none will be plotted.

16. The Initialization Program will be reread into the calculator and run. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

```
AUTO START
 INTIALIZATION
    PROGRAM

ISOMETRIC PLOT

PRERECORDED DATA
FILE
            -1
ISOMETRIC PLOT


TILT ANGLE?

            10

ROT. ANGLE?

            35

CHANGE PEN?
```

*Figure 2-5. Isometric Plot Example Printout*

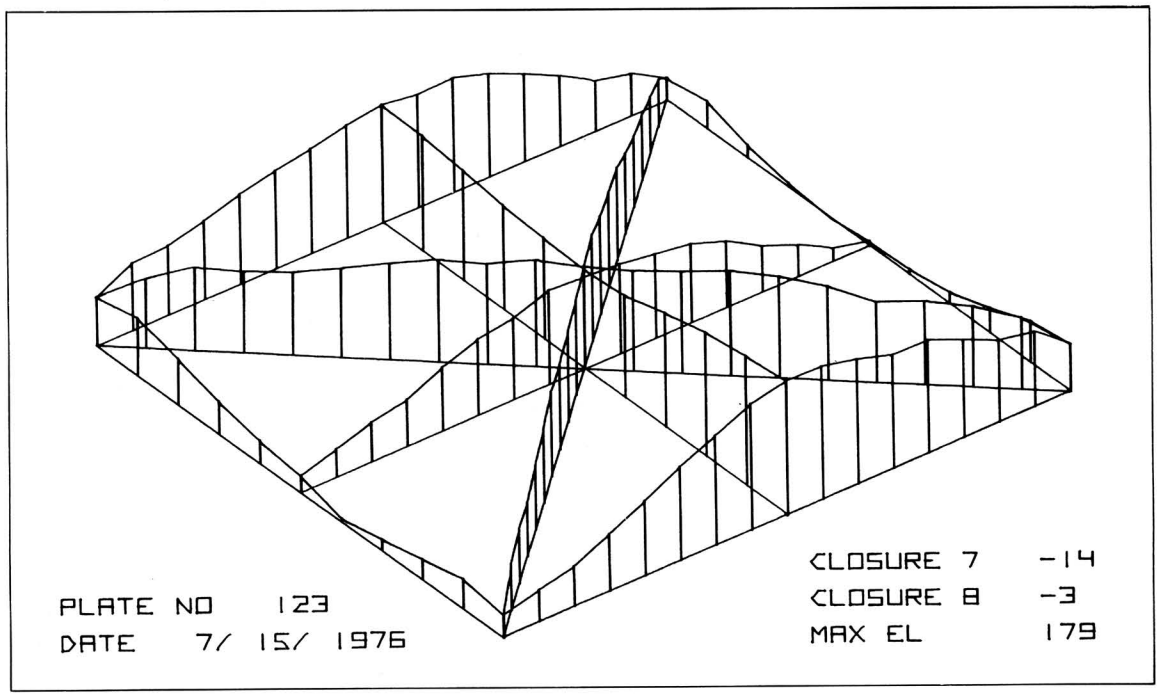



*Figure 2-6. Example Isometric Data Plot*

## NUMERIC DATA PLOT

This program takes the data generated by the Surface Plate Calibration Program and plots it on the 9862A or 7225A Digital Plotter in the most common formats used for certification certificates. This type of display allows the user to have a completely automated data handling procedure from raw, uncorrected readings on the 5505A Laser/Display to the final certification plot.

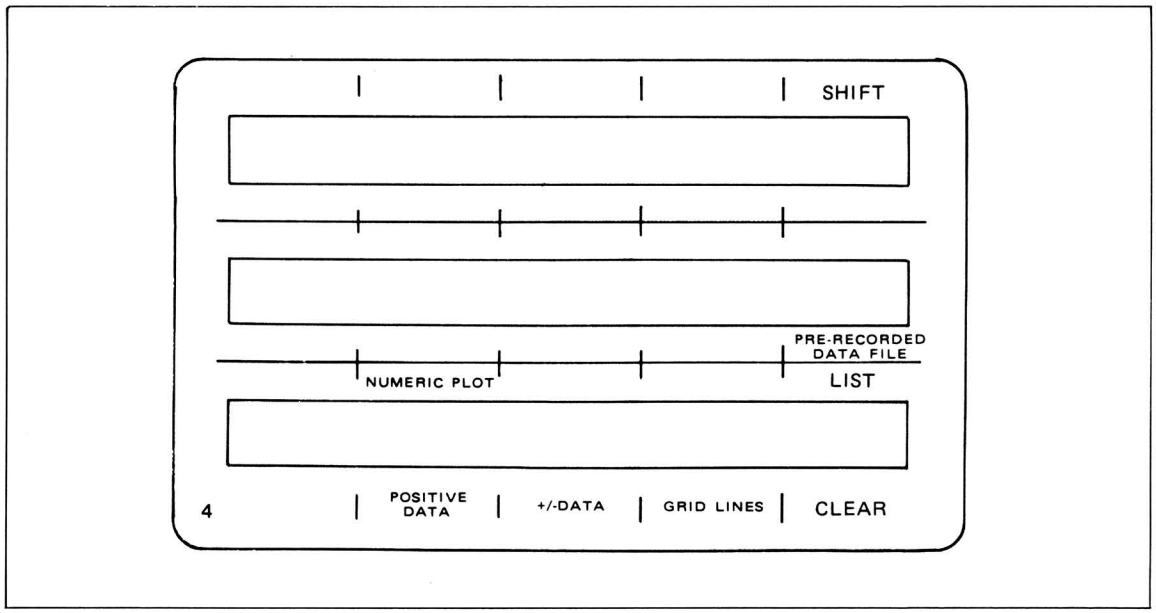



*Figure 2-7. Key Overlay Number 4*

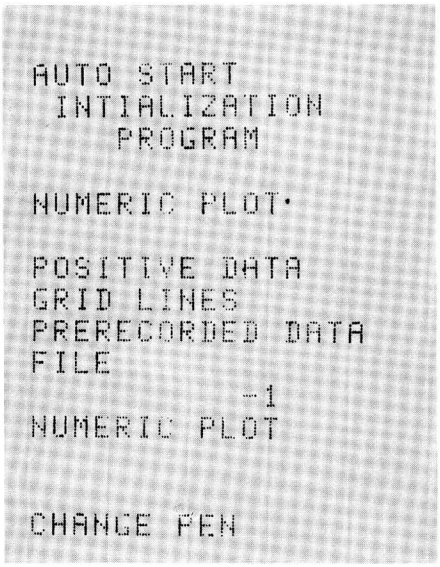
1. Insert the Metrology Program Cartridge into the 9815A Cartridge reader.
2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.
3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.
4. Turn the 9815A Calculator on.
5. Place a new sheet of paper on the 9862A Plotter and turn the plotter on.
6. AUTO START and INITIALIZATION PROGRAM will be printed.
7. Place the NUMERIC PLOT key overlay on the 9815A keyboard.
8. Press the SHIFT key and then the NUMERIC PLOT key. NUMERIC PLOT will be printed.
9. Press either the POSITIVE DATA or ±DATA key for the type of data presenttion desired in the plot. Also select the GRID LINES keys if desired.
10. Enter the file number which contains the surface plate data to be plotted via the numeric keys and press the PRE-RECORDED DATA FILE key. (A sample set of surface plate data is provided in file 9.)
11. Press the RUN STOP key and the 9815A Calculator will read the proper file on the Metrology Program Cartridge.
12. NUMERIC PLOT will be printed. If grid lines were selected the 9862A Plotter will draw the grid lines and CHANGE PEN? will be printed. A different color pen can then be loaded on the plotter to give more contrast in the plot. Press the RUN STOP key.

13. The 9862A or 7225A will now generate the numeric plot.

14. If the surface plate ID number and date of calibration was originally given in the SURFACE PLATE CALIBRATION program these will be plotted. If no surface plate ID number was provided originally then none will be plotted.

15. The Initialization Program will be reread into the calculator and run. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

Numeric Plot with Positive Data




Numeric Plot with +/- Data

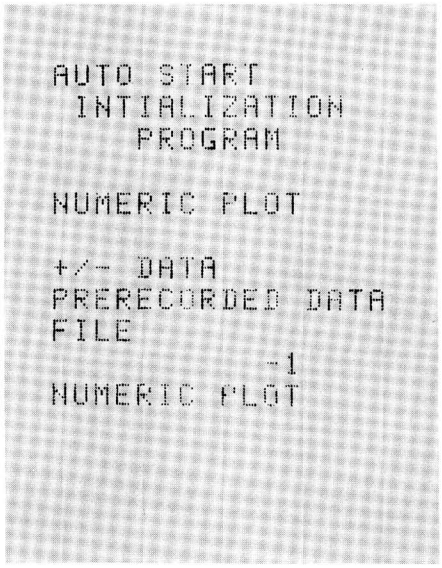
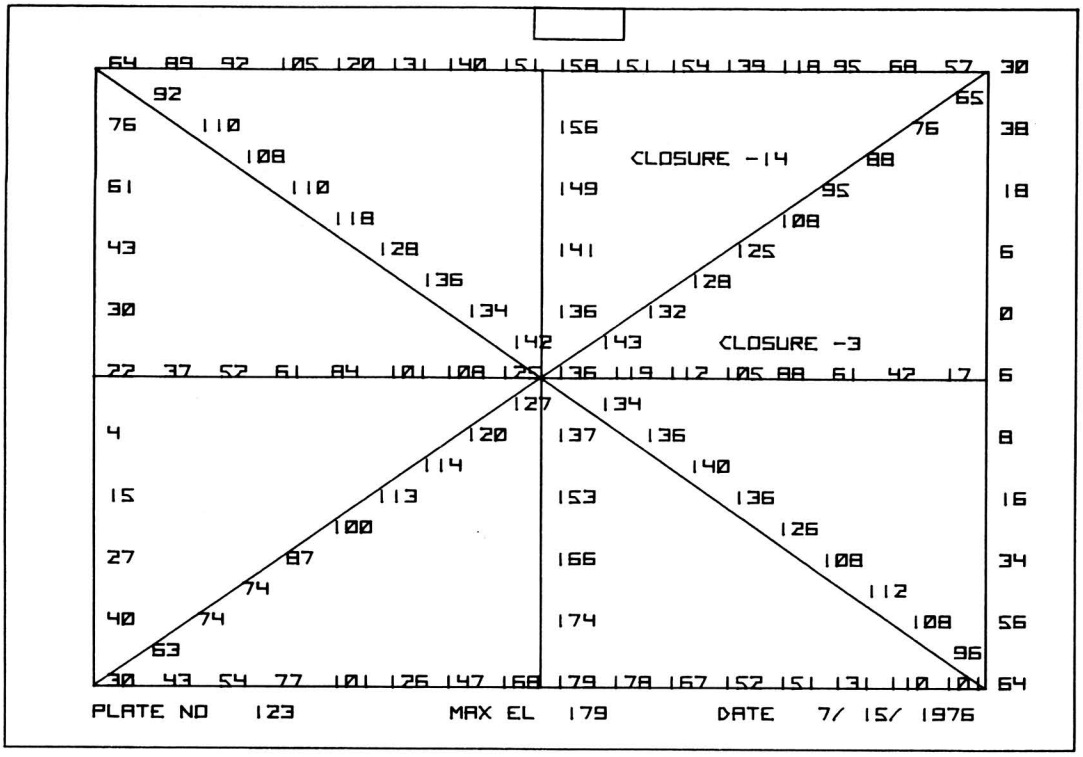



*Figure 2-8. Numeric Plot Example Printout*



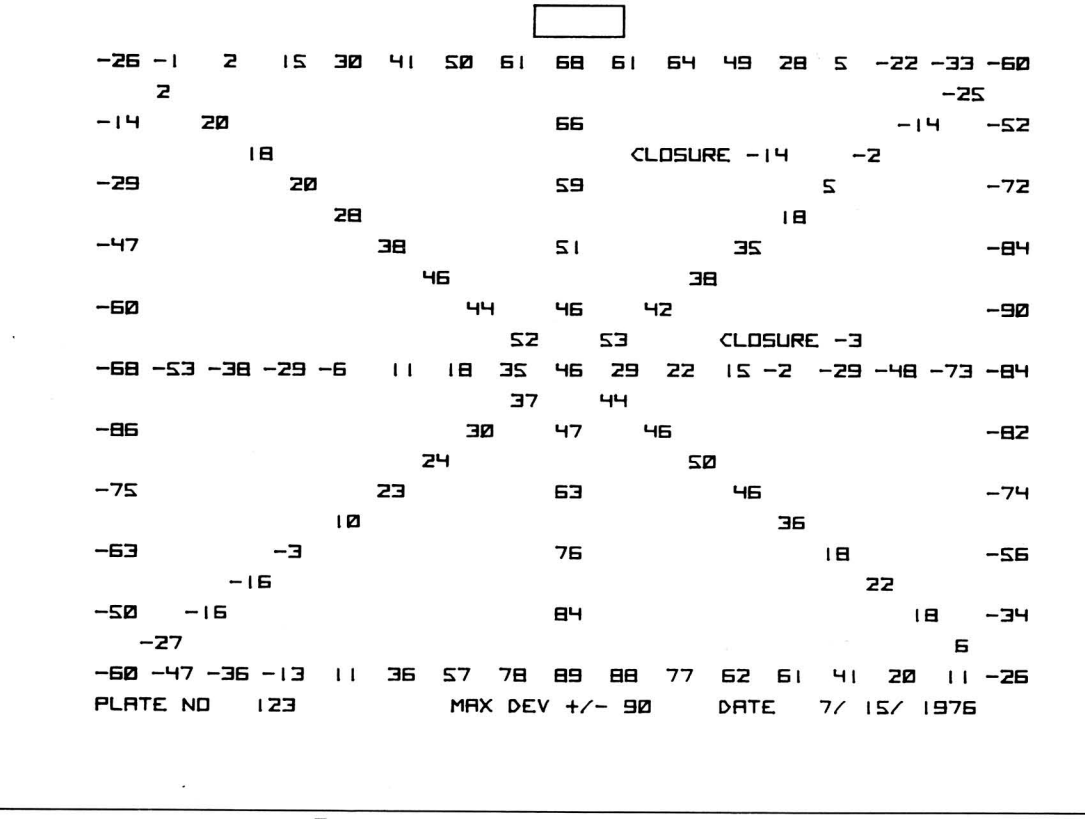




*Figure 2-9. Example Numeric Data Plots*

## LARGE ANGLE CORRECTION

This program supplements the 5526A Angular/Flatness Interferometer. Data can be transmitted directly from the 5505A Laser/Display to the calculator or entered via the keyboard. The corrected reading will be printed in radians, arcseconds, and/or degrees. For small angles (<3,000 arcseconds from the starting point) the readout on the display unit is linear and correct. Larger angular readings must be corrected. The formula used by the calculator program is:

$$\theta_a = \text{arc sin} \quad \frac{\text{Laser Display Reading}}{2.0625}$$

where $\theta_a$ is the corrected angle.

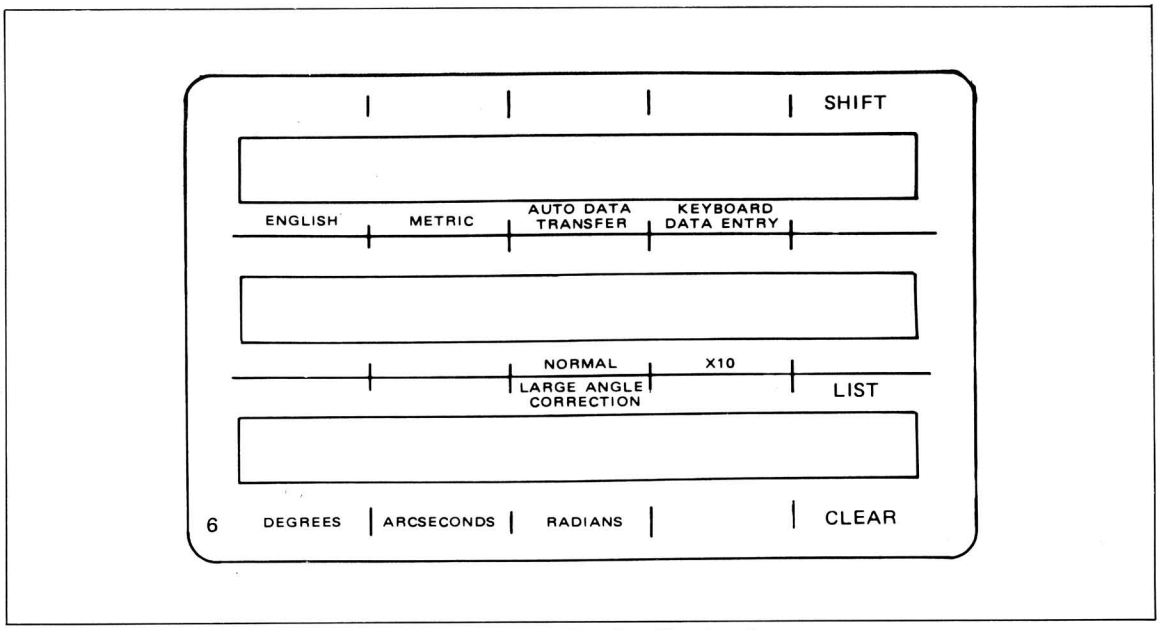



*Figure 2-10. Key Overlay Number 6*

1. Insert the Metrology Program Cartridge into the 9815A Cartridge Reader.
2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.
3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.
4. Turn the 9815A Calculator on.
5. AUTO START and INITIALIZATION PROGRAM will be printed.
6. Place the Large Angle Correction key overlay on the 9815A keyboard.
7. Press the SHIFT key and then the LARGE ANGLE CORRECTION key. LARGE ANGLE CORRECTION will be printed.
8. Select the proper setup keys for the measurement and press the RUN STOP key. (For a better description on the key overlay and setup keys refer to the section title INITIALIZATION PROGRAM.

**NOTE**

The corrected angle can be printed out in Degrees, Arcseconds and Radians. Any combination can be selected.

9. The 9815A Calculator will read the proper file on the Metrology Program Cartridge.

10. LARGE ANGLE CORRECTION will be printed.

11. INPUT DATA will be printed. If automatic data transfer was selected go to step 13.

    If the last data point has been entered, corrected, and printed, press the RUN STOP key. The Initialization Program will be reread into the calculator and run. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

12. Enter the data point with decimal point and sign exactly as it appears on the 5505A Laser/Display via the 9815A Calculator numeric keyboard and press the RUN STOP key.

13. 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.

14. The data will be corrected and printed according to the previously selected format. Return to step 11.

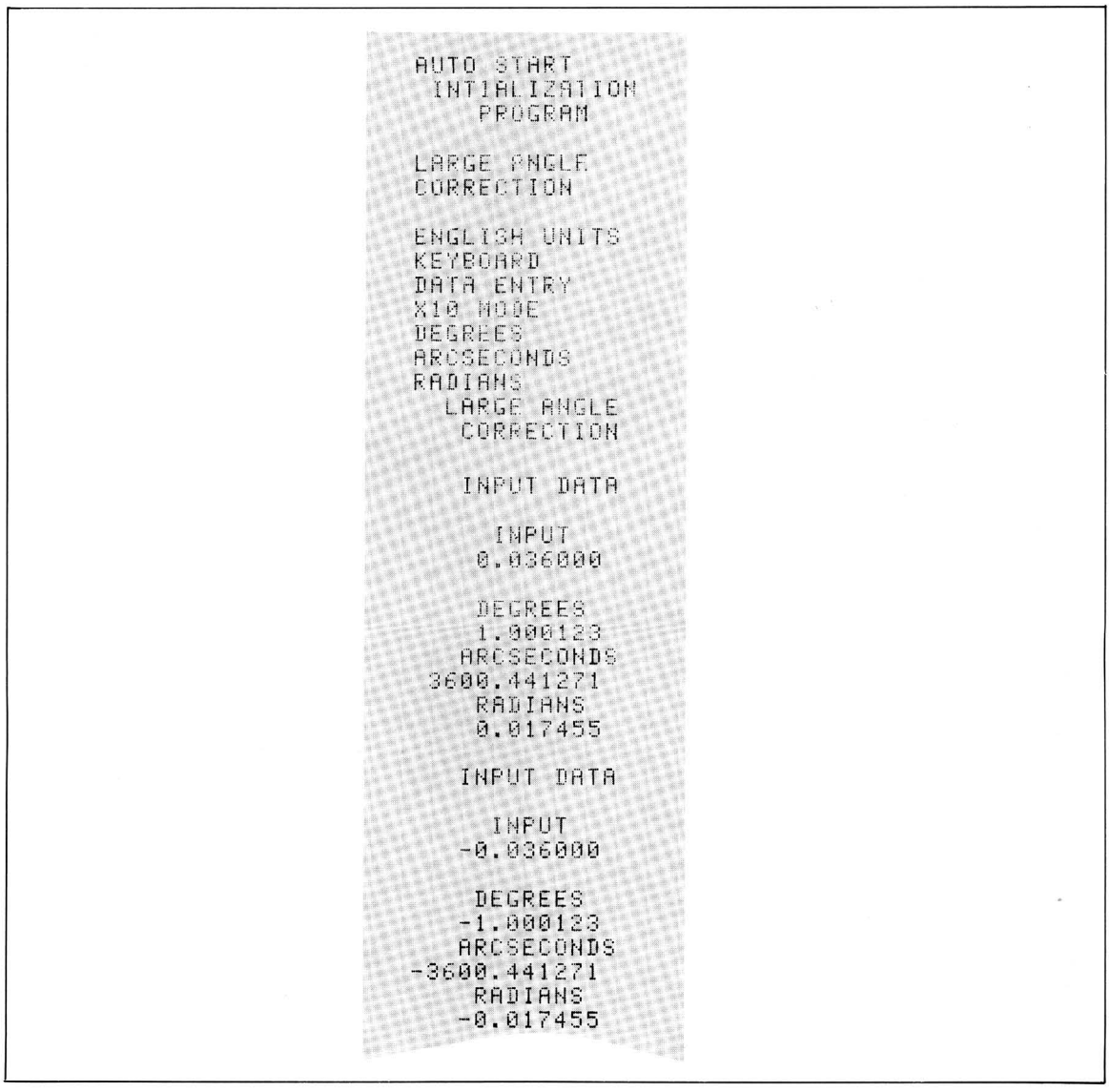



*Figure 2-11. Large Angle Correction Example Printout*

## WAVELENGTH COMPENSATION CALCULATION

This program calculates the compensation factor to be dialed into the thumbwheel switches on the 5505A Laser Display. The factor will take into account the effects of ambient temperature, barometric pressure, humidity, and material temperature. The data can be entered in either English or Metric units. The factor is derived according to the following equations where:

T = ambient temperature

P = barometric pressure (absolute, not corrected to sea level)

R = relative humidity in %

C = compensation thumbwheel setting, ppm (xxx.x)

$$C = \frac{10^{12}}{N + 10^{6}} - 999000$$

where N is given by:

English Units (T in degrees Fahrenheit, P in inches of mercury, R in %)

$$N = 9.74443 * P * \left[\frac{1 + 10^{-6} * P * (26.7 - 0.187 * T)}{0.934915 + 0.0020388 * T}\right]$$

$$-1.089 * 10^{-3} * R * \left[e^{0.032015 * T}\right]$$

Metric Units (T in degrees Celsius, P in millimetres of mercury, R in %)

$$N = 0.3836391 * P * \left[\frac{1 + 10^{-6} * P * (0.817 - 0.0133 * T)}{1 + 0.0036610 * T}\right]$$

$$-3.033 * 10^{-3} * R * \left[e^{0.057627 * T}\right]$$

In each case, C can be corrected for material temperature with:

$$\text{Total } C = C - (T_F - 68°F) * CE_F$$

or

$$\text{Total } C = C - (T_C - 20°C) * CE_C$$

where $T_F$ and $T_C$ = material temperature in °F or °C, and $CE_F$ and $CE_C$ = material coefficient of expansion in ppm/°F or ppm/°C.

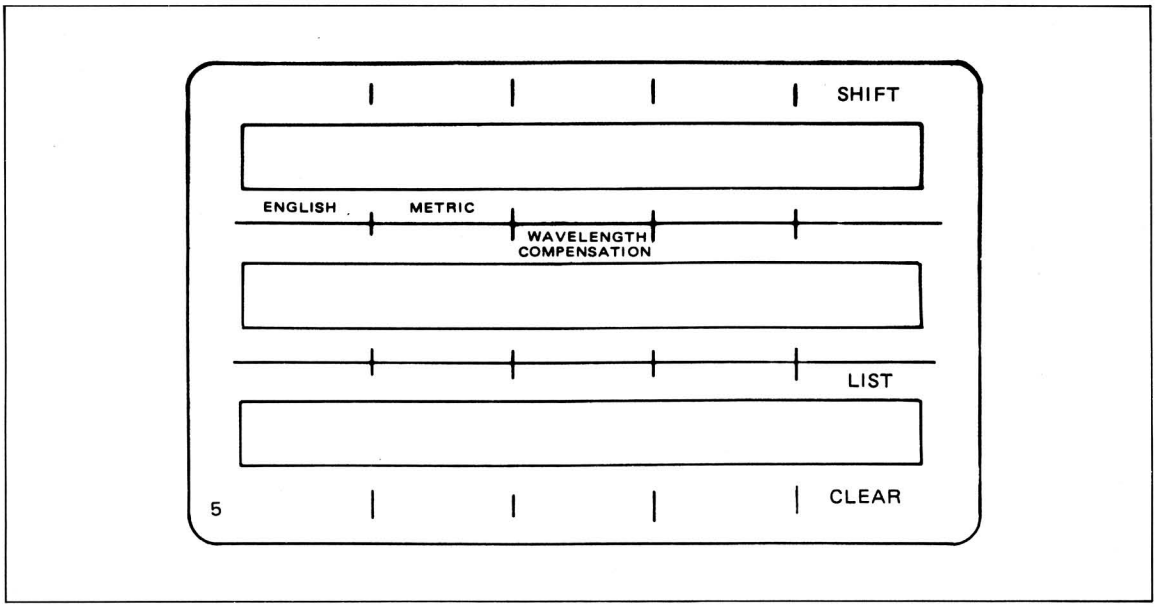



*Figure 2-12. Key Overlay Number 5*

1. Insert the Metrology Program Cartridge into the 9815A Cartridge reader.

2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.

3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.

4. Turn the 9815A Calculator on.

5. AUTO START and INITIALIZATION PROGRAM will be printed.

6. Place the WAVELENGTH COMPENSATION key overlay on the 9815A keyboard.

7. Press the SHIFT key and then the WAVELENGTH COMPENSATION key. WAVELENGTH COMPENSATION will be printed.

8. Select either ENGLISH or METRIC units by pressing the proper key. Press the RUN STOP key.

9. The 9815A Calculator will read the proper file on the Metrology Program Cartridge.

10. WAVELENGTH COMPENSATION CALCULATION will be printed.

11. ENGLISH UNITS or METRIC UNITS will be printed.

12. AIR TEMPERATURE? will be printed. Enter the ambient air temperature in the appropriate units via the calculator numeric keyboard and press the RUN STOP key.

    If the last thumbwheel setting has been printed,press the RUN STOP key with no entry. The Initialization Program will be reread into the calculator and run. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

13. AIR PRESSURE? will be printed. Enter the absolute air pressure in the appropriate units and press the RUN STOP key.

14. HUMIDITY % will be printed. Enter the relative humidity as a percentage and press the RUN STOP key.

15. EXP COEFF?, PPM/C will be printed. If material temperature compensation is *desired*, enter the expansion coefficient in the appropriate units and press the RUN STOP key.

    If no material temperature compensation is desired press the RUN STOP key with no entry and go to step 19.

16. MATL TEMP1? will be printed. Enter the material temperature in the appropriate units and press the RUN STOP key.

17. MATL TEMP2? will be printed. Enter the material temperature in the appropriate units and press the RUN STOP key.

    If only one material temperature is to be used, press the RUN STOP key with no entry and go to step 19.

18. MATL TEMP3? will be printed. Enter the material temperature in the appropriate units and press the RUN STOP key.

    If only two material temperatures are to be used, press the RUN STOP key with no entry and go to step 19.

19. The correct thumbwheel setting for the 5505A Laser/Display will be printed. Return to step 11.

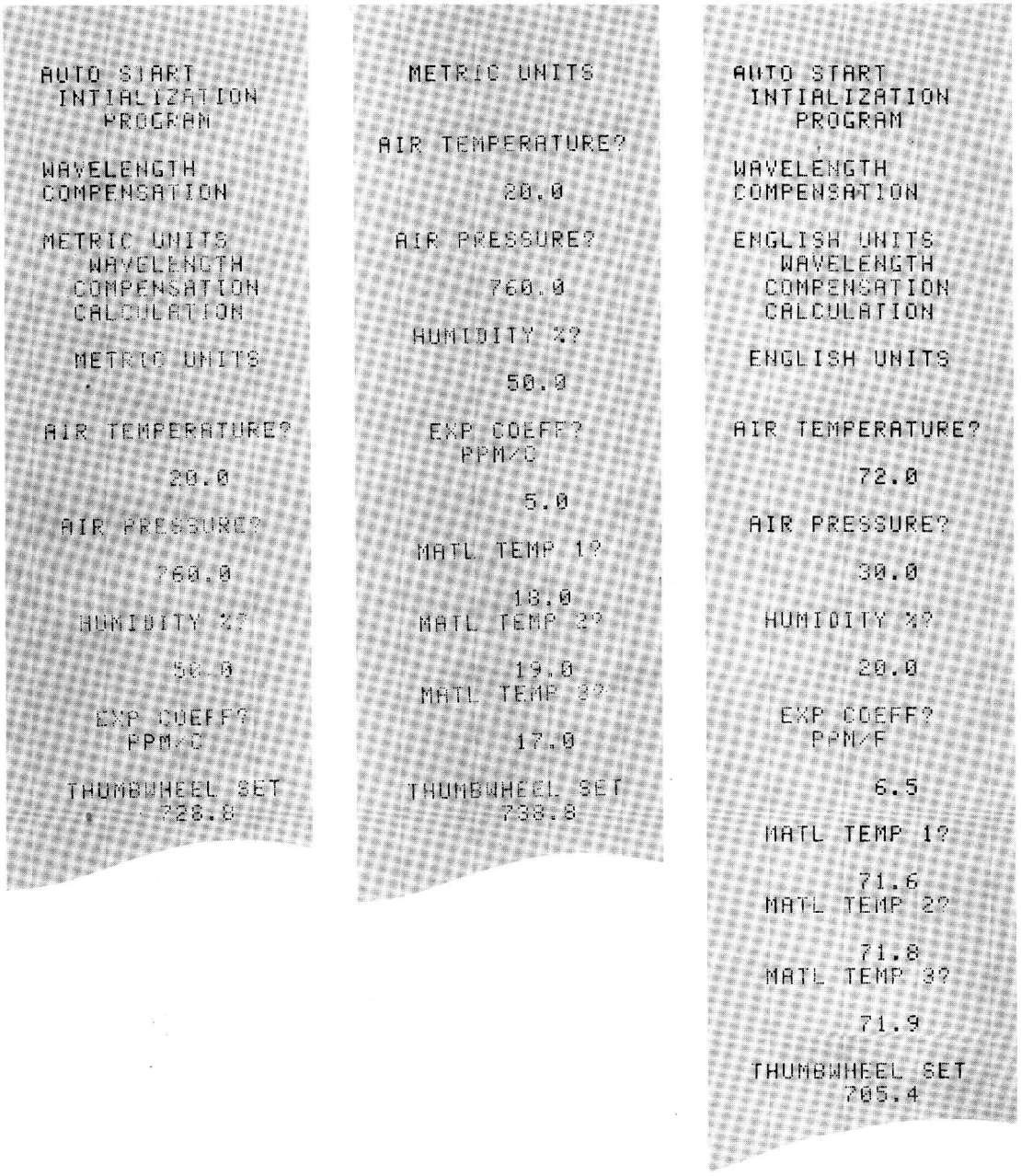



*Figure 2-13. Wavelength Compensation Example Printout*

## STANDARD ERROR ANALYSIS

This program is similar to, but more versatile than, the 10555A Error Plotting output. It allows error analysis in a similar manner as this option, substituting software for the plug-in board. The data can be entered directly from the 5505A Laser/Display into the calculator, or entered from the calculator keyboard. It can be printed and/or plotted on the 7225A Digital Plotter.

The error analysis program works on the assumption that machine movements will be in integral multiples of a user-defined error tolerance. (For example, if the operator inputs an error tolerance [±.005 mm] ±.005 in. then the machine must move in integral multiples of [.01 mm] .01 in. The total distance moved and plotted is variable within the limits of the 5505A Laser/Display. It is not limited to 100 in. (1,000 mm) as the analog hardware of the 10555A Error Plotting Output.

For further information on the standard error plotting procedures, see the operating manual for the 10555A Error Plotting Output.

This program offers two unique features: a selectable error tolerance and a negative error plot. The selectable error tolerance allows the user to gain the maximum resolution on the error plot by defining the machine's positioning accuracy. For example, if the machine's worst positioning error is .000150 inches the operator has the choice of using this or some larger value for the maximum expected error.

The negative error plot provides the convenience of referencing the error plot's X-axis to the machine's movement. For example, if the machine is being calibrated from zero to minus twenty inches then the graph can be drawn from zero to minus twenty. If the machine moves from zero to plus twenty inches then the graph can be drawn from zero to plus twenty.

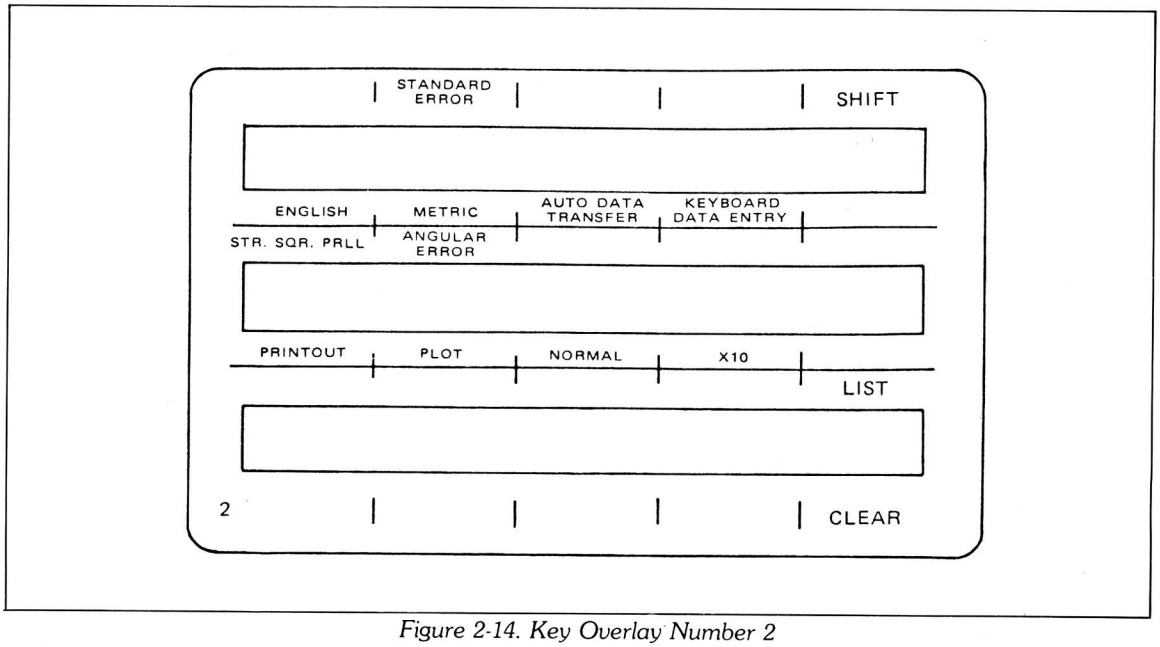



*Figure 2-14. Key Overlay Number 2*

1. Insert the Metrology Program Cartridge into the 9815A Cartridge reader.
2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.
3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.
4. Turn the 9815A Calculator on.
5. AUTO START and INITIALIZATION PROGRAM will be printed.

6. Place the STANDARD ERROR key overlay on the 9815A keyboard.

7. Press the SHIFT key and then the STANDARD ERROR key. STANDARD ERROR will be printed.

8. Select the proper setup keys for the measurement and press the RUN STOP key. (For a better description of the key overlay and setup keys refer to the section titled INITIALIZATION PROGRAM.)

9. The 9815A Calculator will read the proper file on the Metrology Program Cartridge.

10. STANDARD ERROR ANALYSIS will be printed.

11. ERROR TOLERANCE?, (IN INCHES) or (IN MM) will be printed. Enter the error tolerance appropriate for the particular measurement via the calculator numeric keys and press the RUN STOP key.

---

**NOTE**

The error tolerance value entered at this time will define both the minimum machine increment and the y-axis scale for the plot.

---

If the last data point has been entered, printed and/or plotted and the program is no longer required press the RUN STOP key with no entry. The Initialization Program will be reread into the calculator and run. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

12. MACH MUST MOVE IN INTEGRAL MULTIPLES OF will be printed along with a number which is twice the error tolerance entered in step 11.

13. If a plot was asked for, MAXIMUM LENGTH OF TRAVEL?, (IN INCHES) or (IN MM) will be printed. Place a new sheet of paper on the 7225A Digital Plotter and turn it on. Enter the maximum expected length of travel in the units asked for via the calculator's numeric keys and press the RUN STOP key.

---

**NOTE**

This program has the provision for plotting the X-axis from zero to some positive value or zero to some negative value. A negative maximum length entered in this step will yield a negative plot of the data. Make sure that the direction sense on the 5505A Laser/Display is set to yield the same sign as that which is entered; i.e., Negative numbers must appear on the 5505A Laser/Display if a negative maximum length of travel is entered.)

---

The 9862A or 7225A Plotter will draw and label the axis.

14. INPUT DATA will be printed. If automatic data transfer was selected go to step 16.

15. Enter the data point with decimal point and sign exactly as it appeared on the 5505A Laser/Display via the 9815A Calculator numeric keyboard and press the RUN STOP key.

    When the last data point has been entered press the RUN STOP key with no entry and return to step 11.

16. 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.

    If the last data point has been transmitted, press the RUN STOP key twice. Return to step 11.

17. The data will be printed and/or plotted. For keyboard data entry return to step 15. For automatic data transfer return to step 16.

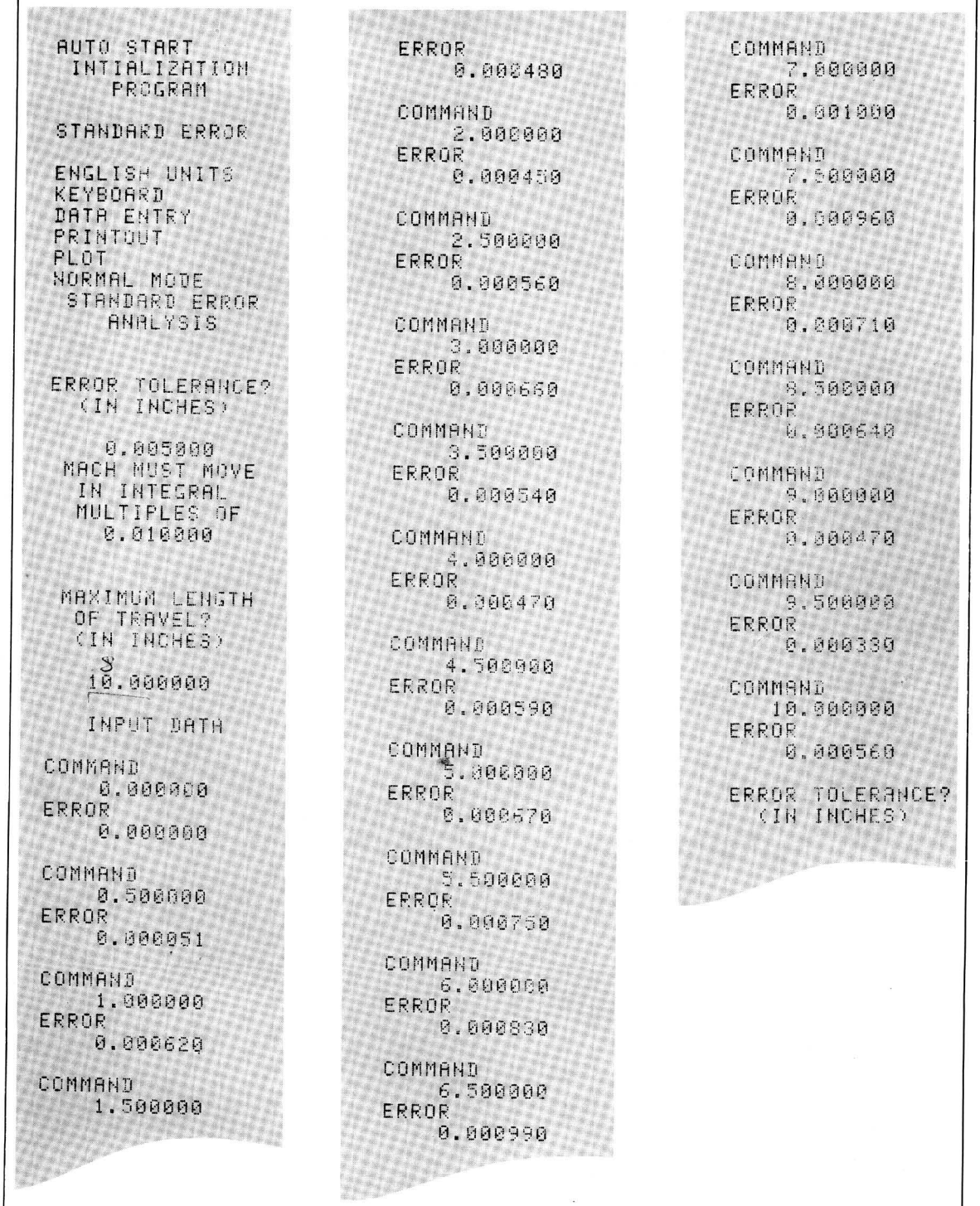



*Figure 2-15. Standard Error Example Printouts, English Units*

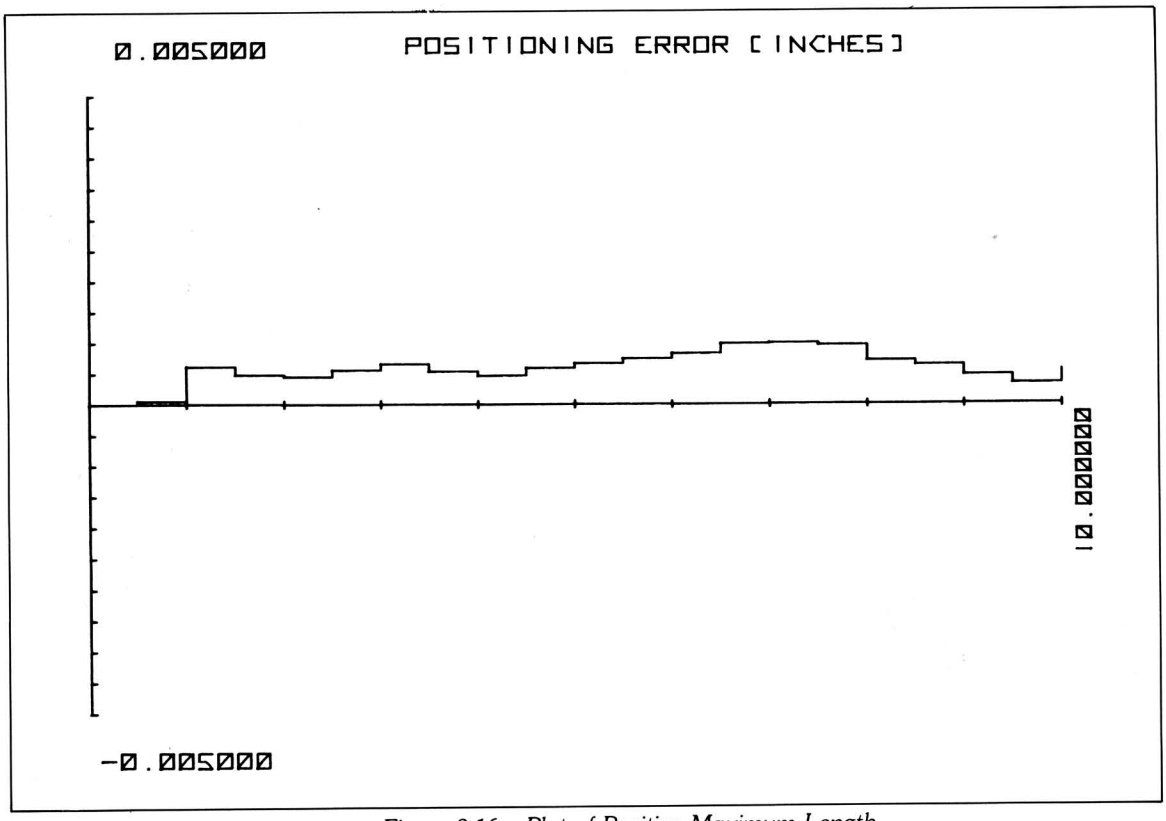



*Figure 2-16a. Plot of Positive Maximum Length*

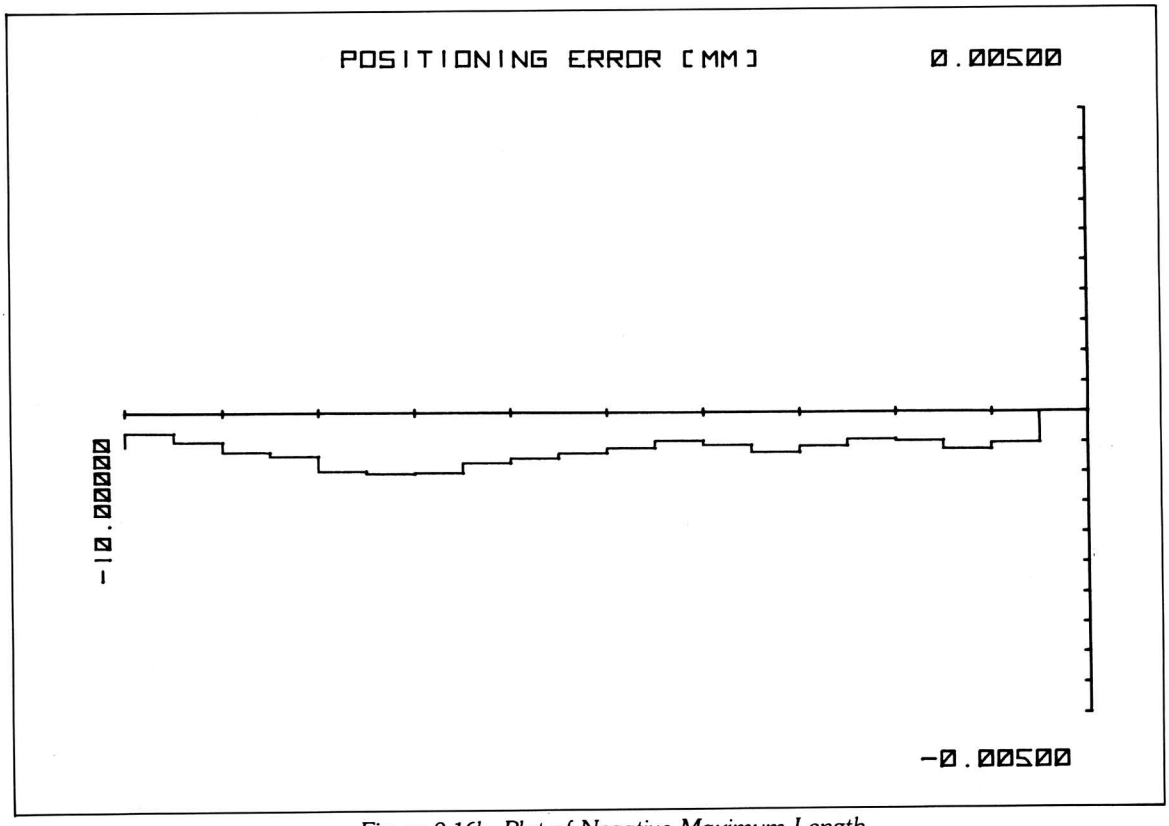



*Figure 2-16b. Plot of Negative Maximum Length*

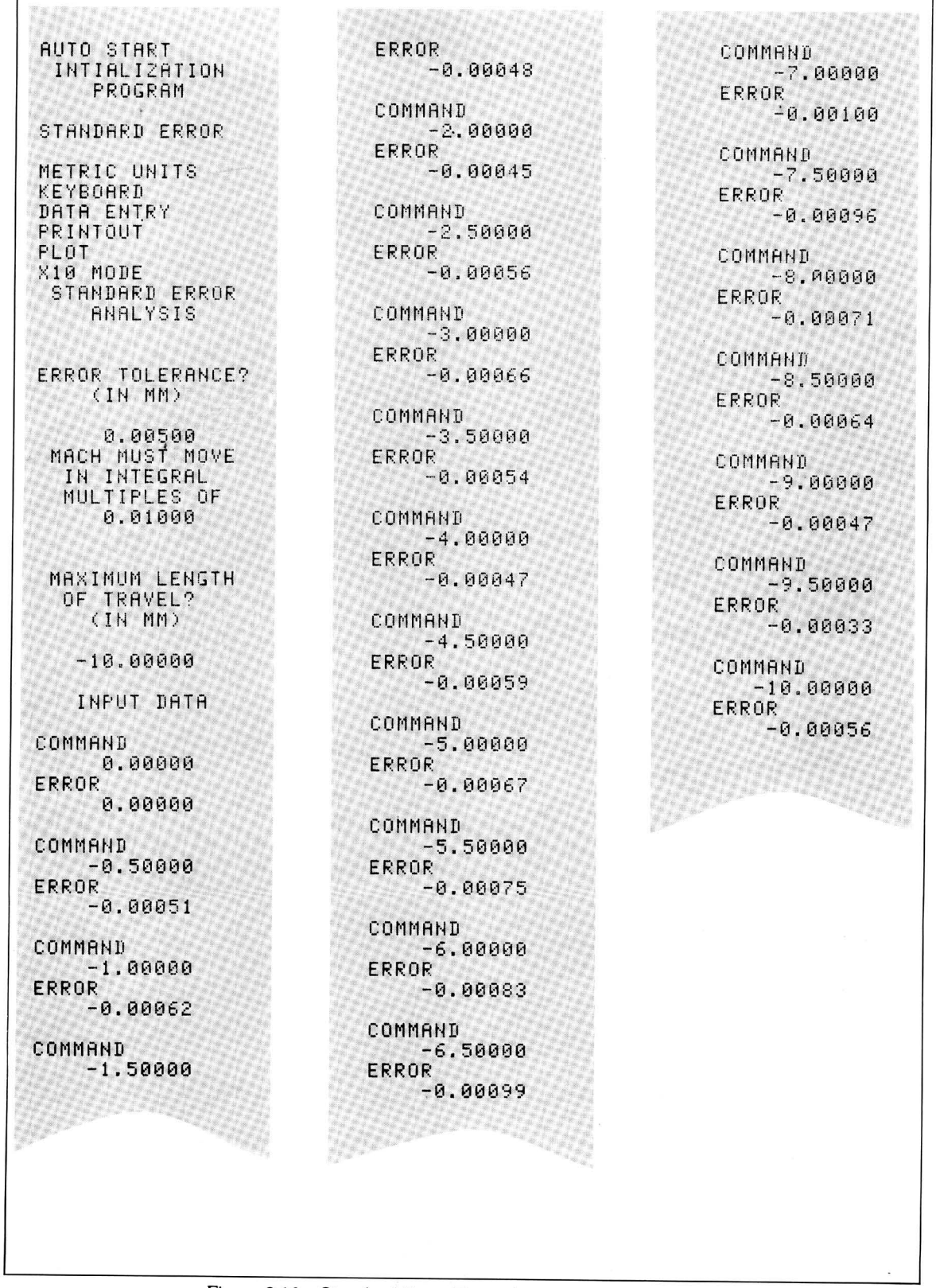



*Figure 2-16c. Standard Error Example Printouts, Metric Units*

## ANGULAR ERROR ANALYSIS

This program enables pitch or yaw data to be plotted as a function of distance when used with the 5526A Angular Interferometer. The data can either be input directly from the 5505A Laser/Display to the calculator or can be manually entered using the calculator keyboard. In plotting the data, the X-coordinate will be calculated by incrementing the previous coordinate by "Delta X" each time a reading is taken. The direction sense switch on the front panel of the 5505A Laser/Display must be set to give the correct sign to the measured data.

This program offers the unique feature of a negative angular error plot. This provides the convenience of referencing the error plot's X-axis to the machine's movement. For example, if the machine is being calibrated from zero to minus twenty inches then the graph can be drawn from zero to minus twenty. If the machine moves from zero to plus twenty inches then the graph can be drawn from zero to plus twenty.

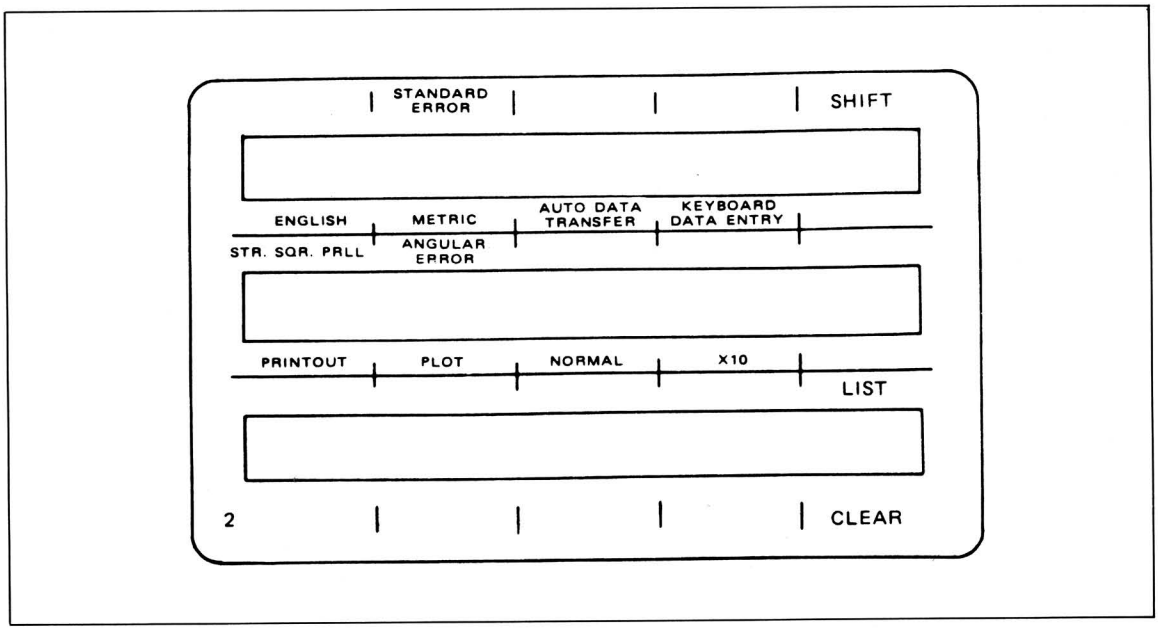



*Figure 2-17. Key Overlay Number 2*

1. Insert the Metrology Program Cartridge into the 9815A Cartridge reader.
2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.
3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.
4. Turn the 9815A Calculator on.
5. AUTO START and INITIALIZATION PROGRAM will be printed.
6. Place the Angular Error key overlay on the 9815A keyboard.
7. Press the Shift key and then the Angular Error key. ANGULAR ERROR will be printed.
8. Select the proper setup keys for the measurement and press the Run Stop key. (For a better description of the key overlay and setup keys refer to the section titled INITIALIZATION PROGRAM.)
9. The 9815A Calculator will read the proper file on the Metrology Program Cartridge.
10. ANGULAR ERROR ANALYSIS will be printed.

11. DELTA X? (IN INCH UNITS) or (IN MM UNITS) will be printed. Enter the distance increment (using a positive increment for machine movement in the positive direction or a negative increment for movement in the negative direction) using the proper units asked for and press the Run Stop key.

    If the last data point has been entered, printed and/or plotted and the program is no longer required press the Run Stop key with no entry. The Initialization Program will be reread into the calculator and run. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

12. If a plot was asked for, MAXIMUM LENGTH OF TRAVEL (SAME UNITS AND SIGN AS DELTA X) will be printed. Enter the maximum expected length of travel along the machine's axis in the same units and sign as used in step 11 and press the Run Stop key.

    MAXIMUM EXPECTED ERROR? (IN ARCSECONDS) will be printed. Enter the maximum expected angular error (as a positive integer number) and press the Run Stop key.

    The 9862A or 7255A Plotter will draw and label the axes. See Figures 2-18 and 2-19 for plot examples.

13. INPUT DATA will be printed. If automatic data transfer was selected go to step 15.

**NOTE**

The first command position is assumed to be zero by the calculator.

14. 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 twenty and one-tenth arcseconds should be entered as 201.)

    When the last data point has been entered, press the Run Stop key with no entry and return to step 11.

15. 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.

    If the last data point has been transmitted press the Run Stop key twice. Return to step 11.

16. The data will be printed and/or plotted. For keyboard data entry return to step 14.

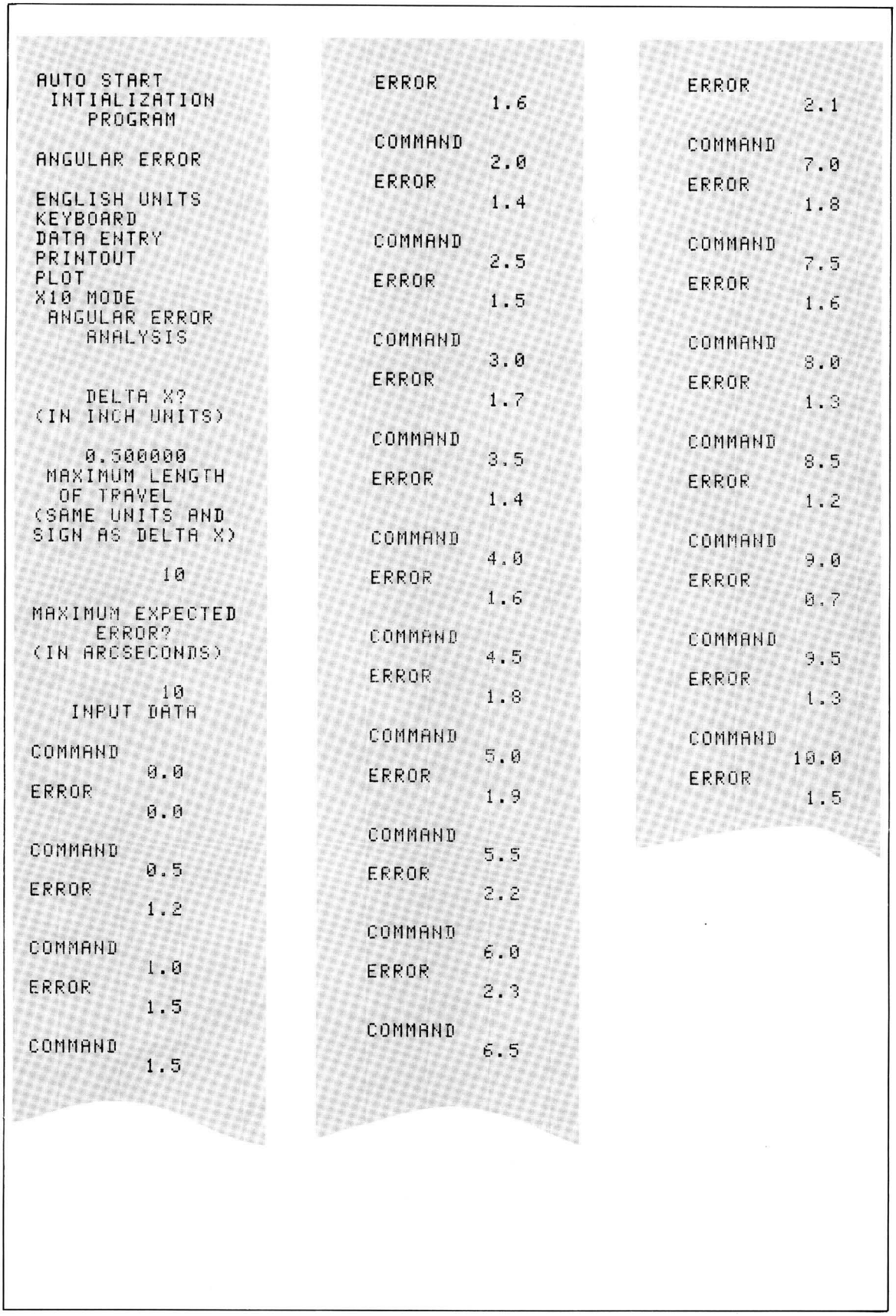



*Figure 2-18. Angular Error Example Printouts, X10 Mode*

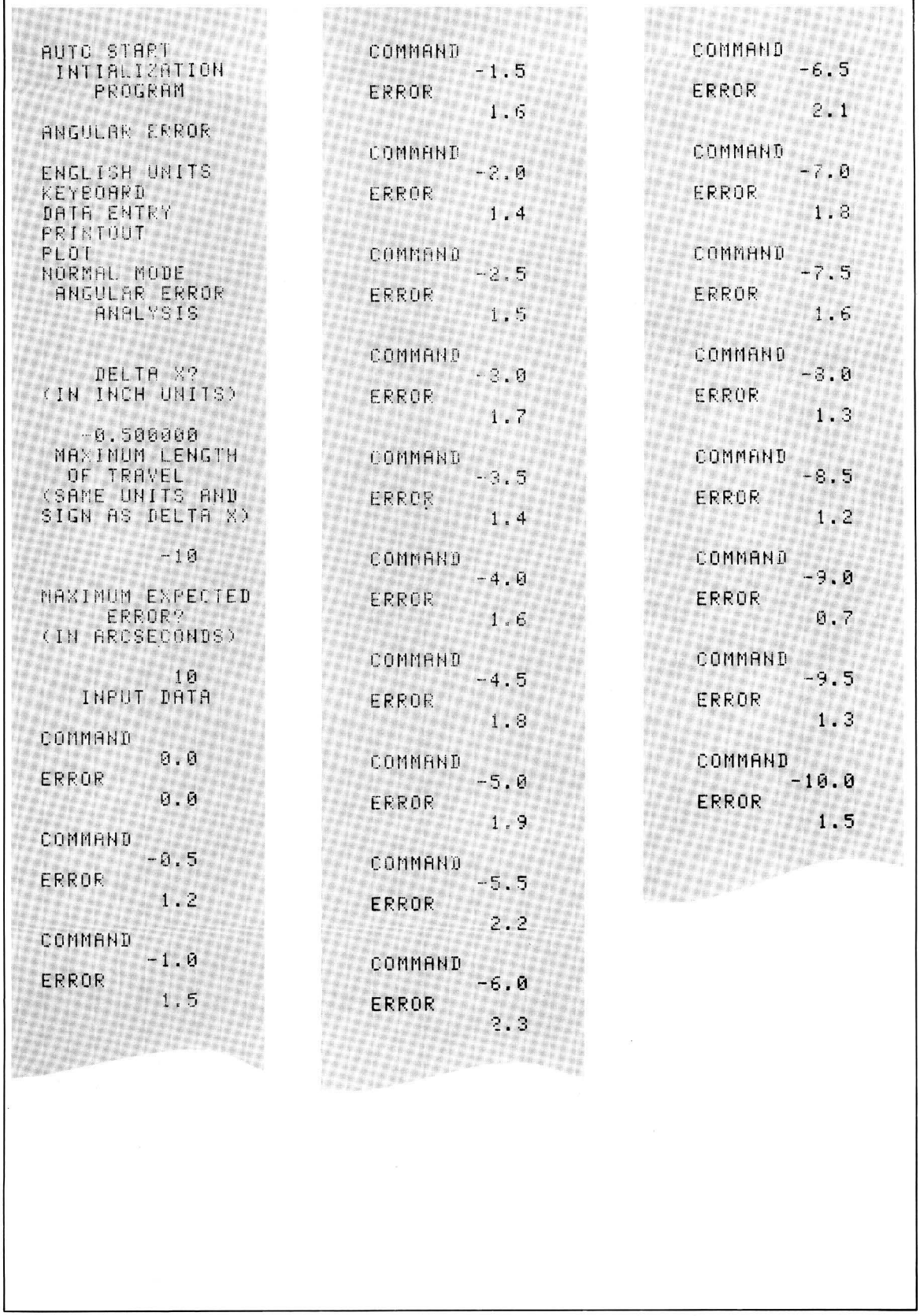



*Figure 2-19. Angular Error Example Printouts, Normal Mode*

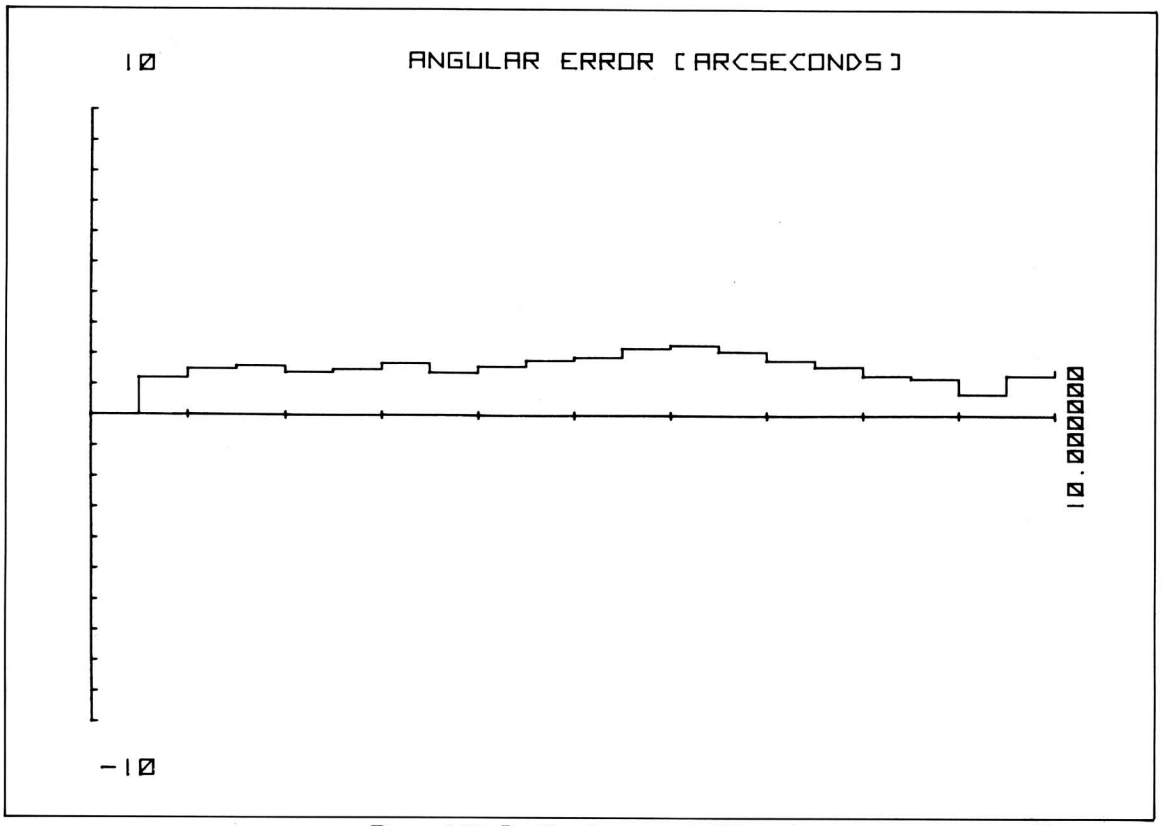



*Figure 2-20. Positive Increment of Travel*

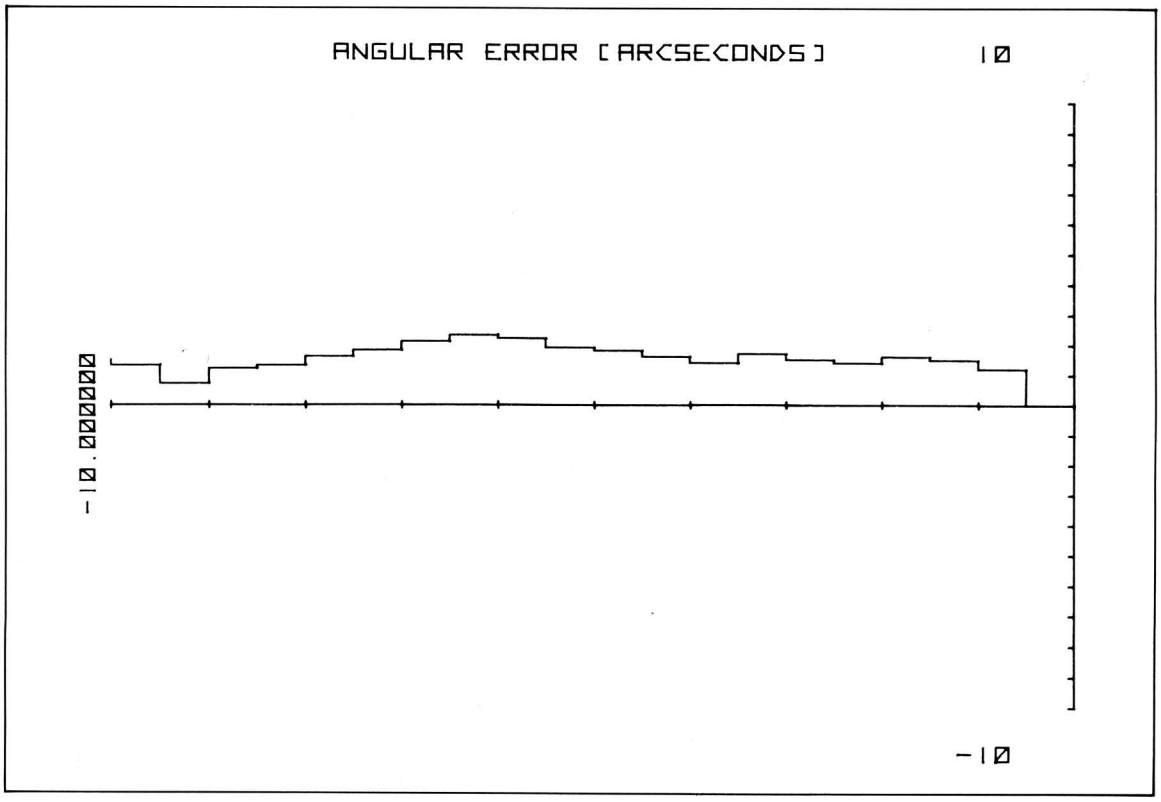



*Figure 2-21. Negative Increment of Travel*

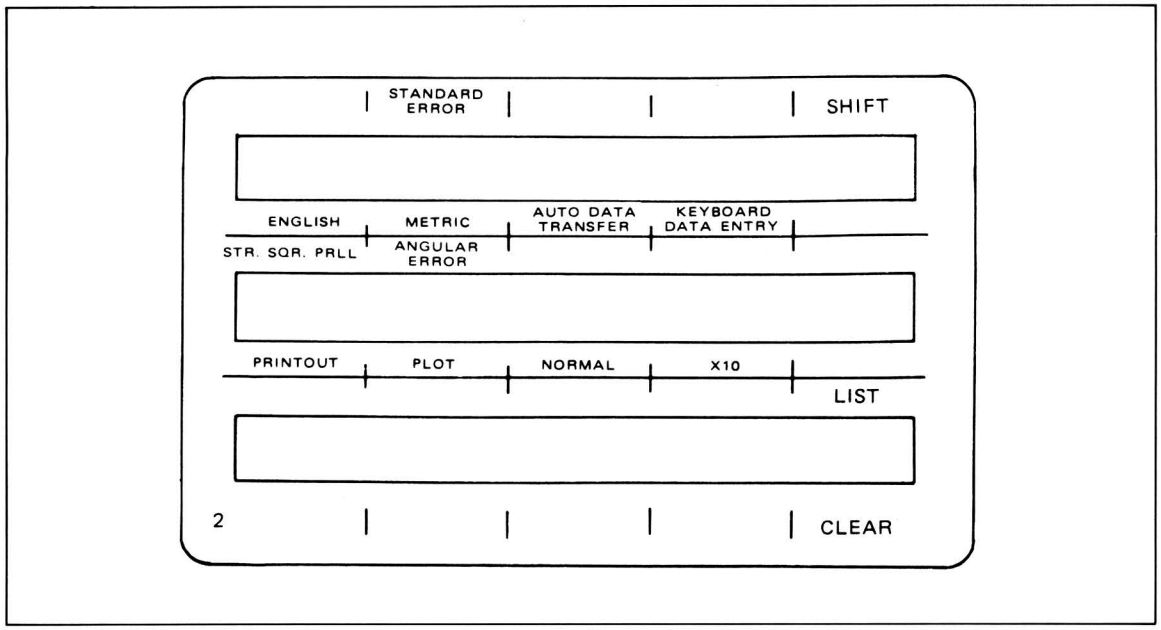



*Figure 2-22. Key Overlay Number 2*

## STRAIGHTNESS, SQUARENESS, AND PARALLELISM

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

Multiple runs of data may be taken on any axis and the program allows the operator to select an average of individual runs and/or an average of several averages. Application Note 156-5 should be consulted to determine the best approach to use for the particular measurement situation.

The 9862A or 7225A Digital Plotter will generate two different graphs, a working graph to help the operator determine when enough straightness data runs have been made and a final certification graph which can be used for future reference.

If a measurement of out-of-parallelism between a spindle rotational axis and a collinear axis of motion is to be made, input of the first line of data with the Straightness Reflector in one orientation, then repeat the run with the Reflector and Spindle rotated 180 degrees. The calculator will ask if 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.

If a measurement of out-of-parallelism between collinear axis, a spindle or Ram axis and a Head or Table Travel axis is to be made, do not rotate the Straightness Reflector. Simply input the first axis of data, then input the second axis and start both runs from the same point. If Parallelism is asked for, multiply $\theta$ by 2 or ask for Squareness and the correct undivided $\theta$ will be printed but labeled Squareness.

Because of the sign convention used with the program, the rotational 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 changing the direction sense switch on the 5505A Laser/Display.

## Least Squares Curve Fitting

1. A technique used to fit curves to data by minimizing the sum of the square of the deviations of the actual data from the curve fit.

2. Linear least squares fit or least squares best line fit is used in the straightness program.

3. Coefficients of the least-squares best line are found by the following equations:

   - Equation for straight line, slope form:

     $Y = mX + b$

     where m = slope and b = intercept as shown below.

   - Straight line through end points of N data points, point slope:

     Mean Value: $\overline{X} = \frac{1}{N} \Sigma X_i$

     Standard Deviation: $\sigma = \left[\frac{\Sigma (\overline{X} - X_i)^2}{N - 1}\right] 1/2$

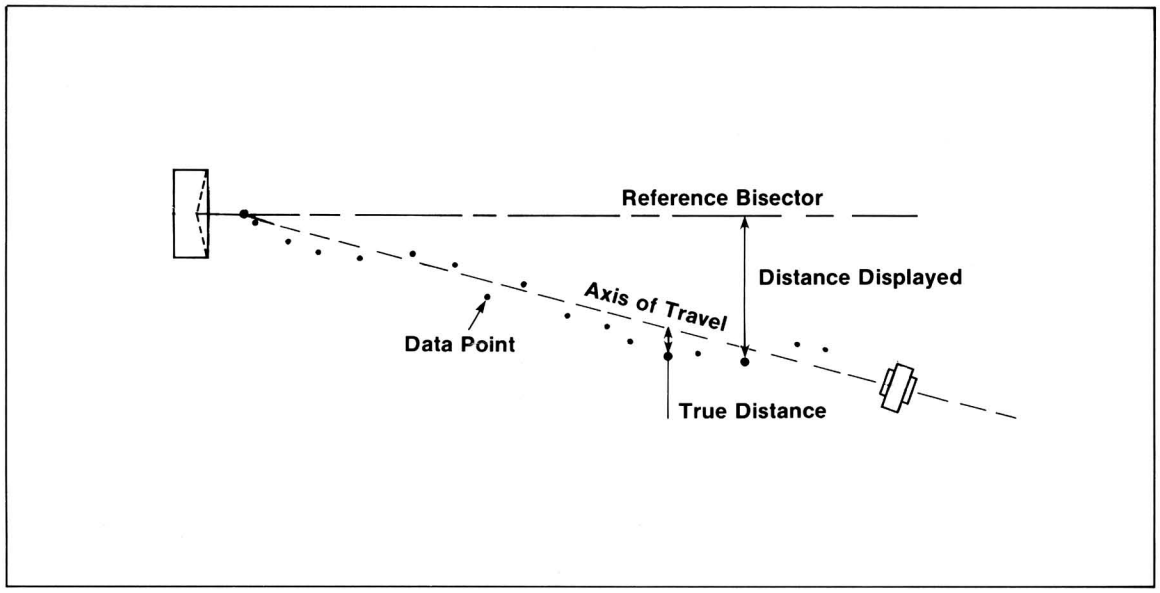



*Figure 2-23. Least Squares Curve Fitting*

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 2-24 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. See Figure 2-25 for a graphic explanation of squareness and both parallelism measurements.

A total of 110 data points per run may be entered.

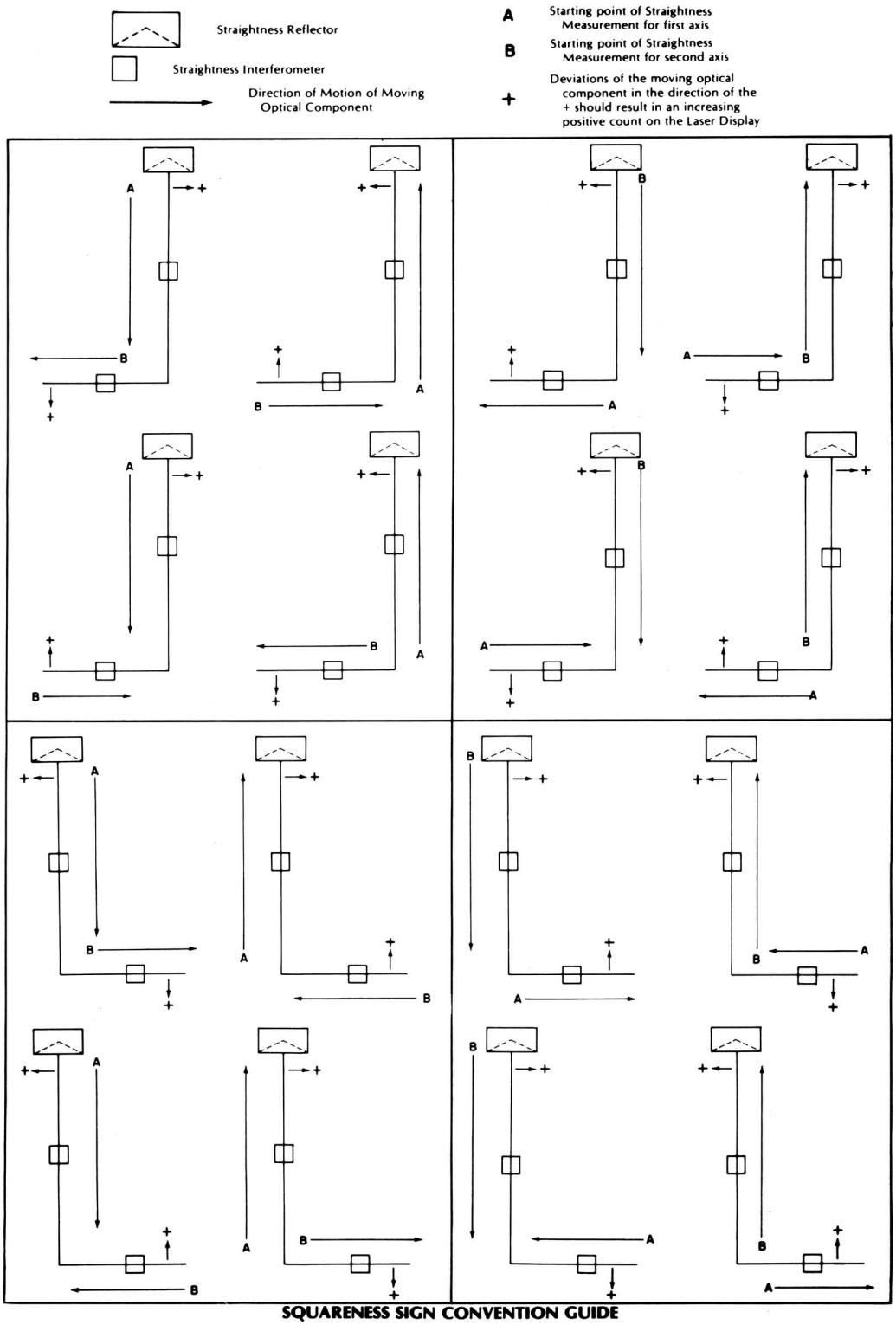
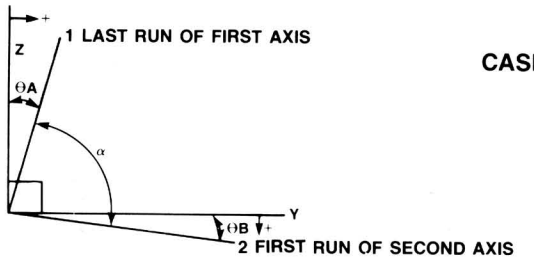
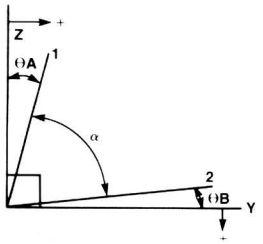



*Figure 2-24. Squareness Sign Convention Guide*

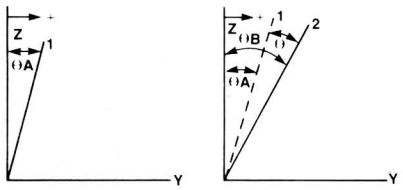



**CASE ONE:** Data taken away from
Optical square in both axis
Data positive in both axis
$\Theta A$ = Slope of data in Axis 1
$\Theta B$ = Slope of data in Axis 2




**CASE TWO:** Data taken away from Optical square in both axis.
Data negative in second Axis

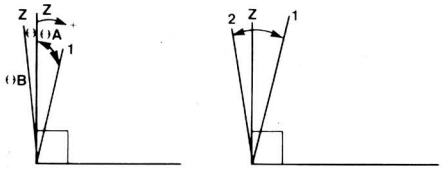
**SQUARENESS = $\alpha$, $\theta$B - $\theta$A + PRISM ERROR = SQUARENESS ERROR**




Data taken from same point
Data positive in both runs
$\Theta = \Theta B - \Theta A$

**NOTE: The Direction Sense Switch must be reversed for the second axis to maintain correct sign of data.**

**PARALLELISM = $\theta/2$, AXIS OF ROTATION TO AXIS OF TRAVEL**




Data taken from same point
data negative in second axis
Parallelism = Squareness = $\Theta$
$\Theta = \Theta B - \Theta B$

**PARALLELISM BETWEEN TWO LINEAR AXIS. Spindle travel to Head travel to plot Collinear Axis use Squareness Program. Use of parallelism program requires not reversing direction sense switch and multiplying error by 2.**

*Figure 2-25. Squareness and Parallelism*

1. Insert the Metrology Program Cartridge into the 9815A Cartridge reader.

2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.

3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.

4. Turn the 9815A Calculator on.

5. AUTO START and INITIALIZTION PROGRAM will be printed.

6. Place the STR, SQR, PRLL key overlay on the 9815A keyboard (overlay #2).

7. Press the Shift key and then the STR, SQR, PRLL key. STR, SQR, PRLL will be printed.

8. Select and press the appropriate or desired modes of operation keys for the measurement from the key overlay and press the Run Stop key. (For a better description of the key overlay and setup keys refer to the section titled INITIALIZATION PROGRAM.)

9. The 9815A Calculator will read the proper file on the Metrology Program Cartridge.

10. STRAIGHTNESS, SQUARENESS, PARALLELISM will be printed.

11. (ENTER DELTA X IN INCH UNITS), (ENTER DATA IN MICROINCH UNITS) or (ENTER DELTA X IN MILLIMETRE UNITS), (ENTER DATA IN 1/100 MICRON UNITS) will be printed after a short delay.

12. LEAST SQUARE LINE FIT? will be printed. If it is desired to fit a least squares straight line to the data, press the Ø key and then the Run Stop key. To fit a straight line through the end points of the data, press the Run Stop key with no entry.

13. YES or END PT LINE FIT SELECTED will be printed in response to the answer given in step 12.

14. STR OPTICS CALIBRATION # ? will be printed. The calibration number for the Straightness Interferometer and the Straightness Reflector can be entered via the 9815A Calculator's numeric keys. Enter the number exactly as it appears on the label of the short-range OPTICS.

---

**NOTE**

The calibration number for the long-range Straightness Interferometer must be multiplied by 0.1 to correct the printout, and Plotter Resolution. A factor of 10 resolution is lost with the long range Straightness Optics.

If a calibration constant of 1 is chosen, press the Run Stop key with no entry.

---

15. AXIS #? will be printed. Enter a numeric integer value corresponding to the axis on which the straightness is to be measured and press the Run Stop key. Check the sign of the data by moving the Interferometer in the direction of positive data and check the correctness of the Laser Display reading. See page 2-33 for sign convention.

16. DELTA X? will be printed. Enter the spacing between measured points in the units specified in step 11. Press the Run Stop key.

17. DATA? will be printed. If automatic data transfer was selected go to step 19.

---

**NOTE**

There are two unique features of this program which should be taken into consideration:

1. After the first data run has been made on the axis the total number of points taken is remembered by the calculator.

   Thereafter, each additional data run will automatically stop accepted data after the number of points taken matches the first data run.

---

2. If the total number of data points taken during the first data run reaches 110 the calculator will automatically stop accepting points for that run.)

18. 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 microinches should be entered as 201.) Press the Run Stop key.

    For the first data run on the axis, when the last data point has been entered, press the Run Stop key with no entry and go to step 20. Each additional data run will stop automatically.

19. 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.

    For the first data run on the axis, when the last data point has been transmitted press the Run Stop key twice. Each additional data run will stop automatically.

20. The straight line will be calculated and subtracted from the data.

21. If a printout was selected the normalized data will now be printed.

---

**NOTE**

If either squareness or parallelism was selected from steps 31 or 32 and this is the first data line of the second axis then the angle will be printed out. This angle is calculated from the last data line taken for axis one and the first data line taken for axis two. See page 2-38 for examples and page 2-33 for Sign Conventions. If the Straightness Reflector was not rotated for this Parallelism, multiply the result by 2. See page 2-34.

---

22. If a plot was selected, for the first data line on the axis PLACE NEW PAPER ON PLOTTER will be printed. Place a new sheet of paper on the 9862A plotter and turn the plotter on.

    SCALE? will be printed. Enter the maximum vertical scale value in microinches or 1/100 micron units and press the Run Stop key. The 9862A Plotter will generate the working plot's axes.

    The 9862A Plotter will generate the data line plot. See page 2-42 and 2-43 for examples.

23. MORE DATA? will be printed. If a new data line is to be averaged with the previously taken data lines, or if a new average is to be taken to be averaged with a previously taken data line average, press the Ø key and then the Run Stop key.

    If the operator is satisfied with the quantity of data taken press the Run Stop key with no entry. Go to step 25.

24. DIRECTION? will be printed. 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, and -1 if the additional data is to be taken in the opposite direction as the first set of data. When the correct response has been entered, press the Run Stop key. Return to step 17.

25. If a printout was selected the calculator will print out the average of the current set of runs.

26. If a plot was selected the average of the current set of runs will be plotted on the AVERAGE axis.

27. NEW AVG? will be printed. If a new set of runs are to be averaged, press the Ø key and then the Run Stop key. Return to step 24.

    If the operator is satisfied with the number of averages taken press the Run Stop key with no entry.

29. If a printout was selected, the calculator will print STRAIGHTNESS (OVERALL AVG), AXIS # and the total average of all the data runs taken.

30. If a plot was selected the total average of all the data runs taken will be plotted on the OVERALL AVERAGE axis.

31. SQRNESS? will be printed. For determination of out-of-squareness between the two axes, press the Ø key and then the Run Stop key.

    PRISM ERROR? will be printed. This refers to the Optical Square Error, and after it has been entered, in arcsecond units, press the Run Stop key. See page 2-33 for Sign Conventions. Return to Step 15.

---

**NOTE**

If the second axis of data has been measured, printed, and/or plotted, go to step 33.

---

    If squareness is not desired press the Run Stop Key with no entry.

32. PRLLISM? will be printed. If a rotational spindle axis parallelism measurement relative to the axis measured above is desired, press the Ø key and then the Run Stop key. Return to step 15.

    If parallelism is not desired press the Run Stop key with no entry.

33. If a plot was selected, PLACE NEW PAPER ON PLOTTER will be printed. Place a new sheet of paper on the 9862A or 7225A and turn the plotter on. Press the Run Stop key. The 9862A or Plotter will draw the axes and plot the final average for the axes measured. This is the final certification graph which can be used for future reference. See note on step 21.

34. The Initialization Program will be reread into the calculator and run. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

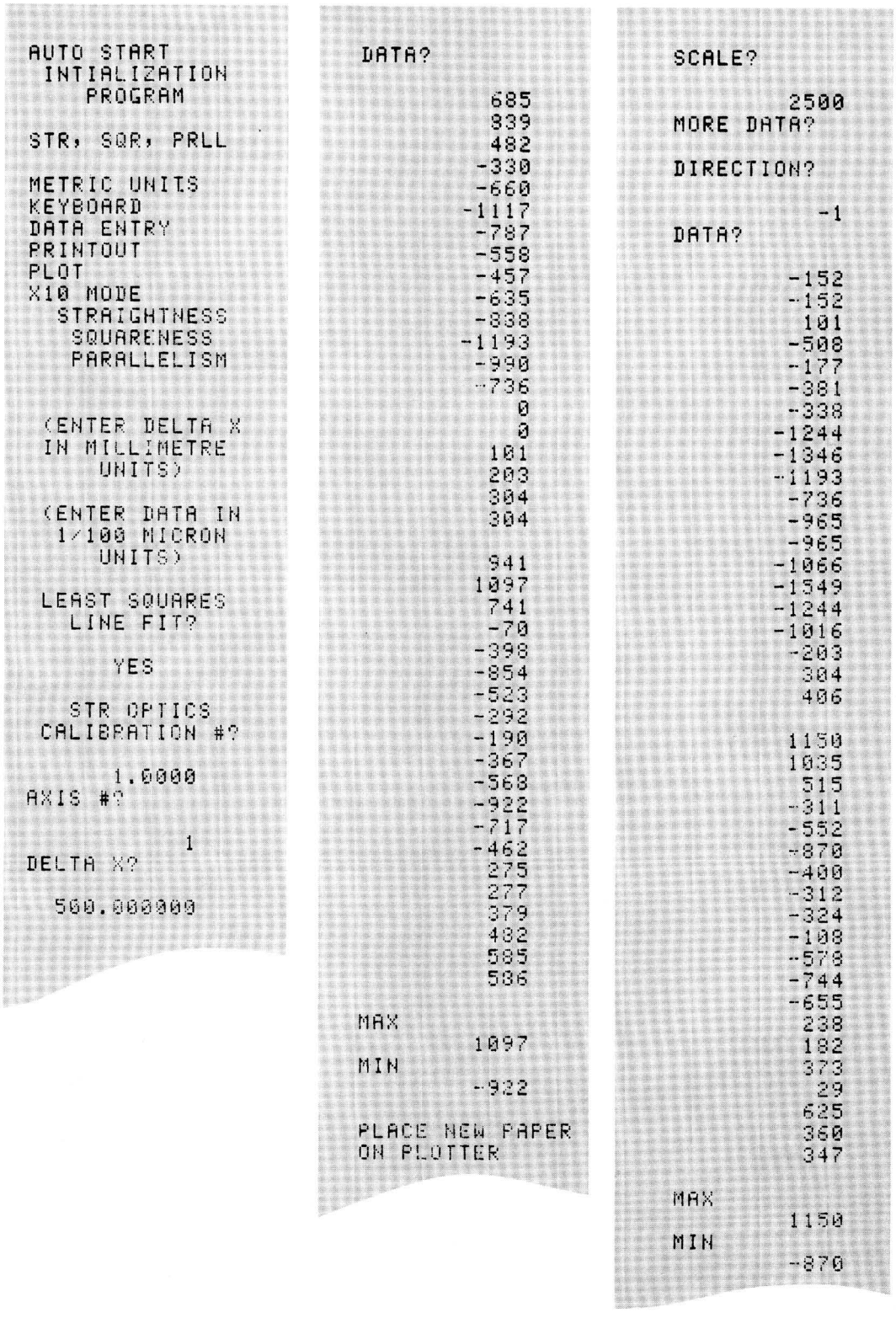



*Figure 2-26. Straightness, Squareness, and Parallelism Example Printouts*

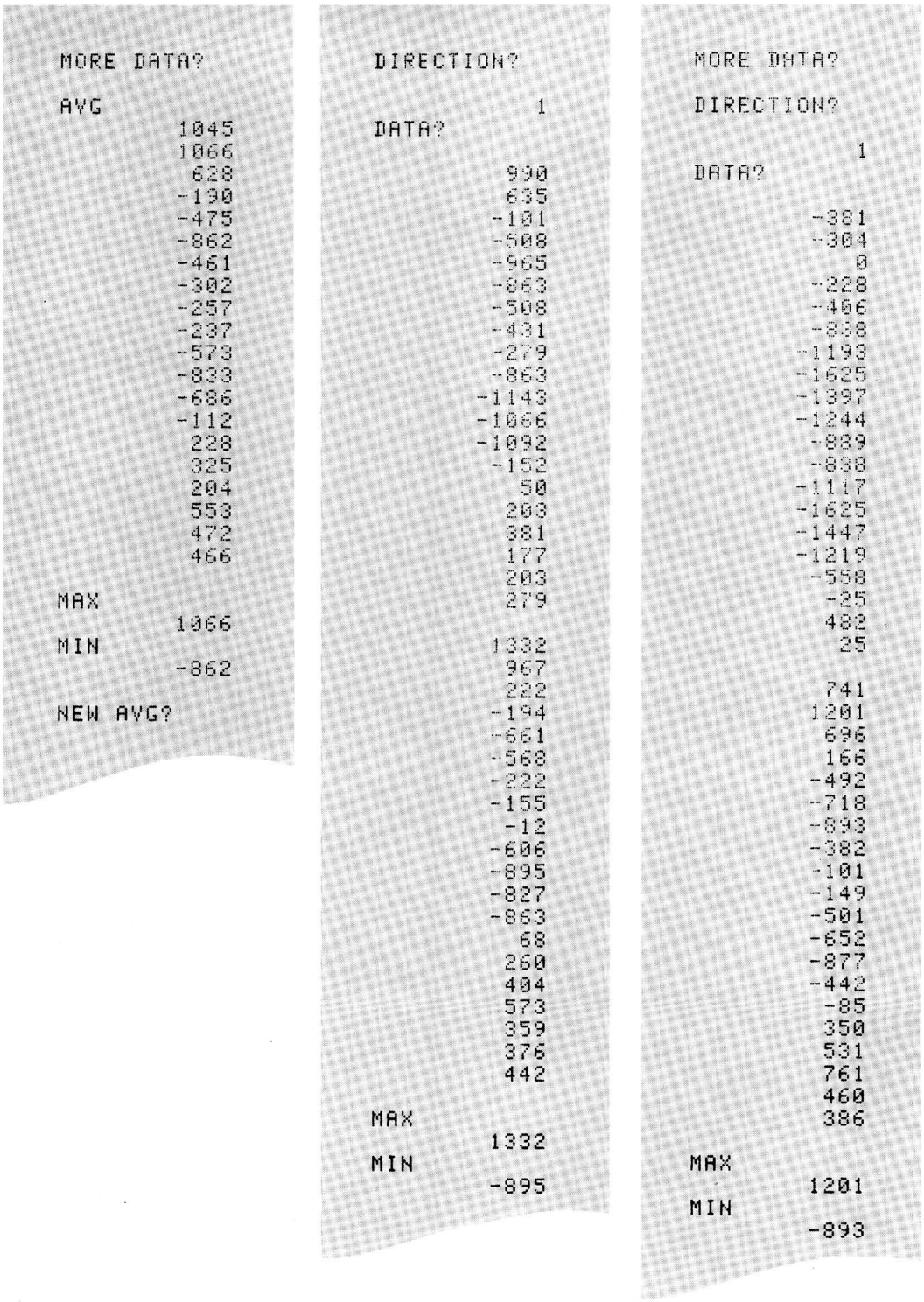



*Figure 2-26. Straightness, Squareness, and Parallelism Example Printouts* (cont'd)

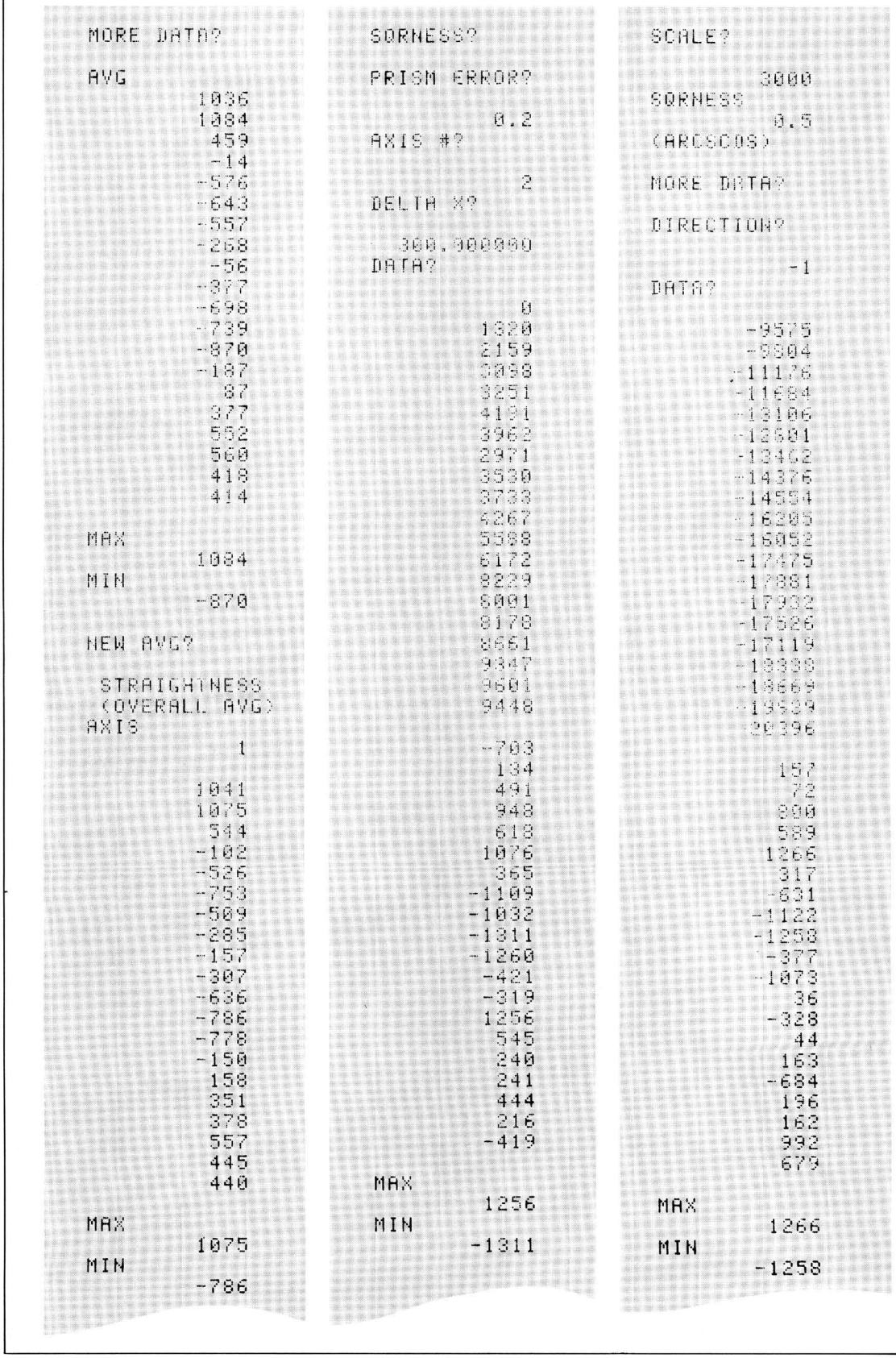
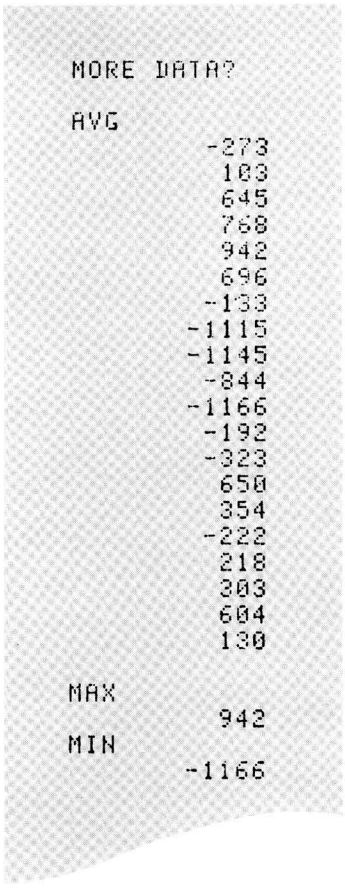



*Figure 2-26. Straightness, Squareness, and Parallelism Example Printouts* (cont'd)



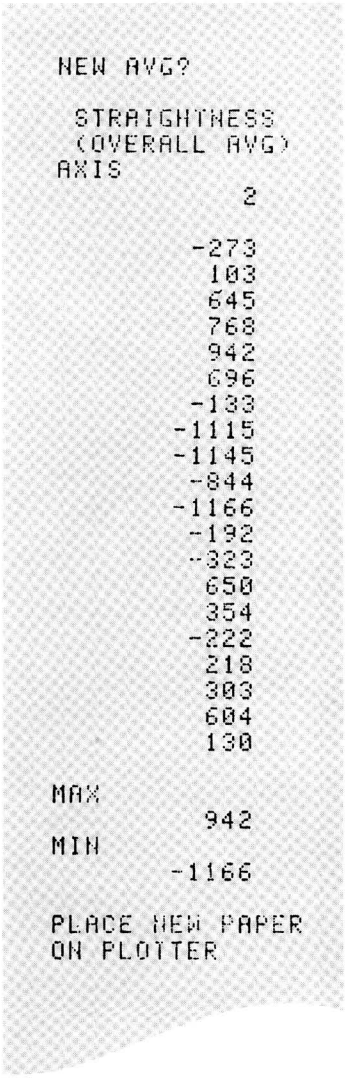




*Figure 2-26. Straightness, Squareness, and Parallelism Example Printouts* (cont'd)

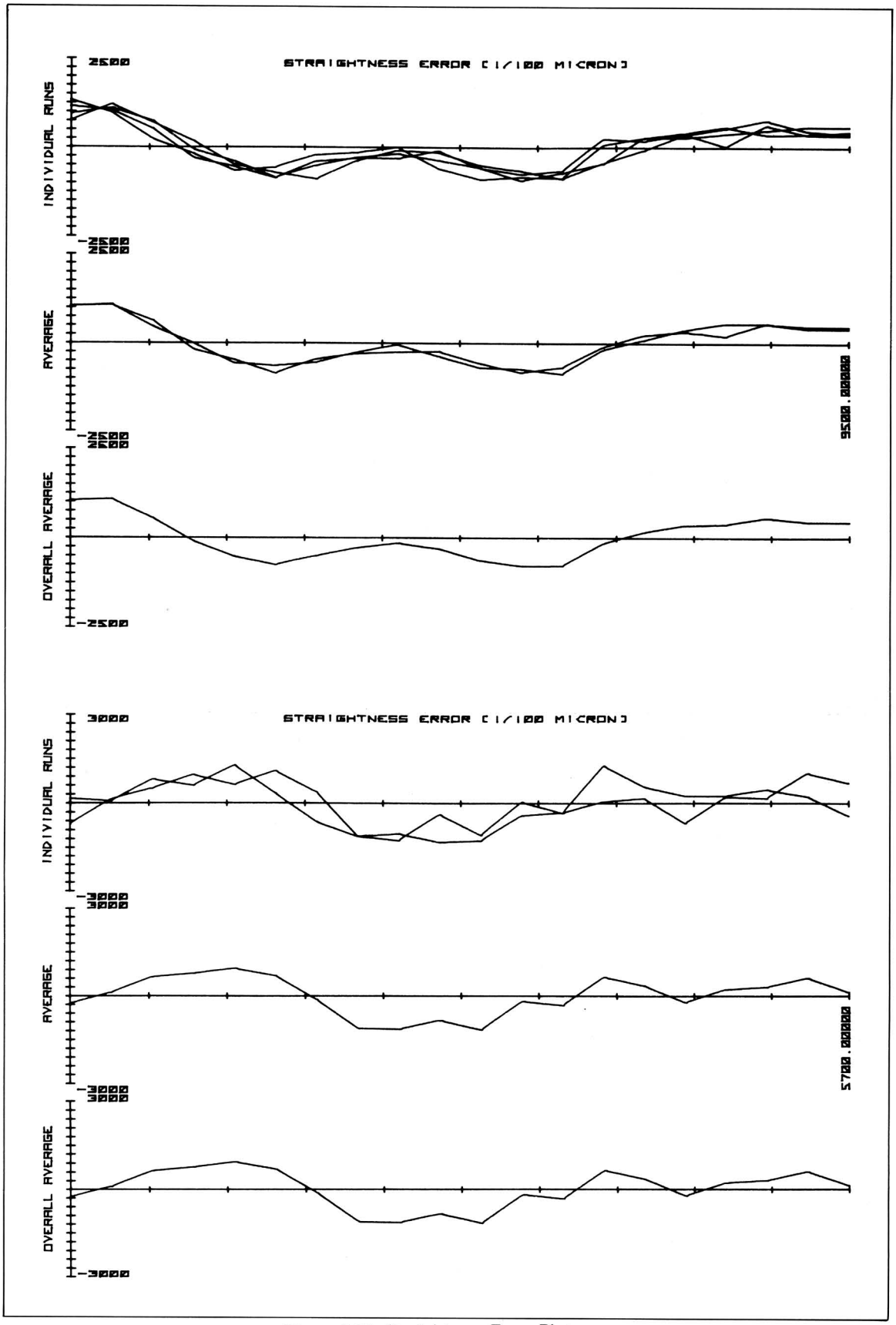



*Figure 2-27. Straightness Error Plots*

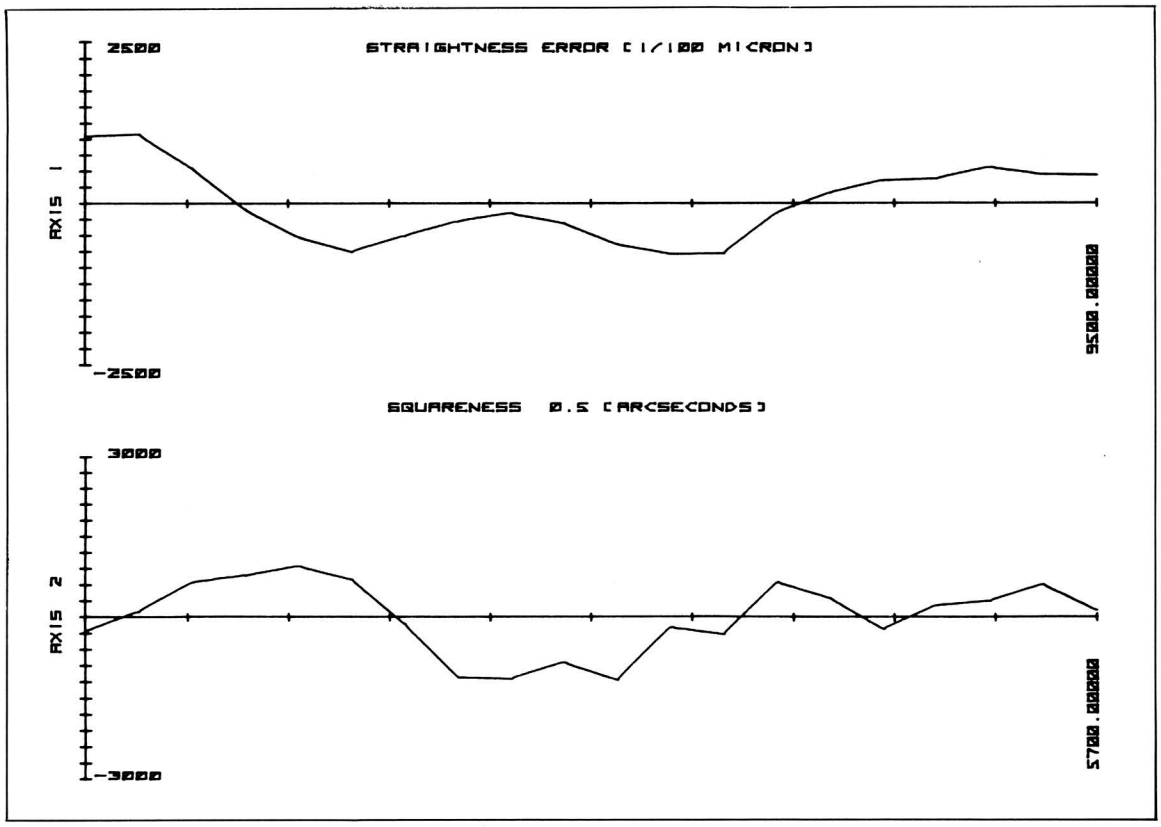



*Figure 2-28. Straightness and Squareness Plots*

## GENERAL ERROR ANALYSIS

This program allows command values to be stored in the calculator memory and calculates the error at each command position as the machine is moved sequentially to each command point. The error at each command position can be printed inside the calculator memory. The error data can then be stored on the Metrology Program Cartridge and used by the Statistical Error Analysis Program to determine a mean and 3 sigma standard deviation, if each measured point has been repeated several times. The mean is the statistical average of each data point and represents the accuracy at that command position. The 3 sigma standard deviation points enclose a band where 99.7 out of 100 points taken at that command position would lie and represents precision.

1. Unidirectional: $C_0C_1C_2C_0C_1C_2C_0C_1C_2$... (each $C_0C_1C_2$ command series is one run)

2. Bidirectional: $C_0C_1C_2C_2C_1C_0C_0C_1C_2$...

3. Single Step: $C_0C_1C_0C_2C_1C_3C_2C_4C_3C_4C_0C_1C_0C_2C_1C_3C_2C_4C_3C_4$...

4. Multiple Step: $C_0C_1C_0C_1C_0C_2C_1C_2C_1C_3C_2C_3C_2C_4C_3C_4C_3$

In the Single Step and Multiple Step Command Sequences, the first and last command points are not used by the statistical Error Analysis Program. (See Figure 2-30 for a graphic explanation of the command sequences used.) For a Multiple Step Command sequence the number of runs selected must be an even number (i.e., 2, 4, 6, etc.).

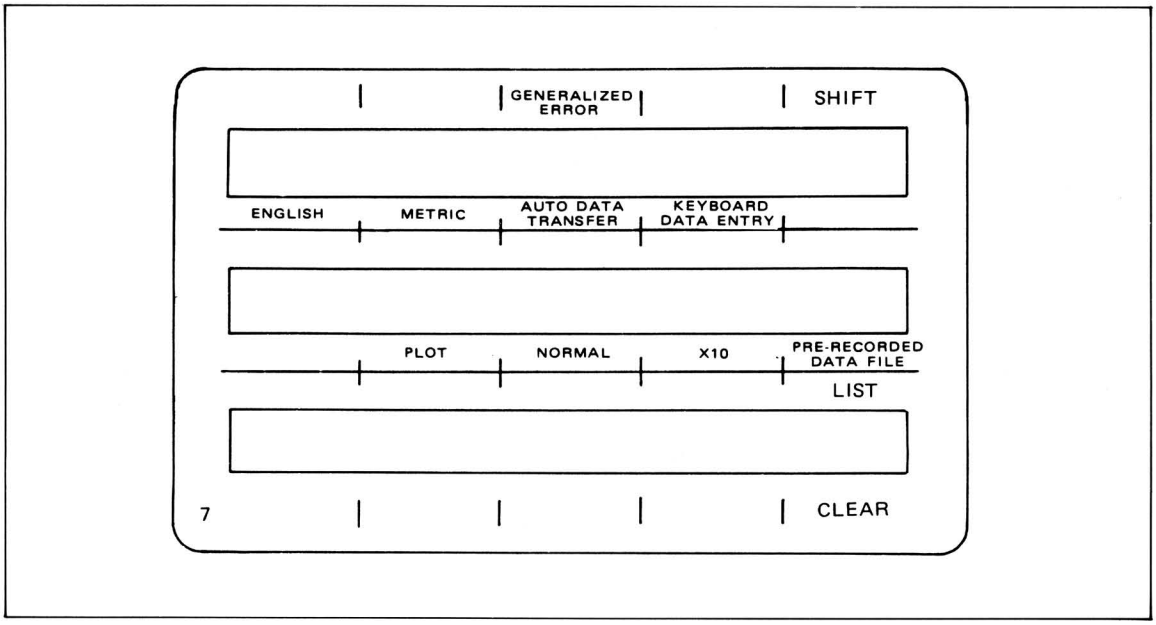



*Figure 2-29. Key Overlay Number 7*

There are four unique features of this program:

1. When several data runs are to be made the operator need only enter one complete run of command values. For a Bidirectional command sequence the operator enters the first run of command points (i.e. $C_0C_1C_2$) only. $C_0C_1C_2C_3C_4$ is all that is necessary for Single and Multiple Step and the calculator automatically formats the commands into the proper sequence.

2. The program has a maximum acceptable error entry which provides a safety valve to the operator. If the error calculated at a particular command value exceeds this maximum acceptable error the calculator will disregard the error value and ask for the command position again. Therefore, if a command position is missed the sequence can be maintained without loss of data.

3. A negative error plot can be generated by entering a negative maximum length of travel which provides the convenience of referencing the error plot's X-axis to the machine movement. For example, if the machine is being calibrated from zero to minus twenty inches then the graph can be drawn from zero to minus twenty. If the machine moves from zero to plus twenty inches then the graph can be drawn from zero to plus twenty.

   (NOTE: If a negative maximum length of travel on the error plot is selected make sure that when the Statistical Error Analysis program is run with the generated error data a negative error plot is also asked for.)

4. Bidirectional data is stored in two unidirectional sets, one forward one backward. Data can be analyzed either bidirectionally or forward, backward, and bidirectionally by the Statistical Error Analysis program.

Figure 2-31 provides tables and formulas for determining the maximum number of runs which can be taken versus the number of commands per run.

In this program the maximum error at each command cannot exceed ±0.099999 inches (±0.999999 mm).

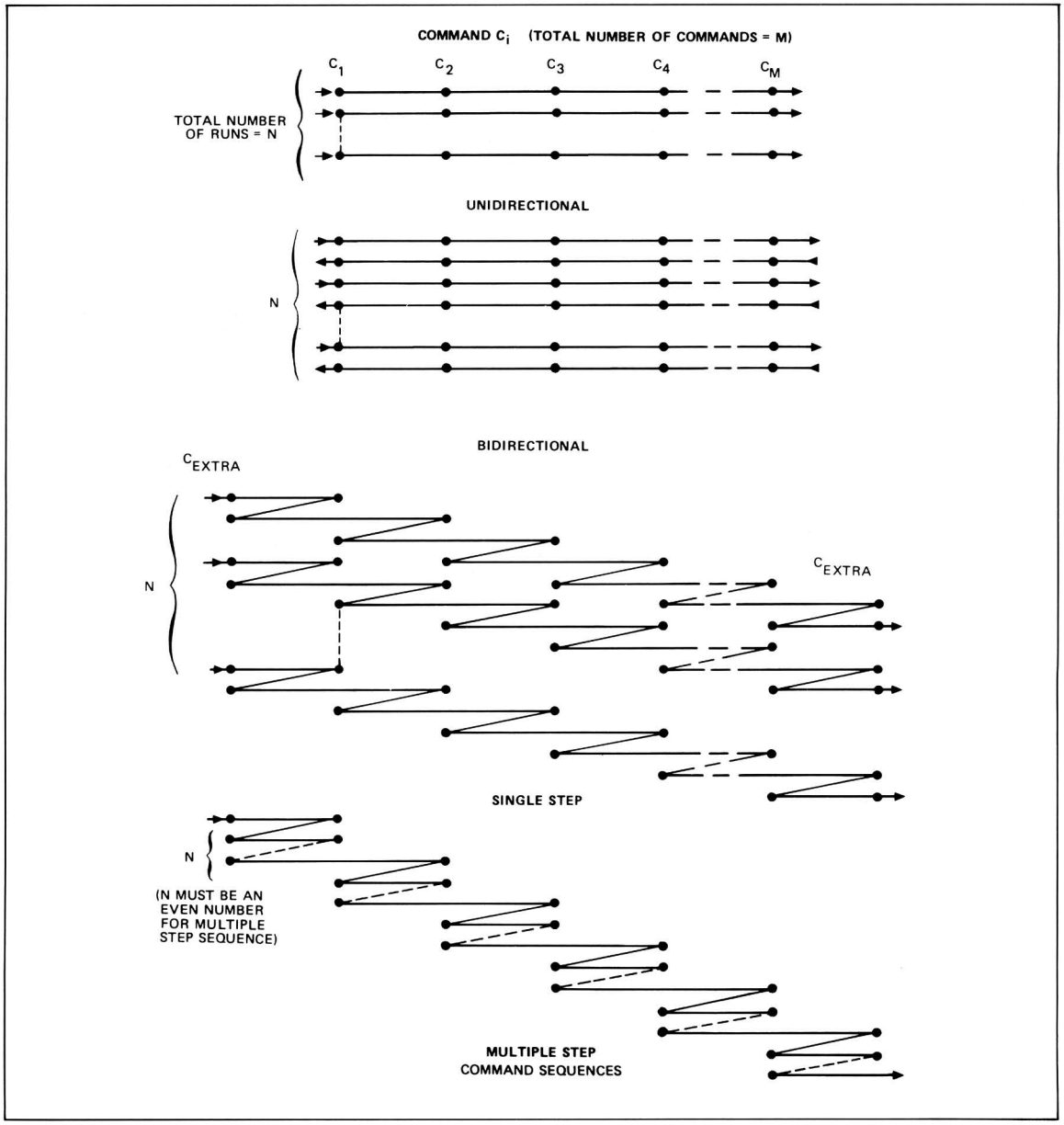



*Figure 2-30. General Error Plots*

UNIDIRECTIONAL & BIDIRECTIONAL

Equation: $\frac{\#\ CMDS/RUN\ *\ (\ 1\ +\ \#\ RUNS/2)}{3ØØ} \leq 1$

(i.e., for 28 CMDS/RUN, is 19 runs acceptable?

$\frac{28\ *\ (1\ +\ 19/2)}{3ØØ}$ = .98 which is acceptable.)

# of RUNS

| # Commands Run | 22 | 21 | 20 | 19 | 18 | 17 | 16 | 15 | 14 | 13 | 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 150 | | | | | | | | | | | | | | | | | | | | | X | X |
| 125 | | | | | | | | | | | | | | | | | | | | | X | X |
| 100 | | | | | | | | | | | | | | | | | | | X | X | X | X |
| 75 | | | | | | | | | | | | | | | | | X | X | X | X | X | X |
| 50 | | | | | | | | | | | | | X | X | X | X | X | X | X | X | X | X |
| 25 | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X | X |

SINGLE & MULTIPLE STEP

Equation: $\frac{\#\ CMDS/RUN*\ (1\ +\ 2\ *\ [\#\ of\ RUNS])}{3ØØ} \leq 1$

(i.e., for 28 CMDS/RUN, is 4 runs acceptable?

$\frac{28\ x\ (1\ +\ 2\ *\ [4])}{3ØØ}$ = .84 which is acceptable)

# RUNS

| # CMDS/RUN | 5 | 4 | 3 | 2 | 1 |
|---|---|---|---|---|---|
| 75 | | | | | X |
| 50 | | | | (X) | X |
| 25 | X | (X) | X | (X) | X |

*Figure 2-31. Maximum Number of Runs versus Number of Commands per Run*

1. Insert the Metrology Program Cartridge into the 9815A Cartridge Reader.

2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.

3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.

4. Turn the 9815A Calculator on.

5. AUTO START and INITIALIZATION PROGRAM will be printed.

6. Place the GENERALIZED ERROR key overlay on the 9815A keyboard.

7. Press the SHIFT key and then the GENERALIZED ERROR key. GENERAL ERROR will be printed.

8. Select the proper setup keys labeled in blank letters under the appropriate key on the key overlay for the measurement and press the RUN STOP key. (For a better description of the key overlay and setup keys refer to the section titled INITIALIZATION PROGRAM.)

---

**NOTE**

If pre-recorded command files are to be used enter the first data file and press PRE-RECORDED DATA FILE key. If a second data file was required to store the entire command sequence enter the second file number and press the PRE-RECORDED DATA FILE key again.

---

9. The 9815A Calculator will read the proper file on the Metrology Program Cartridge.

10. GENERAL ERROR ANALYSIS will be printed.

11. If a pre-recorded command file was entered with the setup keys go to step 16.

    COMMAND TYPE?, 1-UNIDIRECTIONAL, 2-BIDIRECTIONAL, 3-SINGLE STEP, 4-MULTIPLE STEP will be printed. Enter the number corresponding to the type of command sequence selected via the numeric keyboard and press the RUN STOP key.

12. # OF RUNS? will be printed. Enter the *total* number of runs to be taken via the numeric keyboard and press the RUN STOP key.

---

**NOTE**

Refer to Figure 2-21 to obtain the number of points the calculator will accept. If a MULTIPLE STEP sequence is chosen an *even* (i.e., 2, 4, 6, 8 . . . ) number of runs must be selected.

---

13. COMMANDS?, (INCHES) or (MMS) will be printed. Enter the necessary command position via the numeric keyboard in the first run. When the necessary commands for the entire run (i.e., $C_0C_1 \ldots C_m$) have been entered, press the RUN STOP key.

---

**NOTE**

If negative command values are to be used make sure the command value is entered as a negative number and the MAXIMUM LENGTH OF TRAVEL step 18, is negative.

---

14. RECORD CMDS? will be printed. If the operator wishes to record the command values on an available data file for future use, press the Ø key and then the RUN STOP key.

    If the commands are not to be stored, press the RUN STOP key with no entry and go to step 16.

15. FILE #? will be printed. Enter the available file number and press the RUN STOP key.

    If two data files are required to store the command sequence FILE #? will be printed again after the first data file has been filled. Enter the second data file and press the RUN STOP key.

    If the file number entered is an illegal number (i.e. Ø through 31, or -Ø) ILLEGAL, NEW FILE #? will be printed. Enter a new data file number and press the RUN STOP key.

16. MAX ACCEPTABLE ERROR?, (INCHES) or (MMS) will be printed. Enter the maximum acceptable error in the units asked and press the RUN STOP key.

    **NOTE**

    The acceptable error value is a *safety valve* to protect the data if a command value in the sequence is missed. The MAX ACCEPTABLE ERROR does not determine the scale on the plot if a graphical plot was selected. (See step 19 MAXIMUM EXPECTED ERROR.)

17. If the plot option was not selected go to step 20.

18. MAXIMUM LENGTH OF TRAVEL?, (IN INCHES) or (IN MMS) will be printed. Turn the 9862A Plotter on, enter the maximum length of travel of the machine and press the RUN STOP key. This entry defines the X-Axis scale on the plot.

    **NOTE**

    If negative command values are to be used enter the maximum length of travel as a negative number.

19. MAXIMUM EXPECTED ERROR?, (IN INCHES) or (IN MMS) will be printed. Enter the maximum expected error via the numeric keyboard and press the RUN STOP key. The value entered defines the Y-Axis scale on the plot.

    The 9862A Plotter will plot and label the axes. See Figure 2-33 for example.

20. DATA?, (INCHES) or (MMS) will be printed.

21. COMMAND and the command value will be printed. If automatic data transfer was selected go to step 23.

22. Enter the data point as an integer value as it appears on the 5505A Laser Display with sign and decimal point. Press the RUN STOP key and go to step 24.

23. For automatic data input, move the equipment to the first command value. When the data point is 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. Repeat step 23 as necessary for each command value.

24. ERROR and the value of the error will be printed and plotted. Go to step 21.

    If the maximum acceptable error value is exceeded ERROR TOL EXCEEDED will be printed. Return to step 21.

    When the last data point has been transmitted press the RUN STOP key twice. Go to step 25.

25. RECORD ERRORS? will be printed. If the operator wishes to record the error data on an available data file for future use, press the Ø key and then the RUN STOP key.

    If the error data are not to be stored press the RUN STOP key with no other entry and go to step 27.

26. File #? will be printed. Enter the available file number and press the RUN STOP key.

    If two data files are required to store the error data FILE #? will be printed after the first data file has been filled. Enter the second data file and press the RUN STOP key.

    If the file number entered is an illegal number (i.e., Ø through 31, or -0) ILLEGAL,NEW FILE #? will be printed. Enter a new data file number and press the RUN STOP key.

**NOTE**

The data must be stored on a file before it can be used to the STATISTICAL ANALYSIS program.

27. INITIALIZATION PROGRAM will be printed. Another program can now be selected.

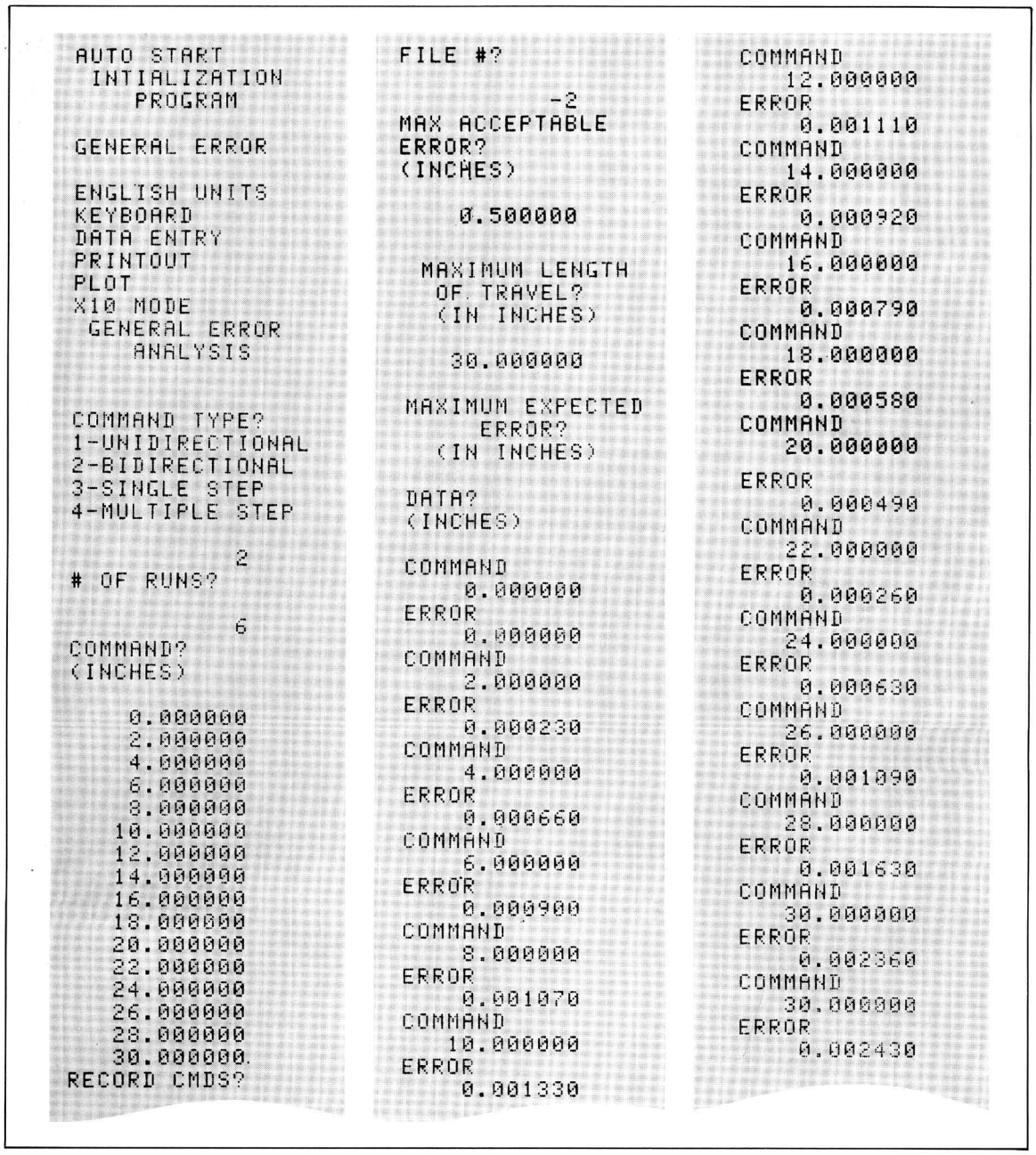



*Figure 2-32. General Error Analysis Example Printout*

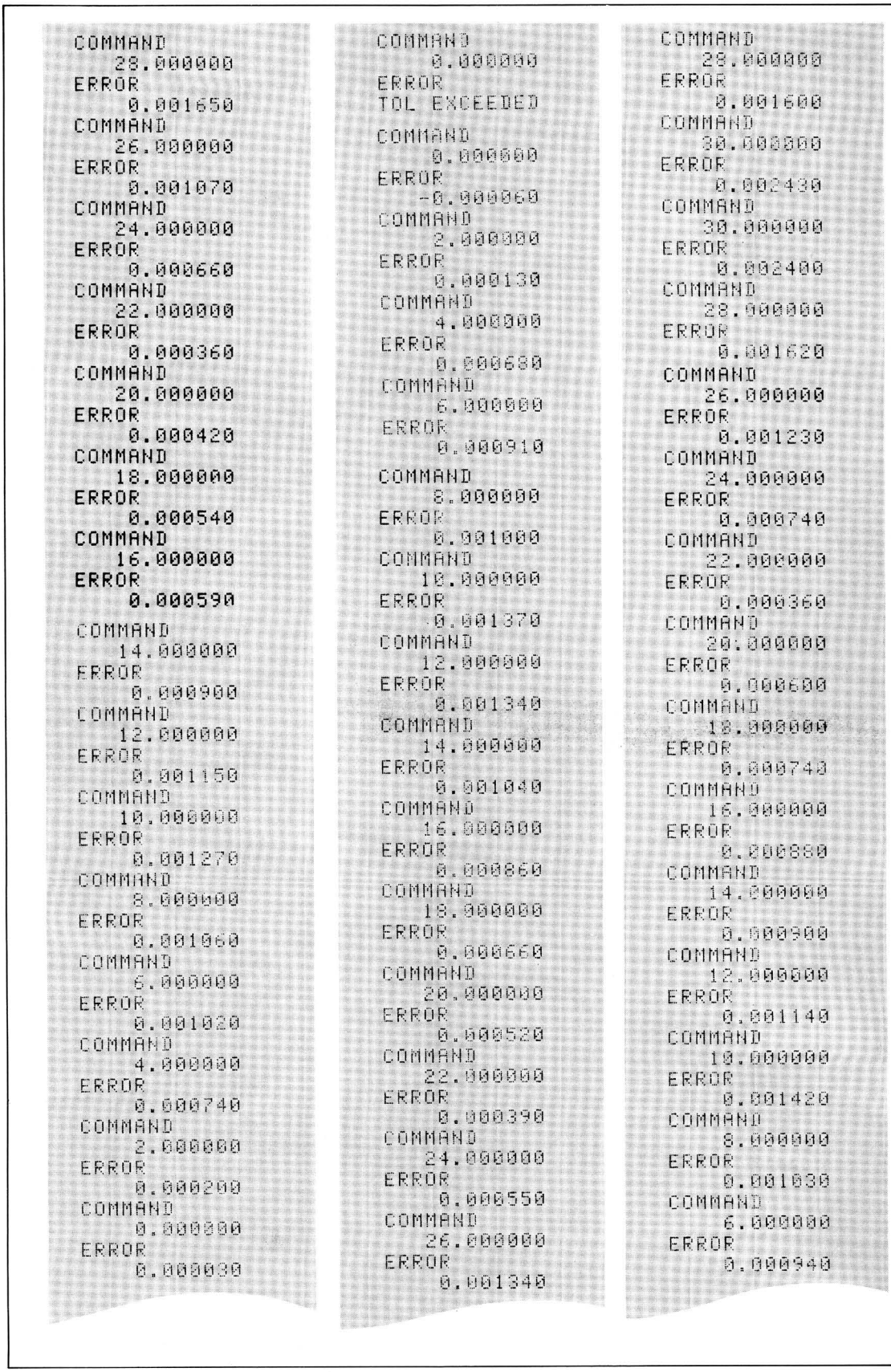



*Figure 2-32. General Error Analysis Example Printout* (cont'd)

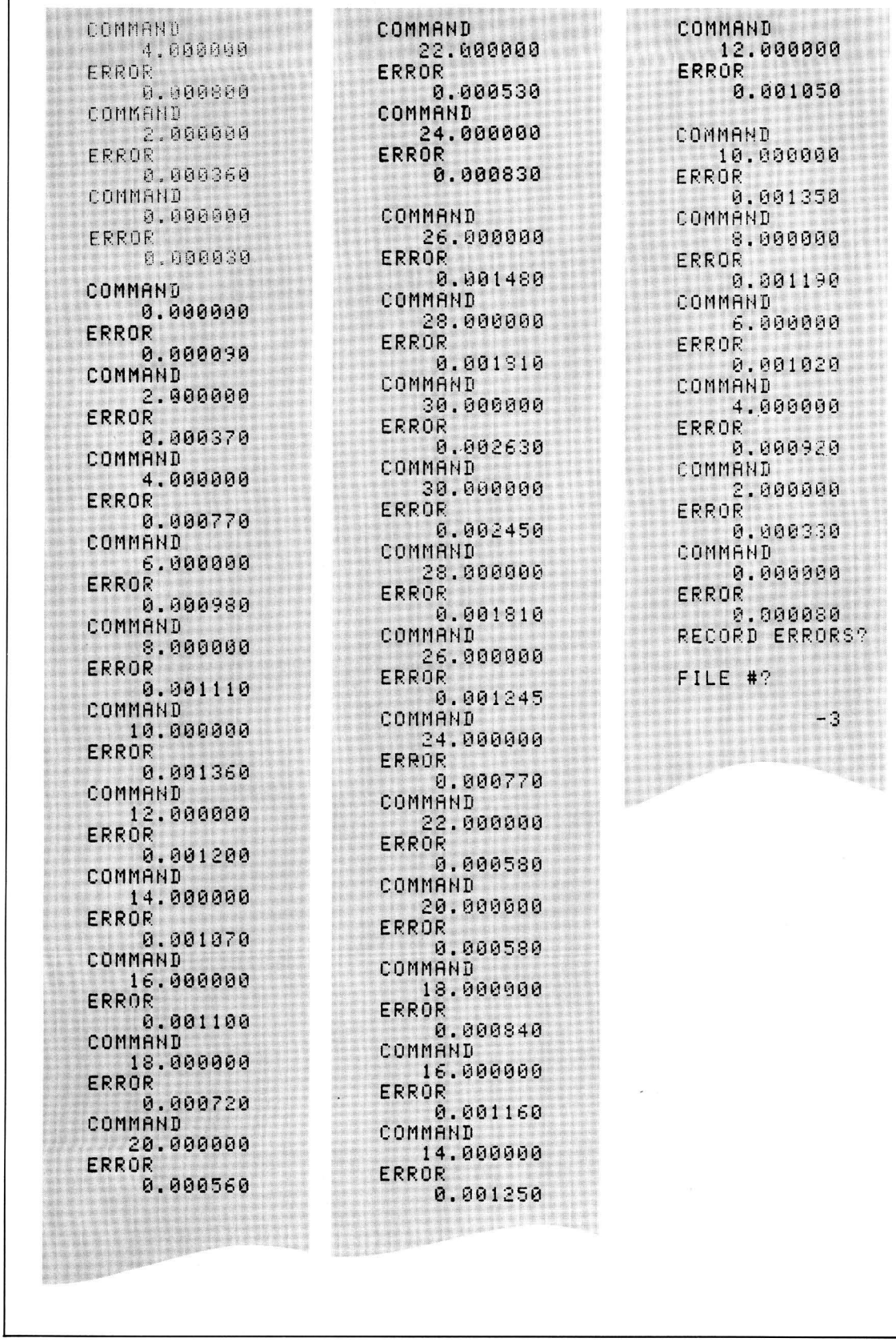



*Figure 2-32. General Error Analysis Example Printout* (cont'd)

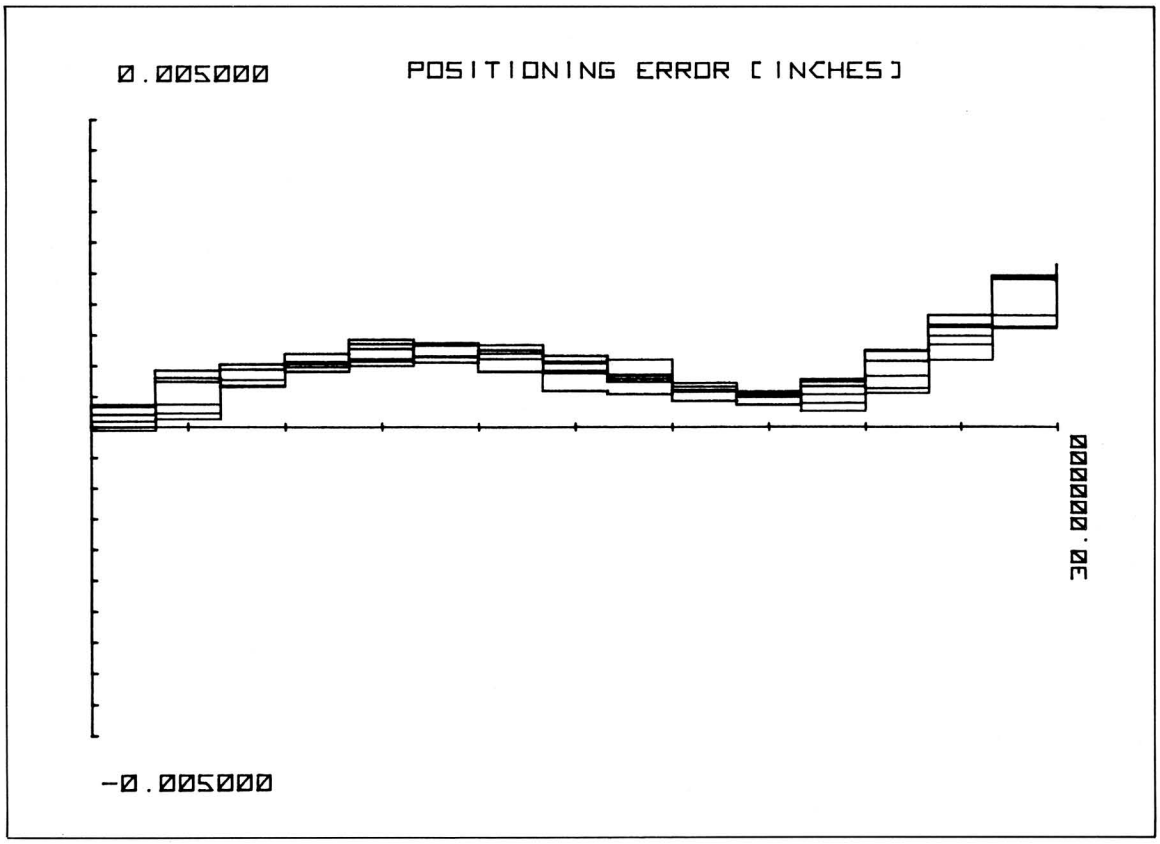



*Figure 2-33. General Error Analysis Plot*

## Review of Basic Statistics

1. Normal Distribution Curve

a. The normal distribution curve is a continuous probability function represented by a symmetrical bell-shaped curve,shown in Figure 2-34. This curve is also known as the normal curve, normal curve of error, probability curve, Gaussian curve, Laplacian curve, normal distribution curve, and bell-shaped curve.

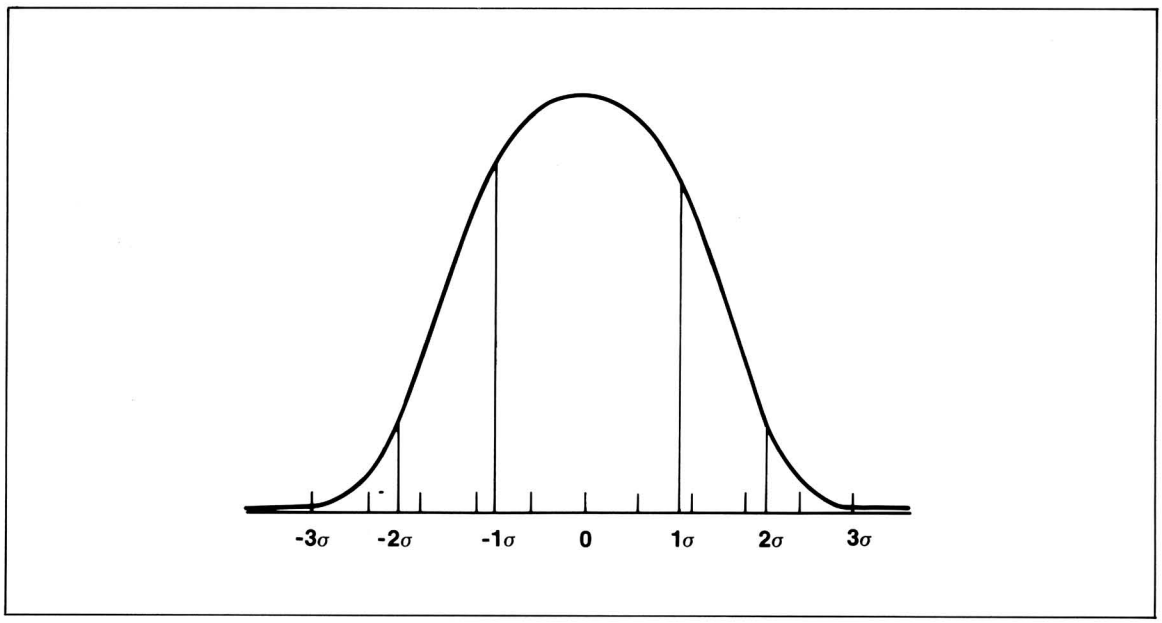



*Figure 2-34. Normal Distribution Curve*

b. It portrays the distribution of a population of data and samples of that population. For an example, we will assume throughout this discussion that our sample set of data is composed of position measurements on a machine tool.

c. The two parameters which define a normal distribution are $\overline{X}$ (read as "X bar"), the mean, and $\sigma$ (read "sigma"), the standard deviation.

d. $\overline{X}$, the arithmetic mean or in common language the average, is defined as the sum of a set of readings divided by the number of readings in that set. A set of readings refers to measurements of the same position taken on concurrent runs during a defined time interval, under like operating conditions of the machine and environment.

$$\overline{X} = X_1 + X_2 + X_3 \ldots + X_n = \frac{\Sigma X_n}{n}$$

e. When one or more of the above variables of a reading are changed a new set of readings will result, resulting in a new X. $\overline{\overline{X}}$ (read X double bar) is the average of the averages sometimes called *grand average.*

$$\overline{\overline{X}} = \overline{X}_1 + \overline{X}_2 + \overline{X}_3 \ldots + \overline{X}_n = \frac{\Sigma \overline{X}_n}{n}$$

f. $\sigma$, is found by (1) squaring the deviations of individual measurements from the mean, (2) summing the squares, (3) dividing by (n - 1) for small values of n, 4) extracting the same root.

$$\sigma = \left(\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + (X_3 - \overline{X})^2 - \ldots + (X_n - \overline{X})^2}{n - 1}\right)^{1/2} = \left(\frac{\Sigma (X_n - \overline{X})^2}{n - 1}\right)$$

This formula applies for any universe of possible measurements and does not rely on the universe being normal. This is more correctly termed the sample standard deviation(s).

g. The NMTBA recommendations are based on the simplifying assumption that non-repeatable positioning errors on a machine tool are (a) random, and (b) will follow a normal distribution. The VDI takes a similar approach but uses slightly different methods of calculating the mean and standard deviation.

2. Dispersion — the variation or scatter of a set of readings taken at the same position as in step 1 (d) above.

   a. Dispersion is also called range, standard deviation, repeatability, precision or variability.

   b. Range is the difference between the largest and smallest values of a variable (X) and is the simplest measure of dispersion.

   c. Two of the most useful measures of dispersion are range and the standard deviation.

   d. This is necessary to gage the reliability of the calculated averages.

   e. It is also used to determine causes of the variation in a set or series of sets of measurements.

   f. The standard deviation which was previously defined is also referred to as the standard measure of dispersion.

   g. The standard deviation is a measure of repeatability, or basic variability within a set of measurements.

   h. Precision refers to repeatability, basic variability, or standard deviation.

3. Average Value, Absence of Bias, Accuracy

   a. Accuracy of measurements refers to the agreement of the mean of the measurement x, to the "true" value being measured for.

   b. The "true" value is represented by the laser wavelengths.

   c. Bias refers to the displacement from the "true" value. Accuracy refers to the absence of bias.

4. Sample Size and Confidence Intervals

   a. As a general statement, an increased sample size will give a more accurate range, and a higher degree of confidence in the relationship of individual measurements to all possible measurements at that point and a better approximation of the normal distribution. The NMTBA recommends seven runs or sets of each measurement point. A bidirectional measurement would contain 14 runs of data. As described above a set of measurements would include 7 runs unidirectional or 14 runs bidirectional (7 forward and 7 reverse).

   b. The confidence interval is related to the standard deviation of a set of measurements. The standard deviation is divided into sections that contain all of the possible measurements statistically predictable from the known sample (set).

   c. The following confidence intervals are the most commonly used. Percentages shown only apply to normal distributions.

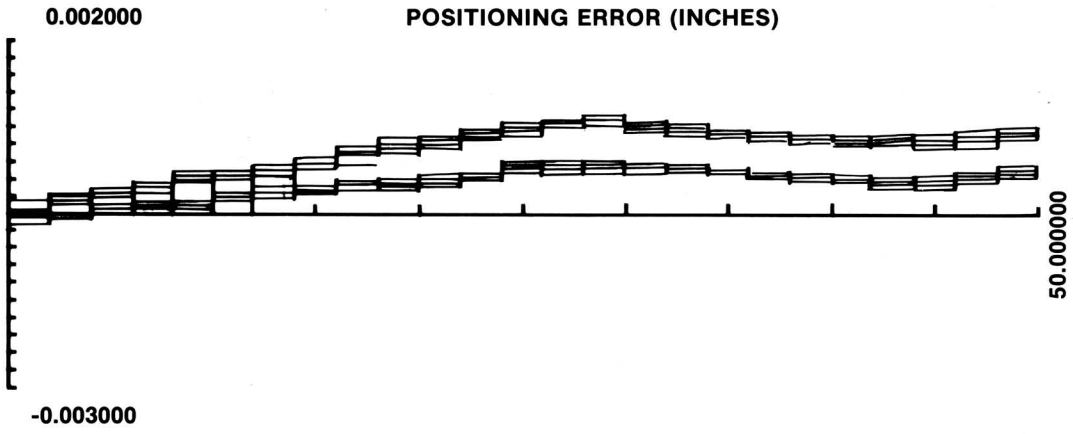
      $\overline{X}$ +/- 1$\sigma$ is the 68.26% interval.

      $\overline{X}$/ +/- 2$\sigma$ is the 95.46% interval.

      $\overline{X}$ +/- 3$\sigma$ is the 99.73% interval.

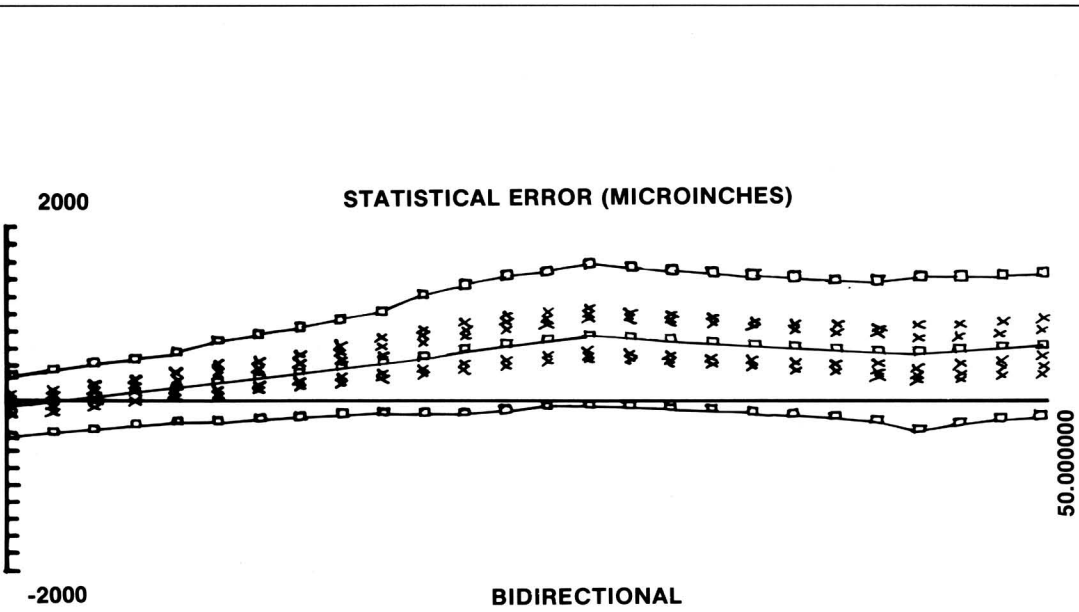
      A $\pm 3\sigma$ computation would take a set of measurements and predict from that set size (number of data points) and range what the range of 99.73% of all possible measurements in that set.

   d. Both the NMTBA and the German VDI standard use the $\pm 3$ confidence interval as the basis of their respective accuracy definitions. They are in fact saying that, if further samples within a set are taken, 99.73% of the new samples will also fall within the $\pm 3\sigma$ limits.



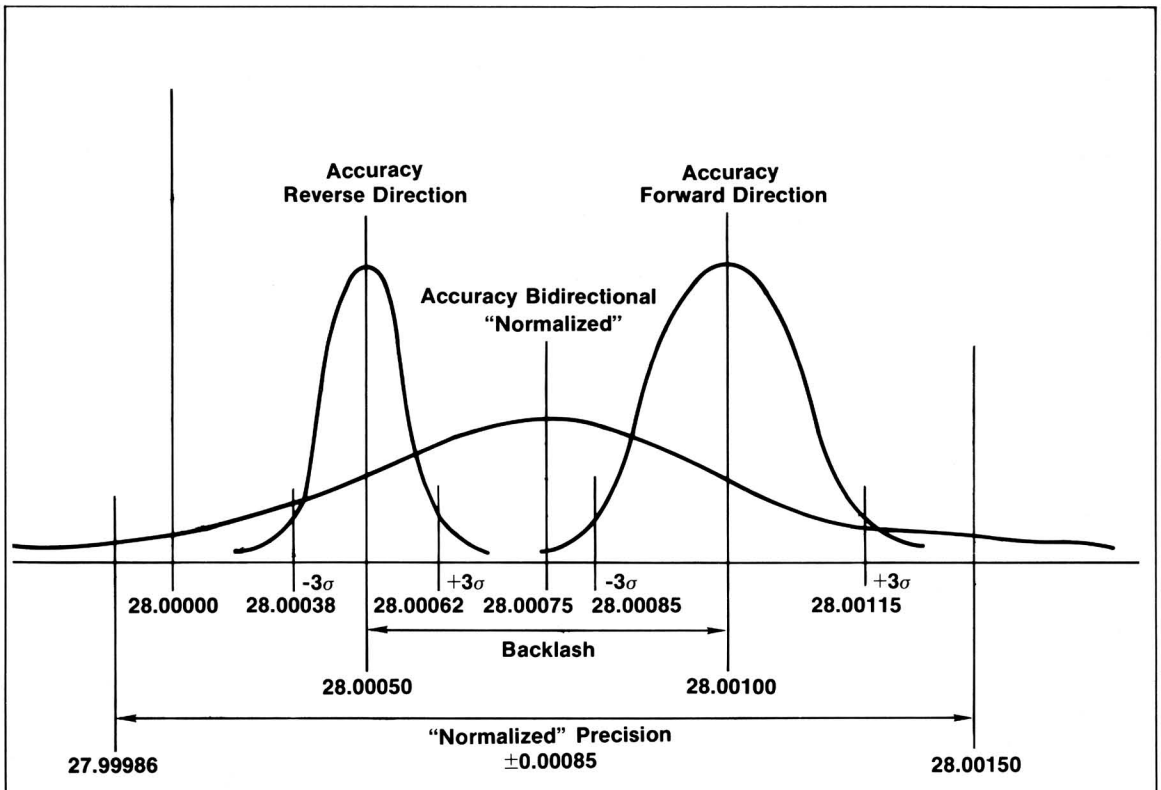

**Note: Actual linear positioning data sampled 8 times at each target position. Space between vertical groupings is backlash.**

*Figure 2-35. Positioning Error (inches)*




**Note: "Normalized" mean and $\pm 3\sigma$ of data shown above in Figure 2-35. X's are actual data points. Centerline is the mean, "Accuracy". Outside lines are the "Precision".**

*Figure 2-36. Statistical Error (Microinches)*




**Note: Example of the data from Figure 2-35 analysed at only one target position, 28 inches. This follows the NMTBA recommendations. The peak to the left is reverse direction data. The line at 28.00050 in. is the accuracy of the reverse direction data to the target position of 28.000000. The lines of 28.000380 and 28.000620 are limits of the precision computed to ±3σ or 99.73%. The forward direction accuracy is the line at 28.00100. The forward direction precision is 28.000850 to 28.00115 or ±0.000150. Backlash is the separation in forward and reverse accuracies. It should be evident from this example that this machine is more accurate when positioning in the reverse direction and will not position as the "Normalized" curve indicates.**

*Figure 2-37. Normalized Precision*

To apply the above NMTBA recommendations we can use the positioning data shown in Figure 2-35 of a 50-inch travel. Figure 2-36 is the statistical analysis including the actual data points, mean, and +/-3σ distribution of the machine travel. Only four data points in each direction were used in Figure 2-36. The NMTBA recommends a minimum of seven. Only four data points reduces the chance of obtaining the same mean and +/-3σ that would be obtained from seven or ten data points. The formula compensates with a wider distribution curve. Figure 2-36 and 2-37 are two methods of showing the similar data. Figure 2-37 is one target position, 28 inches. Figure 2-36 is all 25 target positions.

Shown in Figure 2-38 is the forward direction and Figure 2-39 is the reverse direction data of the same target positions along the same axis, as in Figure 2-35.

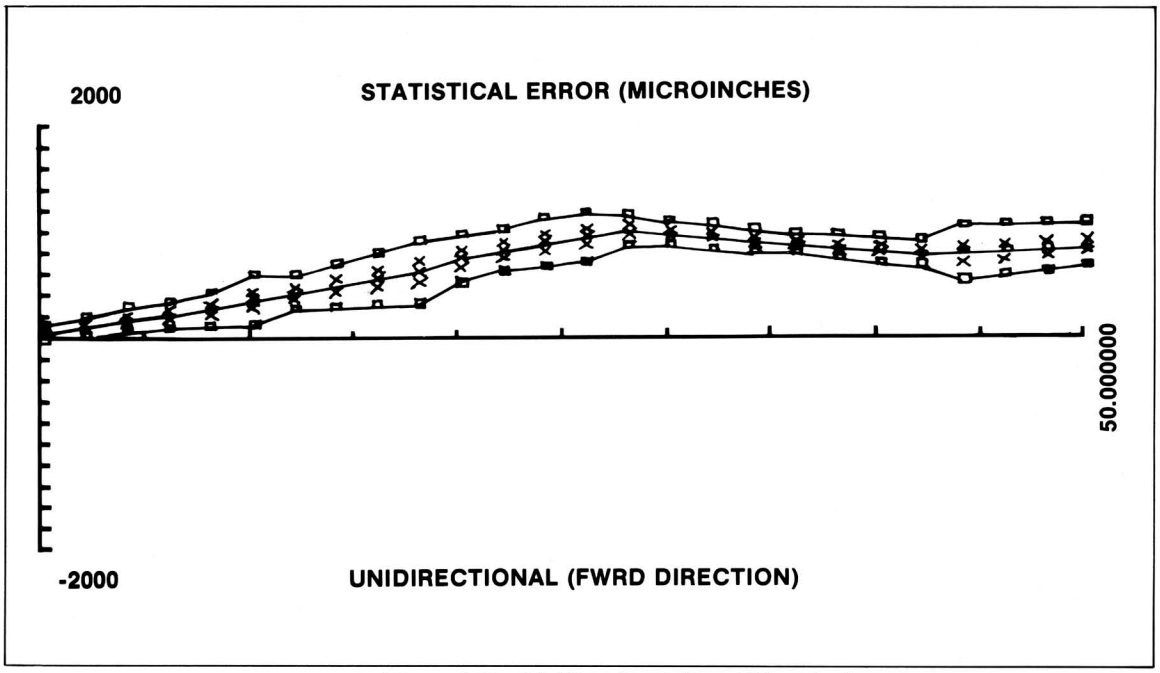



*Figure 2-38. Unidirectional (Fwrd Direction)*

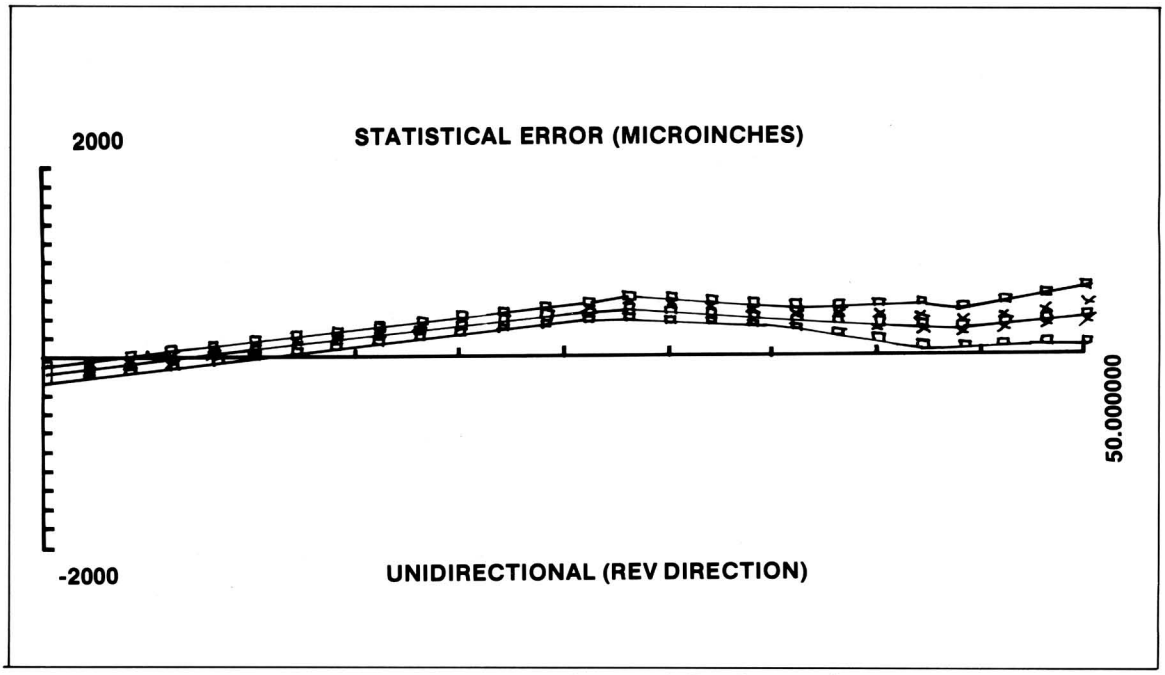



*Figure 2-39. Unidirectional (Rev Direction)*

The physical separation between the forward and reverse direction data can be seen in Figure 2-37 for the 28 in. position and somewhat for the entire axis in Figure 2-36. This physical offset is the backlash or lost motion between the forward and reverse positioning attempts at the 28 in. target position.

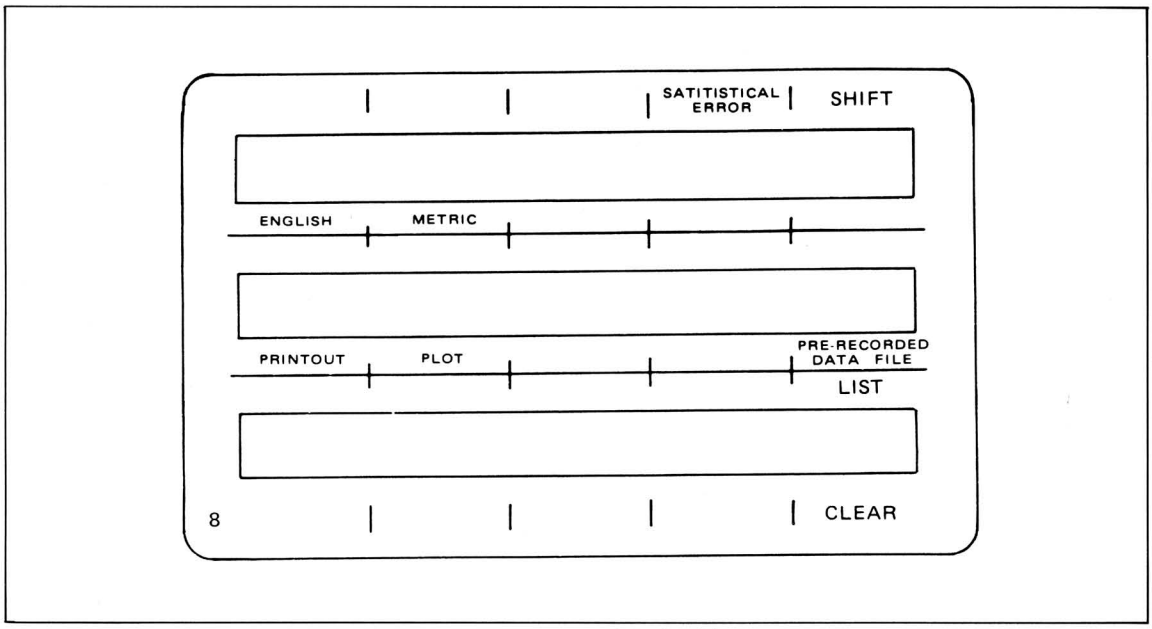



*Figure 2-40. Key Overlay No. 8*

### Method of Least Squares Best Line Fit

The least-squares best line fit method is based on the linear regression equation

$$Y_e = mx + b,$$

where $y_e$ represents the estimate of the value of y at the point x.

This method determines a line of best fit from a set of n given points (x, y), where the standard deviation of the x's is

$$S_x = \sqrt{\frac{\Sigma\,(\overline{X} - x)^2}{n}}$$

By statistical methods, it is found that

$$m = \frac{(\Sigma y)\,(\Sigma x) - n\,(\Sigma xy)}{(\Sigma x)^2 - n\,(\Sigma x^2)}$$

and

$$b = \frac{(\Sigma x)\,(\Sigma xy) - (\Sigma y)\,(\Sigma x^2)}{(\Sigma x)^2 - n\,(\Sigma x^2)}$$

Inserting these values for m and b into the linear regression equation $y_e = mx + b$ enables a user to determine a good estimate of the value of y for a given value of x.

## STATISTICAL ERROR ANALYSIS

This program accepts data from the Generalized Error Analysis program and computes means and +/-3 standard deviations in accordance with the National Machine Tool Builders' Association recommended techniques for machine tool positioning accuracy calibration. The data from the Generalized Error Analysis program, and the mean and +/-3 standard deviation ($\pm 3\sigma$ or $\pm 3$ sigma) can be printed and/or plotted. The data may be in either Unidirectional, Bidirectional, Single Step, or Multiple Step format. *For Bidirectional data statistical analysis can be performed on either or both unidirectional sets of data and/or the two unidirectional sets combined.*

## Procedure

1. Insert the 10585A Metrology Program Cartridge into the 9815A Cartridge reader.

2. Set the operating mode switch on the 9815A Calculator keyboard to AUTO START.

3. Set the printer mode switch on the 9815A Calculator keyboard to NORM.

4. Turn the 9815A Calculator on.

5. AUTO START and INITIALIZATION PROGRAM will be printed.

6. Place the STATISTICAL ERROR key overlay on the 9815A keyboard.

7. Press the SHIFT key and then the STATISTICAL ERROR key. STATISTICAL ERROR will be printed.

8. Enter the file number which contains the error data generated by the Generalized Error Analysis program via the numeric keyboard and press the PRE-RECORDED DATA FILE key. (If two data files were asked for in the Generalized Error Analysis program enter the two files in the same sequence as used in the Generalized Error Analysis program. Repeat step 8 for the second data file.)

9. Select the proper setup keys labeled in black letters under the appropriate key on the key overlay. (For a better description on the key overlay and setup keys refer to the section titled Initialization Program.)

10. The 9815A Calculator will read the proper file on the 10585A Metrology Program Cartridge.

11. STATISTICAL ERROR ANALYSIS will be printed.

12. If a printout was selected (COMMANDS IN INCH UNITS), (ERROR DATA IN MICROINCHES) or (COMMANDS IN MM UNITS), (ERROR DATA IN 1/100 MICRONS) will be printed.

13. If a Bidirectional data format was used in the Generalized Error Analysis program BIDIRECTIONAL DATA, UNIDIRECTIONAL CALCULATIONS? will be printed. If the two unidirectional data runs (one forward and one reverse) are to be individually calculated before the bidirectional calculation, press the Ø key and then the RUN STOP key.

    If only the bidirectional calculation is desired press the RUN STOP key with no entry.

14. If the plot option was not selected go to step 16.

    NEW PLOT PAPER, MAX LENGTH OF TRAVEL?, (IN INCHES) or (IN MM) will be printed. Place a new piece of paper on the plotter and turn the 9862A Plotter on.

    Enter the maximum length of travel in the units specified and press the RUN STOP key.

    (NOTE: If the error data was taken with negative command values enter the maximum length of travel as a negative number.)

15. MAX EXPECTED ERROR?, (MICROINCHES) or (1/100 MICRON) will be printed. Enter the maximum expected error and press the RUN STOP key. This entry will determine the Y-axis scale on the plot.

    The 9862A Plotter will draw and label the axes.

16. UNI FWRD DIR, UNI REV DIR, BID, SGL STEP, or MULTI STEP will be printed.

17. CMD and the command value will be printed.

18. DATA and the error values will be printed and/or plotted with an X.

19. MEAN and the mean value of the error data will be printed and/or plotted with an O. The mean value is the accuracy.

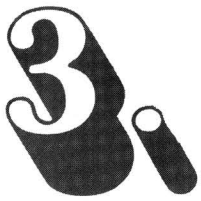
20. 3*STD SEV and three times the standard deviation of the data will be printed and/or plotted with an O. The 3*STD DEV is the ±3 Sigma range of accuracy or the precision.

21. Steps 17-20 will be repeated for the entire command sequence.

22. If Bidirectional Data format was used and undirectional calculations were selected in step 13, steps 17-20 will be repeated if a printout was selected. If the plot option was selected return to step 14.

    After the Bidirectional calculations were made go to step 23.

23. INITIALIZATION PROGRAM will be printed. Another program can now be selected.



# Metrology Program Cartridge Duplication

## INTRODUCTION

When all of the available data storage files on the 10585A Metrology Program Cartridge are used, or when the 9815A Calculator cannot read a file use the following procedure to duplicate the metrology program cartridge:

## PROCEDURE

1. Insert the protected (i.e. slide the record arrows to the left) 10585A Metrology Program Cartridge into the 9815A Cartridge reader.

2. Set the operating mode switch on the 9815A Calculator keyboard to **AUTO START**.

3. Set the printer mode switch on the 9815A Calculator keyboard to **NORM**.

4. Turn the 9815A Calculator on. **AUTO START** and **INITIALIZATION PROGRAM** will be printed.

5. Press the **E** key and then the **J** key located in the user definable key set on the left side of the 9815A Calculator keyboard.

6. **CARTRIDGE FILE MARKING** will be printed and the 9815A will read and run the program.

7. **METROLOGY TAPE FILE MARKING, PLACE NEW UNPROTECTED TAPE CARTRIDGE IN CALCULATOR** will be printed. Remove the 10585A Metrology Program Cartridge and place a new, *unprotected* tape cartridge in the 9815A Cartridge reader. Press the **RUN STOP** key.

8. The program will properly mark the new tape cartridge. Allow approximately 7 minutes for completion of this operation.

9. **REFER TO MANUAL FOR PROCEDURE ON HOW TO COPY METROLOGY TAPE** will be printed.

10. Remove the new tape cartridge and place the 10585A Metrology Program Cartridge in the 9815A Cartridge reader.

11. Press the **CLEAR** key and then the file number to be copied (file Ø is the first file). Press the **LOAD** key.

12. Remove the 10585A Metrology Program Cartridge and place the new tape cartridge into the 9815A Cartridge. Press the **RECORD** key.

13. Repeat steps 10 through 12 for files 1 through 8.

14. Remove the new tape cartridge and place the 10585A Metrology Program Cartridge in the 9815A Cartridge reader. Press the following key sequence: **1 6 5 (GOLD KEY) STORE CLEAR 1 1 ENTER 9 LOAD.**

15. Remove the 10585A Metrology Program Cartridge and place the new tape cartridge into the 9815A Cartridge reader. Press the following key sequence: **CLEAR 1 5 0 ENTER 1 1 ENTER 9 (GOLD KEY) RECORD.**

16. Press the following key sequence: **CLEAR (GOLD KEY) STORE.**

17. Remove the new tape cartridge and place the 10585A Metrology Program Cartridge in the 9815A Cartridge reader.

18. Press the **CLEAR** key and then the file number to be copied (file 1Ø is the first file). Press the **LOAD** key.

19. Remove the 10585A Metrology Program Cartridge and place the new tape cartridge into the 9815A Cartridge reader. Press the **RECORD** key.

20. Repeat steps 17 through 19 for files 11 through 17 and files 2Ø through 25 (skip files 18 and 19).

21. Press the following key sequence: **1 6 5 (GOLD KEY) STORE**.

22. With the new tape cartridge still in the 9815A Cartridge reader press the following key sequence: **CLEAR 1 5 4 ENTER 1 1 ENTER 2 7 (GOLD KEY) RECORD**.

23. Press the following key sequence: **CLEAR (GOLD KEY) STORE.**

24. Remove the new tape cartridge and place the 10585A Metrology Program Cartridge in the 9815A Cartridge reader.

25. Press the **CLEAR** key and then the file number to be copied (file 28 is the first file). Press the **LOAD** key.

26. Remove the 10585A Metrology Program Cartridge and place the new tape cartridge into the 9815A Cartridge reader. Press the **RECORD** key.

27. Repeat steps 24 through 26 for files 29 through 31.

28. If the data files (files 32 through 52 and -1 through -38) are to be copied go to step 29. Otherwise, refer to step 34.

29. Press the following key sequence: **1 6 5 (GOLD KEY) STORE.**

30. Remove the new tape cartridge and place the 10585A Metrology Program Cartridge, which contains the user generated data files, in the 9815A Cartridge reader.

31. Press the following key sequence: **CLEAR 1 1 ENTER (date file #) LOAD.**

32. Remove the 10585A Metrology Program Cartridge and place the new tape cartridge in the 9815A Cartridge reader. Press the following key sequence: **CLEAR 1 5 4 ENTER 1 1 ENTER (Data file #) (GOLD KEY) RECORD.**

33. Repeat steps 30 and 32 for each data file to be copied.

34. Press the **REWIND** key and when the tape cartridge stops remove and label the new tape cartridge.

35. Place the 10585A Metrology Program Cartridge in the 9815A Cartridge reader and press the **REWIND** key. Remove the tape cartridge when the tape is rewound.


10585-90003

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