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LASER-ERROR-CORRECTION CONTROL UNIT
FOR MACHINE TOOLS

R. R. Burleson

May 1978

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OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

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Prepared for the Department of Energy
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ABSTRACT

An ultraprecision machining capability is needed to meet the requirements for aspherical, optical-quality surfaces for the laser fusion program. A minicomputer-based control system was developed for use on a Moore Number 3 measuring machine as part of its transformation into a very accurate contouring machine tool. This control system is a marriage of the "stepping-motor", open-loop, positioning system and the interferometric-feedback system. A 30-cm-diameter aluminum disc was machined to a 133-cm-radius spherical contour. A contour error of 250 nm (2500 Å) was observed.

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SUMMARY

An ultraprecision machining capability is needed to meet the requirements for aspherical, optical-quality surfaces for the laser fusion program. A minicomputer-based control system was developed for use on a Moore Number 3 measuring machine as part of its transformation into a very accurate contouring machine tool. The objectives of this project were to: (1) attain an optimum tradeoff between hardware and software; (2) use a modular design for easy maintenance; (3) use the EIA standard RS-274-B numerical control tape service; (4) drive the x and y axes with a positioning resolution of 5.08 nm and a feedback resolution of 10 nm; (5) drive the x and y axes at a velocity of 0.05 cm/sec in the contouring mode and 0.18 cm/sec in the positioning mode; (6) eliminate the possibility of tape reader errors, and (7) allow editing of the part description data.

Based upon experience with the control systems currently in use on diamond-turning machine tools, a new control concept has been devised. It is a marriage of the "stepping-motor", open-loop, positioning system and the interferometer-feedback system. In this dual system, pulse trains are generated by the computer and fed to the stepping-motor-like drives for the slides. A laser interferometer feedback system was added which "corrects" the pulse train to the stepping motor by adding or deleting individual pulses. As long as the drive-system errors do not have wavelength components that are too short to be corrected by the interferometer feedback, adequate tool position control is obtainable.

This system was designed to provide a flexible and easily maintainable control unit for a machine tool. Flexibility was built into the system through the use of the minicomputer. The operator-panel switch settings, the machine parameters, and the part-description data are all read into the minicomputer. The software in the minicomputer then decides whether the action requested is allowed; and, if so, it will load the interpolators, read a block of part description data from the disk, or whatever else is requested. The position readouts and the machine and laser status lights are continuously updated by the minicomputer. Since the minicomputer is the controlling element of the system, most changes that may be required simply necessitate a change in software.

A 30-cm-diameter aluminum disc was machined to a 133-cm-radius spherical contour to evaluate the system. A contour error of 250 nm (2500 Å) was observed. Based upon the results obtained, two additional control systems are being assembled to handle the production workload.

INTRODUCTION

An ultraprecision machining capability is needed for the laser fusion program. For this work, a precision air-bearing spindle has been mounted horizontally on a modified vertical column of a Moore Number 3 measuring machine base located in a development laboratory at the Oak Ridge Y-12 Plant.^(a) An open-loop control system previously installed on this machine¹ was inadequate to meet the upcoming requirements since accuracy is limited to 0.5 μm by the errors in the machine's gears and leadscrew. A new controller was needed that could monitor the actual position of the machine and perform real-time error correction on the programmed tool path. It was necessary that this project: (1) attain an optimum tradeoff between hardware and software; (2) use a modular design for easy maintenance; (3) use a standard NC tape service; (4) drive the x and y axes with a positioning resolution of 5.08 nm and a feedback resolution of 10 nm; (5) drive the x and y axis motors at a velocity of 0.05 cm/sec in the contouring mode and 0.18 cm/sec in the positioning mode; (6) eliminate the possibility of tape-reader errors; and (7) allow editing of the part description data. This report describes the work that was done to develop and install the new machine controller.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the Department of Energy.

MACHINE-TOOL CONTROL UNIT

SYSTEM DESCRIPTION

This system is to control a three-axis (x, y, c) turning machine with full and continuous-path positioning capability. The major components of the control system, consisting of the pedestal controls, the video terminal, and the electronics cabinet with status displays, can be seen in Figure 1.

A block diagram of the control system is presented in Figure 2. Commands are received by the minicomputer from the pedestal controls. If the system is in the manual, single-block, or automatic mode, the minicomputer loads the digital differential analyzer (DDA)² with the correct distance, then loads the timing and add-command generator with the correct speed. The laser correction is then loaded with the requested error bound, and the clock is turned on. The command signals from the DDAs are corrected by the laser correction circuitry, and the corrected command signals cause the motors to move the slides in the required direction at the specified feedrate. The laser is used to measure the distance traveled by the slides. This information is then routed to the position-display and laser-correction circuitry. During this process, the minicomputer is used to monitor and display the status of the laser, machine, and program. A computer routine is used to check for any change in the pedestal controls that would require the system to change operations.

CONTROL UNIT

Theory

This system was designed to provide a flexible and easily maintainable control unit for a machine tool. Flexibility was built into the system through the use of the minicomputer. The operator-panel switch settings, the machine parameters, and the part-description data are all read into the minicomputer, shown in Figure 3.

The software in the minicomputer then determines whether the action requested is allowed; if so, it will load the DDAs, read a block of part description data from the disk, or do whatever else is requested. The position readouts and the machine and laser status lights are continuously updated by the minicomputer. Since the minicomputer is the controlling element of the system, most changes in the system strategy will only require a change in the software.

Modular design has been incorporated into the hardware system for ease of maintenance. This was done through the use of an Input/Output (I/O) Bus that allows all modules to be interconnected at a common point. Each axis of the machine is controlled independently so that a failure in one axis will not affect the operation of the total machine. All similar functions are contained on a single printed circuit board. That is, an input receiver board was designed that takes the signals from switches, filters them, then puts them on the I/O Bus when requested. Several of these boards are used in the system to filter all switches. The

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Figure 1. LASER-ERROR-CORRECTION MACHINE-TOOL CONTROL SYSTEM.

Figure 2. CIRCUITRY FOR THE MACHINE-TOOL CONTROL UNIT AND THE THREE-AXIS TURNING MACHINE.

entire control unit is composed of only nine different types of printed circuit boards. This modular design, combined with software that allows fault isolation down to a single board, results in an easily maintainable system.

System Controls

The system controls are contained on a remote pedestal, seen in Figure 4, for easy access by the operator. These controls are:

1. Mode - This switch allows the operator to select one of six modes of operation. The controls that are in effect in each mode are contained in the area of the panel labeled with that particular mode.
2. Manual Feed - Incremental feeds from 0.02 to 2.500 μm (0.001 to 100 mils) can be selected, and rapid feeds from 0.005 to 25 mm/sec (0.001 to 5.0 ipm) are also selectable.

Figure 3. PRINCIPAL COMPONENTS OF THE MACHINE-TOOL CONTROL SYSTEM.

Figure 4. PEDESTAL-MOUNTED CONTROL PANEL.

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3. Jog - This feature allows the operator to move any axis in either direction. The manual-feed control sets either the distance or the speed that the selected axis will move. The "jog" light will stay on until the machine has stopped.
4. Display - This group of controls selects either English or metric resolution. In the "in" position, the displays will read inches; in the "mm" position, the displays will read millimeters. Reset switches for each axis are also provided.
5. Laser - This set of switches enables or disables the laser error correction. Controls are also available to retune the laser or restart the laser electronics.
6. Feedrate Override - This feature allows the operator to vary the tool velocity with respect to the part surface during a machining pass without changing the tool path. This feature is also operational in the manual mode.
7. Optional Stop - At various times during a machining process, it may be advantageous to stop the cycle. Certain points on the tape contain optional stops. Through the use of this feature, the operator has the option to stop at these points.
8. Cycle Start - Through the use of this feature, a machining cycle is continued from the last block executed.

9. Clear - This feature resets all error conditions and resets the machining cycle to the first block.
10. Feed Hold - After completion of a block, the machine will stop if this feature has been initiated. The "feed-hold" light will stay on until the machine has stopped.
11. Stop - This control immediately stops all slide motion. After this button has been activated, the machining cycle must be restarted.
12. Start - This feature allows the operator to store a program on the disk, read a program from the disk into memory preparatory to machining, or execute a sequence search of a program already in memory. The "start" light will stay on until the search is complete.

Status Displays

The functionally grouped status displays, shown in Figure 5, are:

1. Program End - The machine cycle has come to its programmed end. An attempt to continue from this point will cause the machining cycle to be reset to the first block.
2. Program Stop - The machining cycle has come to a programmed stop. The program will continue with the next block when the "cycle-start" button is activated.

Figure 5. SYSTEM-STATUS DISPLAY PANEL.

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3. Optional Stop - An optional stop has been encountered with the "optional-stop" switch in the "on" position. The program will continue with the next block when the "cycle-start" button is activated.
4. End of Block - The machine is at the end of a block of data and is waiting to continue.
5. Hold - The "feed-hold" button has been activated, and the system will stop at the end of the present block.
6. Run - A machining cycle is in the process of being executed.
7. Retune Status - Indicates that the laser PZT tuning/check is in process.
8. Retune Error - The laser is out of tune and the "retune" button should be activated.
9. Pulse Error - The laser signal and the receiver signals are out of phase, and the "restart" button should be activated.
10. Laser Error - There is an over-current condition in the laser. The laser should be retuned.
11. Limit Error - The machine has encountered a limit switch or a clamp is engaged.
12. Interpolation Fault - An interpolation fault has occurred during the execution of a block, and the system has stopped.
13. Write Error - While attempting to write onto the disk, a "write error" was encountered. This problem could be caused by a full disk or by a bad block of data.
14. Read Error - While reading from the disk or tape reader, a "read error" was encountered.
15. Search Error - The file requested in a program search or the sequence number selected in a sequence number search was not found.
16. Axis Displays - The x and y-axis displays show the position of their respective axis accurate to 10 nm with metric resolution or 1 μ in with English resolution. The c-axis display shows its position accurate to 2 μ deg. All position displays are referenced to the NC part tape setup point.
17. Sequence Number - A part program is broken down into various machining processes which are identified by separate sequence numbers. The sequence number of the machining process in operation is displayed.

ERROR CORRECTION

Theory

Based upon experience with the control systems currently in use on diamond-turning machine tools, a new control concept has been devised. It is a combination of the stepping-motor, open-loop positioning system, used successfully on the previous Moore turning machines, and the interferometer feedback system used on the larger-optical-component turning machines. In this dual system, pulse trains are generated by the computer and fed to the stepping-motor-like drives for the slides.

If the reduction unit, the leadscrew, and the nut were dimensionally perfect, the tool would be positioned exactly as commanded except for the very small lag introduced by the finite compliance of the drive shaft and gearing, and the finite mass of the slide. Unfortunately, they are not dimensionally perfect, nor is it felt to be cost effective to make them dimensionally "adequate" for providing $0.1\text{-}\mu\text{m}$ optical components. Therefore, a laser-interferometer feedback system has been added which "corrects" the pulse train to the stepping motor by adding or deleting individual pulses. As long as the drive-system errors do not have wavelength components that are too short to be corrected by the interferometer feedback, adequate tool-position control is obtainable. The lag problem is eliminated by utilizing very high gains on the two axes.

Drive System

The first problem to be overcome was to obtain a very-high-gain, stepping-motor-like drive for the slides. A system was purchased with a resolution of 10,000 steps per revolution (S/R) and a maximum following error of 10 steps (Figure 6). These drive systems utilize a permanent-magnet DC motor with a resolver mounted on the same shaft as the motor. This arrangement creates a very stable system. This system is driven by a two-state, pulse-width-modulated motor driver. Since these motors were limited to 100,000 steps per second, with available gearing this restriction meant a maximum rapid traverse speed of 0.04 cm/sec. A method was developed to change the resolution of the drive system so that, by turning a switch, the resolution could be changed to 2000 S/R and, therefore, a maximum rapid traverse speed of 0.2 cm/sec. In the manual mode, they have a resolution of 2000 S/R, while in the automatic mode they have a resolution of 10,000 S/R.

Feedback Element

The next major obstacle to overcome was to develop a method for accurately measuring the displacement of the slides. A laser interferometer was selected for the job. A layout of the components of the laser interferometer is presented in Figure 7. A picture of the laser mounted on the machine, with the oil-tight covers removed, is included as Figure 8. The available electronic systems had a resolution of $\lambda/4$, where λ is the wavelength of a He/Ne laser. This resolution was electronically extended to $\lambda/40$ through the use of a laser extender. Since $\lambda/40$ is an awkward number with which to work, a fringes-to-inches

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Figure 6. STEPPING-MOTOR-LIKE DRIVE SYSTEM THAT IS USED TO POSITION THE MACHINE.

converter was utilized to convert $\lambda/40$ to 10-nm pulses in metric resolution, or 1 μ in pulses with English resolution. The fringes-to-inches converter is compensated for barometric pressure, temperature, and relative humidity by the computer system.

Correction Circuitry

Having now obtained a high-gain drive system and a high-resolution feedback element, the remaining problem was to develop the circuitry to compare the commanded position with the actual position and correct for any errors. This development takes the command pulse to the motors and either adds, subtracts, or takes no action, depending on the amount and sign of the error. The laser up-and-down pulses, the command pulses, and the command sign enter the anticoincidence logic where an up-and-down error signal is developed (see Figure 9). The error signal is then brought to an up/down counter and stored. The error signal stored in the counter is then compared to the error limit stored in the limit-bound register.

Figure 7. MAJOR COMPONENTS OF THE LASER INTERFEROMETER SYSTEM.

When the error is greater than the error limit, a signal is developed that tells the Add/Sub (a pulse circuit) to begin correcting. The Add/Sub will then either insert or delete one pulse, depending on the sign of the error. The velocity-loop circuitry enables the Add/Sub only every n th command pulse. The smaller the value of n , the tighter the loop.

The unique feature of this development is the makeup of the motor-drive signal. In a standard numerical control (NC) controller with interferometric feedback, the system is required to build up an error before the controller is able to drive the motors. With this development, no error is required to drive the motors; and, consequently, a tighter loop is obtained. This development is also unique in that it is a completely digital approach, whereas a standard NC controller uses an almost totally analog approach.

SOFTWARE

The control system is capable of operating under six different modes. The software for each mode has been written into a program that runs under the Digital Equipment Corporation RT-11 disk operating system. Following is a brief discussion about the operation of each mode.

When a part-description tape is received, it must be transferred to a disk file before any machining can take place. This transfer is made by inserting the tape into the tape reader,

Figure 8. LASER SYSTEM THAT IS MOUNTED ON THE MACHINE.

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Figure 9. ERROR-CORRECTION CIRCUITRY.

selecting the program storage mode, dialing in the part number, then pushing the "start" button. The tape will be read in and stored in a file on Disk 1. The file will be called "PADS.xxx," where xxx is the part number. If an editing of the part description is required, the "feed-hold" button must be pushed after the "start" button. This action will cause the program to exit to the system monitor where the editor can be used to modify the part description. The program can then be reentered. The "start" light will stay on until the program storage is complete. The stored part description can then be accessed by the program search mode. The part number should be entered, then the "start" button pushed. The "start" light will stay on until the search is complete.

Once the part description has been loaded, the operator can do a sequence search at any time by entering the sequence search mode, entering the desired sequence number, and pushing the "start" button. The "start" light will stay on until the search is complete.

When in the manual mode, the operator has complete control of the machine. The "manual-feed" switch is used to select either a distance movement or a rapid feed speed. Then, by pressing the appropriate "jog" button, any axis can be moved in either direction. If a distance movement is selected, a momentary pressing of the appropriate "jog" button is sufficient; but, if a rapid feed is selected, the appropriate axis will continue moving only as long as the "jog" button is pressed. The appropriate "jog" light will stay on as long as that axis is in motion.

The single-block and automatic modes are very similar. The only difference is that when in the single-block mode, the system halts after each block is executed and waits for a "cycle start" to continue. When the system is in the automatic mode, the part description, loaded with a program search, is in control of the machine. When the "cycle-start" button is pressed, the controller will begin executing the part description data from the point selected by the sequence search, or if the "clear" button was pressed from the first block. The "cycle-start" light will stay on as long as the machine is in the "run" state. A "feed hold" can be used to stop the machine after the present block is finished being executed, after which a "cycle start" will continue on from that point. The "stop" button will cause the machine to stop immediately and reset the part description to the first block.

RESULTS

Several test parts (133-cm spherical radius on a 30-cm-diameter aluminum disc) were cut to a tolerance of 10 μ in. A complete set of positioning tests were also run successfully. The results are given in Appendix A. The system performed as designed. During these tests it was found that precautions must be taken to ensure that the laser equipment has come to thermal equilibrium with the machine tool before beginning operation. This adjustment can be accomplished by keeping power on the laser system continuously during its day-to-day operation.

An outline of the operating procedure is included in this report (Appendix B); requirements for the standard RS-274-B NC tape are listed (Appendix C); a listing of the device register

assignments is provided (Appendix D); a printout of the software listings is available (Appendix E); as well as drawings of all hardware items (Appendix F).

CONCLUSIONS AND RECOMMENDATIONS

This control unit has proven that an open-loop, stepping-motor-like drive coupled with a laser interferometer offers a good method of control for a precision machine tool. Because the machine operators were involved in the layout of the operator's controls, this control unit has been extremely well received and easily used by machine-shop personnel.

Due to the versatility of this control unit, two additional units are being assembled for the production facility. Using the minicomputer as the system controller also permits certain adaptive control features or gaging features to be incorporated into the system in the future. To this end, a study is now in progress to determine the feasibility of using this control system on an ultraprecision inspection machine.

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APPENDIX A
SYSTEM EVALUATION

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A series of positioning checks were run on the machine, utilizing the dynamic-error monitor system. This system compares the commanded position of the machine with the actual position of the machine as measured by a test laser interferometer. Two tests were run on the machine.

Test 1

Test laser was mounted at the same height as the positioning laser to determine the accuracy of the positioning system. A view of the test setup that was used is provided in Figure A-1; the results are seen in Figure A-2.

Test 2

Test laser was mounted at the tool height to determine the viability of the machine and control system. The test setup used is shown in Figure A-3; the results are reported in Figure A-4.

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Figure A-1. TEST ARRANGEMENT FOR MEASUREMENTS MADE AT THE POSITIONING LASER HEIGHT.

(a) No Correction.

(b) $\pm 10\text{-}\mu\text{in}$ Error Bound.

(c) $\pm 4\text{-}\mu\text{in}$ Error Bound.

(d) $\pm 1\text{-}\mu\text{in}$ Error Bound.

Figure A-2. DYNAMIC-ERROR-MONITOR PLOT OF THE POSITIONING ERROR AT THE POSITIONING LASER HEIGHT, MOVING AT 0.2 ipm.

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Figure A-3. TEST ARRANGEMENT FOR MEASUREMENTS MADE AT THE TOOL HEIGHT.

(a) No Correction.

(b) $\pm 1\text{-}\mu\text{in}$ Error Bound.

Figure A-4. DYNAMIC-ERROR-MONITOR PLOT OF THE POSITIONING ERROR AT THE TOOL HEIGHT, MOVING AT 0.2 ipm.

The charts obtained are a plot of positioning error versus position. A graph of the error bound (ie, the error allowed before the system would attempt correcting) versus the positioning error is given in Figure A-5.

Figure A-5. SUMMARY OF THE POSITIONING-ERROR TESTS.

APPENDIX B
OPERATING PROCEDURE

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Introduction

Basic information required to operate this control system is described in the sections to follow. The last two sections contain information that the advanced user may need but is not required for operation of this system. This Appendix should be read only after a thorough understanding of the pedestal controls and status displays has been obtained, since these functions are discussed here.

Rapid Feed Movement

1. Place the "mode" switch in the "manual" position.
2. Select the desired feedrate from the right side of the "manual feed" switch.
3. Push the appropriate "jog" button.
4. The machine will rapid feed as long as the "jog" button is pushed.

Incremental Movement

1. Place the "mode" switch in the "manual" position.
2. Select the increment desired from the left side of the "manual feed" switch.
3. Push the appropriate "jog" button.
4. The machine will now increment the selected distance.

Storing Part Programs

1. Place the "mode" switch in the "program storage" position.
2. Enter the last three digits of the part tape number into the thumbwheel switches.
3. Load the part tape into the tape reader, sprocket out.
4. Turn the tape reader on.
5. Push the "start" button.
6. When the tape reader stops moving, remove the part tape.
7. The "start" light will go out when the storage is complete.
8. Should the "read error" or "write error" light come on, an error was found in the part tape.

Retrieving Part Programs

1. Place the "mode" switch in the "program search" position.
2. Enter the last three digits of the part tape number into the thumbwheel switches.
3. Push the "start" button.
4. Should the "search error" light come on, that part program is not in storage.

Sequence Searching Part Programs

1. Program should have been previously retrieved.
2. Place the "mode" switch in the "seq. no. search" position.
3. Enter the sequence number into the thumbwheel switches.
4. Push the "start" button.
5. Should the "search error" light come on, that sequence number does not exist.

Running a Part Program

1. Program should have been previously retrieved.
2. Place the "mode" switch in the "automatic" position.
3. Push the "clear" button.
4. Push the "cycle start" button.
5. The part program will now begin execution.

Entering Laser Compensation

1. Push the "retune" button.
2. Follow the information displayed on the terminal.

Listing Part Tapes

1. Type on the terminal twice;

(CTRL) C

2. A period will appear on the terminal.

3. To enter the date, type on the terminal:

. DATE DD-MMM-YY (RETURN);

where DD is the day, MMM is the month, and YY is the year.

4. Type on the terminal:

. R PIP (RETURN)

5. An asterisk will appear on the terminal.

6. To list the part tapes, type on the terminal:

*DX1:/L (RETURN)

7. To delete a part tape, type on the terminal:

*DX1:PADS.NNN/D (RETURN) *DX1:/S (RETURN);

where NNN is the part tape number.

8. To list the mylar tape just stored, type on the terminal:

*TT:=PADS.000 (RETURN)

9. To return to the machining program, type on the terminal:

(CTRL) C

10. A period will appear on the terminal.

11. Type on the terminal:

.R MACHG (RETURN)

Initial Startup

1. Turn on control system power.

2. Place disk labeled "16K system" into the left disk drive.

3. Place disk labeled "machining programs" into the right disk drive.

4. Set computer switch register to 1 111 011 100 000 000.

5. Lower, then raise the computer "halt" switch.
6. Push the computer "load adrs" switch.
7. Push the computer "start" switch.
8. The terminal will display: RT-11SJ V02C-02.
9. Type on the terminal: .R MACHG (RETURN).
10. Turn on the motor power.

APPENDIX C

REQUIREMENT FOR STANDARD RS-274-B NC TAPE

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Position: x and y resolution (point to point) = $1.25 \mu\text{in.}$

x and y resolution (contour) = $0.25 \mu\text{in.}$

c resolution (point to point) = 2°

c resolution (contour) = 2°

Present data incrementally drop leading zeros.

x maximum travel = 18 in

y maximum travel = 11 in

c maximum travel = 360°

Feedrate = Present data in inverse time $F = 1/T$ (minutes)

F format shall always be 6.4

T maximum = 5 min

T minimum = 5 msec

$5 > \text{ipm (point to point)} > 0.001$

$1 > \text{ipm (contour)} > 0.001$

Maximum change in ipm per data block is $\text{ipm} = 0.1$; and, in addition, this change must be followed by 10 msec of constant ipm.

G Codes: G00 Point to Point

G01 Linear Interpolation

M Codes: M00 Program Stop

M01 Optional Stop

M02 Program End

M30 Tape End

N Codes: The block sequence number address "n" followed by three digits shall be the first word in a block.

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APPENDIX D
DEVICE REGISTER ASSIGNMENTS

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Device Register - Manual [(164000) input of manual increment and rapid feed from control panel]

Bit	Mnemonic	Description
00	MI 1	Manual increment of 0.001 mil
01	MI 2	Manual increment of 0.010 mil
02	MI 3	Manual increment of 0.1 mil
03	MI 4	Manual increment of 0.5 mil
04	MI 5	Manual increment of 1.0 mil
05	MI 6	Manual increment of 10.0 mils
06	MI 7	Manual increment of 100.0 mils
07	STOP	Stop all movement
08	RF 1	Rapid feed at 0.001 ipm
09	RF 2	Rapid feed at 0.01 ipm
10	RF 3	Rapid feed at 0.1 ipm
11	RF 4	Rapid feed at 0.5 ipm
12	RF 5	Rapid feed at 1.0 ipm
13	RF 6	Rapid feed at 2.0 ipm
14	RF 7	Rapid feed at 5.0 ipm
15	IN	Set to inches mode

Device Register - Mode [(164002) input of switches from control panel]

Bit	Mnemonic	Description
00	XL	Run or increment x axis left
01	XR	Run or increment x axis right
02	YI	Run or increment y axis in
03	YO	Run or increment y axis out
04	CC	Run or increment c axis CCW
05	CW	Run or increment c axis CW
06	PS	Program storage mode
07	SNS	Sequence number search mode
08	M	Manual mode
09	SB	Single block mode
10	A	Automatic mode
11	FO	Laser feedback on
12	LE	Limit error
13	IF	Interpolation fault
14	PF	Program search mode
15	ID	Interpolation done

Device Register - Seq. No. [(164004) input sequence number]

Bit	Mnemonic	Description
00	SN 11	Sequence number digit 1, bit 1
01	SN 12	Sequence number digit 1, bit 2
02	SN 14	Sequence number digit 1, bit 4
03	SN 18	Sequence number digit 1, bit 8
04	SN 21	Sequence number digit 2, bit 1
05	SN 22	Sequence number digit 2, bit 2
06	SN 24	Sequence number digit 2, bit 4
07	SN 28	Sequence number digit 2, bit 8
08	SN 31	Sequence number digit 3, bit 1
09	SN 32	Sequence number digit 3, bit 2
10	SN 34	Sequence number digit 3, bit 4
11	SN 38	Sequence number digit 3, bit 8
12		
13		
14		
15		

Device Register - Feed [(164006) input of feedrate override switch]

Bit	Mnemonic	Description
00	F0 1	Feedrate override at 10%
01	F0 2	Feedrate override at 20%
02	F0 3	Feedrate override at 30%
03	F0 4	Feedrate override at 40%
04	F0 5	Feedrate override at 50%
05	F0 6	Feedrate override at 60%
06	F0 7	Feedrate override at 70%
07	F0 8	Feedrate override at 80%
08	F0 9	Feedrate override at 90%
09	F1 0	Feedrate override at 100%
10	F 11	Stop
11	OSO	Optional stop on
12		
13		
14		
15		

Device Register - Laser [(164010) input laser status]

Bit	Mnemonic	Description
00	RF	Retune failure
01	RS	Retune status
02	LCS	Laser current status
03	HE	Laser head error
04	ROK	Reference OK
05	XC	x pulso converter error
06	YE	y pulse converter error
07		
08		
09		
10		
11		
12		
13		
14		
15		

Device Register - LMT [(164012) input limit switches and motor drive status]

Bit	Mnemonic	Description
00	XRL	x axis right limit
01	XLL	x axis left limit
02	XHL	x axis home limit
03	XB	x axis busy limit
04	XH	x axis home limit
05	YIL	y axis in limit
06	YOL	y axis out limit
07	YHL	y axis home limit
08	YB	y axis busy limit
09	YH	y axis home limit
10	CCL	c axis CCW limit
11	CCWL	c axis CW limit
12	CHL	c axis home limit
13	CB	c axis busy limit
14	CH	c axis home limit
15		

Device Register - Status [(164014) input automatic controls]

Bit	Mnemonic	Description
00	SCH	Start search
01	CSTART	Cycle start
02	FH	Feed hold
03	CLEAR	Clear
04	STP	Stop
05	RST	Laser restart
06	RTU	Laser retune
07	XDR	x display reset
08	YDR	y display reset
09	CDR	c display reset
10	ID	Interpolation done
11		
12		
13		
14		
15		

Device Register - Lights [(164040) output to status lights]

Bit	Mnemonic	Description
00	PRE	Program end
01	PST	Program stop
02	OS	Optional stop
03	EB	End of block
04	HD	Holding
05	RN	Running
06	LE	Limit error
07	ITF	Interpolation fault
08	WE	Write error
09	RE	Read error
10	SE	Search error
11	LSE	Laser error
12	RTS	Retune status
13	RTE	Retune error
14	PE	Pulse error
15		

Device Register - Control [(164042) output of control parameters]

Bit	Mnemonic	Description
00	FL	First load to DDA
01	CL	Clear all
02	RG	Reset "start" button
03	RC	Reset "clear" button
04	RH	Reset "hold" button
05	RN	Reset "stop" button
06	RS	Reset "search" button
07	RR	Retune laser
08	RP	Restart laser converters
09	IC	Interrupt control
10		
11		
12		
13		
14		
15		

Device Register - DSEQNO [(164044) output of sequence number]

Bit	Mnemonic	Description
00	SN 11	Sequence number digit 1, bit 1
01	SN 12	Sequence number digit 1, bit 2
02	SN 14	Sequence number digit 1, bit 4
03	SN 18	Sequence number digit 1, bit 8
04	SN 21	Sequence number digit 2, bit 1
05	SN 22	Sequence number digit 2, bit 2
06	SN 24	Sequence number digit 2, bit 4
07	SN 28	Sequence number digit 2, bit 8
08	SN 31	Sequence number digit 3, bit 1
09	SN 32	Sequence number digit 3, bit 2
10	SN 34	Sequence number digit 3, bit 4
11	SN 38	Sequence number digit 3, bit 8
12		
13		
14		
15		

Device Register - Display [(164046) output of lights to control panel]

Bit	Mnemonic	Description
00	LXL	Light x left
01	LXR	Light x right
02	LYI	Light y in
03	LYO	Light y out
04	LCC	Light c CCW
05	LCW	Light c CW
06	LCSTART	Light cycle start
07	LFH	Light feed hold
08	LCLEAR	Light clear
09	LSTP	Light stop
10	LSCH	Light start search
11		
12		
13		
14		
15		

Device Registers [(164050) - (164064)]

Device Register - IT
(164050) Output of interval timer

Device Register - XLDDA
(164052) Output of least significant 16 bits of x distance

Device Register - XMDDA
(164054) Output of most significant 16 bits of x distance

Device Register - YLDDA
(164056) Output of least significant 16 bits of y distance

Device Register - YMDDA
(164060) Output of most significant 16 bits of y distance

Device Register - CLDDA
(164062) Output of least significant 16 bits of c distance

Device Register - CMDDA
(164064) Output of most significant 16 bits of c distance

Device Register - Feedback [(164066) output of feedback control parameters]

Bit	Mnemonic	Description
00		
01	LF	Laser feedback on
02	SX	x axis sign
03	SY	y axis sign
04	SC	c axis sign
05	CC	Clock control
06	IC	Interrupt control
07	XER	x axis extended resolution
08	SRH	x axis return home
09	YER	y axis extended resolution
10	YRH	y axis return home
11	CER	c axis extended resolution
12	CRX	c axis return home
13		
14		
15		

Device Registers [(164100) - (164112)]

Device Register - LPX

(164100) Input least significant 4 digits of x position

Device Register - IPX

(164102) Input next significant 4 digits of x position

Device Register - MPX

(164104) Input most significant digit and sign of x position

Device Register - LPY

(164106) Input least significant 4 digits of y position

Device Register - IPY

(164110) Input next significant 4 digits of y position

Device Register - MPY

(164112) Input most significant digit and sign of y position

Device Registers [(164114) - (164146)]

Device Register - LPC

(164114) Input least significant 4 digits of c position

Device Register - IPC

(164116) Input next significant 4 digits of c position

Device Register - MPC

(164120) Input most significant digit and sign of c position

Device Register - XEROR

(164140) Output error bound to x axis

Device Register - YEROR

(164142) Output error bound to y axis

Device Register - LFNO

(164144) Output least significant 4 digits of λ

Device Register - HFNO

(164146) Output most significant 4 digits of λ

APPENDIX E
SOFTWARE LISTINGS

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.GLOBAL IRAD50,COMP,FSTART,FDATA,$UTI,$USRSW,$NLCHN,$LRECL
.MCALL ..V2...REGDEF,.ENTER,.WRITW,.CLOSE,.EXIT,.FETCH,.LOCK
.MCALL .LOOKUP,.QSET,.READW,.READC,.PROTECT,.INTEN,.SYNCH
..V2..
.REGDEF
$USRSW=1
$NLCHN=6
$LRECL=210
PS=177776
MO0=177777
MO1=177776
MO2=177775
M30=30.
GO0=177777
GO1=177776
LAS=174000
BXS=100000
BYS=40000
BCS=20000
PRE=177776
PST=177775
US=177773
EB=177767
HU=177757
RN=177737
LME=177677
IIF=177577
WE=177377
RE=176777
SE=175777
LSE=4000
KIS=10000
RIE=20000
PLE=40000
FL=1001
CL=2
KG=4
KC=10
RH=20
RNU=40
KSC=100
RR=200
RF=400
INTRC=1000
SN11=1
SN12=2
SN14=4
SN18=10
SN21=20
SN22=40
SN24=100
SN28=200
SN31=400
SN32=1000
SN34=2000
SN38=4000
EK=1200
LF=2
SA=4
SY=10
SC=20
CCT=40
IC=100
MI1=1

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MI2=2
MI3=4
MI4=10
MI5=20
MI6=40
MI7=100
STOP=200
RF1=400
RF2=1000
RF3=2000
RF4=4000
RF5=10000
RF6=20000
RF7=40000
IN=100000
LXL=177776
LXR=177775
LYI=177773
LYO=177767
LCC=177757
LCW=177737
LCSI=177677
LFH=177577
LC=177377
LS=176777
LSCH=175777
LMXL=1
LMXR=2
LMYI=40
LMYO=100
XL=1
XR=2
YI=4
YO=10
CC=20
CW=40
PTS=100
SNS=200
M=400
SB=1000
A=2000
FO=4000
LE=143
IF=20000
PF=40000
ID=100000
FO1=1
FO2=2
FO3=4
FO4=10
FO5=20
FO6=40
FO7=100
FO8=200
FO9=400
FO10=1000
FO11=2000
OSU=4000
RF=1
RS=2
LCS=4
HE=10
KUK=20
XE=40


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YE=100
SCH=1
CST=2
FH=4
C=10
S=20
RST=40
RTU=100
LFNO=164144
HFNO=164146
XEROR=164140
YEROR=164142
LMT=164012
LASER=164010
FEEDBK=164066
MANUAL=164000
FEED=164006
XMDDA=164054
XLDDA=164052
YMDDA=164060
YLDDA=164056
CMDDA=164064
CLDDA=164062
IT=164050
MPX=164104
IPX=164102
LPX=164100
MPY=164112
IPY=164110
LPY=164106
MPC=164120
IPC=164116
LPC=164114
MODE=164002
STATUS=164014
CONTRL=164042
LIGHTS=164040
DISPLAY=164046
SEGNU=164004
DSEGNU=164044
ENRRWD=52

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```

;/////////////////////////////////////////////////////////////////
;THIS ROUTINE IS ENTERED TO DETECT
;THE POSITION OF THE MODE SWITCH
;/////////////////////////////////////////////////////////////////

```

```

FSTART: JSR      R4,SOTI          ;INIT WORK AREA
        .WORD    .+2
        .WORD    START1
START1: CLR      PS
        MOV      #60160,LFNO
        MOV      #61050,HFNO
        MOV      #177774,XEROR    ;SET ERROR BOUND
        MOV      #177776,YEROR
        CUM      DISPLAY          ;RESET LIGHTS
        CLR      LIGHT
        CUM      LIGHT
        CUM      LIGHTS
        BIS      #RR,CONTRL        ;RETUNE LASER
        CLR      USEGNU
        JSR      PC,LASTAT          ;CHECK LASER STATUS
        .CSET    #GAREA,#5
        MOV      #PAREA,-(SP)
        MOV      #24,R4
        .PROTECT (SP)+,R4

```

```

NOP
MOV     #PWRDN, (R4)+
MOV     #340, (R4)
MOV     #PAREA, -(SP)
MOV     #170, R4
.PROTECT (SP)+, R4
NOP
MOV     #AUTO25, (R4)+
MOV     #340, (R4)+
MOV     #PAREA, -(SP)
.PROTECT (SP)+, R4
NOP
MOV     #AUTO26, (R4)+
MOV     #340, (R4)
START:  BIT     #PTS, MODE           ;CHECK FOR PROGRAM STORAGE MODE
        BEQ     STA1
        JMP     STORE
STA1:    BIT     #PF, MODE           ;CHECK FOR PROGRAM SEARCH MODE
        BEQ     STA2
        JMP     PSCH
STA2:    BIT     #SNS, MODE          ;CHECK FOR SEQUENCE SEARCH MODE
        BEQ     STA3
        JMP     SEUSCH
STA3:    BIT     #M, MODE            ;CHECK FOR MANUAL MODE
        BEQ     STA4
        JMP     MANL
STA4:    BIT     #SB, MODE           ;CHECK FOR SINGLE BLOCK MODE
        BEQ     STAS
        JMP     AUTO
STAS:    BIT     #A, MODE           ;CHECK FOR AUTOMATIC MODE
        BEQ     START
        JMP     AUTO

;//////////////////////////////////////
;THIS ROUTINE IS ENTERED WHEN THE MODE SWITCH IS
;IN THE PROGRAM STORAGE POSITION
;//////////////////////////////////////
STORE:   COM     DISPLAY            ;RESET LIGHTS
STORE1:  JSR     PC, LASTAT
        BIT     #PTS, MODE          ;CHECK FOR PROGRAM STORAGE MODE
        BNE     ST01
        JMP     START
ST01:    BIT     #SCH, STATUS        ;CHECK FOR SEARCH STORE
        BEQ     STORE1
        BIS     #RSC, CONTROL       ;RESET SEARCH BUTTON
        MOV     #LSCH, DISPLAY      ;TURN LIGHT ON
        .ENTER  #AREA, #0, #DXON, #-1
        BCC     ST02
        BIS     #CL, CONTROL        ;RESET SYSTEM
        MOV     #WE, LIGHTS        ;TURN ON ERROR LIGHTS
        .CLOSE  #0
        .CLOSE  #1
        JMP     STORE
ST02:    .FETCH  #HSPACE, #PRNAME
        .LOOKUP #AREA, #1, #PRNAME
        BCS     ST03
        CLR     R1
        .READW  #AREA, #1, #BUF1, #1280., R1 ;SET BUFFER POINTER TO
        BCC     ST012              ;ERROR CHECK
        TSTB    ERRWD              ;END OF FILE?
        BEQ     ST012
ST08:    BIS     #CL, CONTROL        ;RESET SYSTEM
        MOV     #RE, LIGHT
        MOV     #RE, LIGHTS        ;TURN ON READ ERROR LIGHT
        .CLOSE  #0
        .CLOSE  #1

```

```

        .CLOSE #1
        JMP      STORE
ST04:   .WRITW #LIST,#0,#BUF1,#1280.,R1
        BCS      ST03
        ADD      #5,R1          ;INCREMENT BUFFER POINTER
        BR       ST05
ST06:   .WRITW #LIST,#0,#BUF1,#1280.,R1
        BCS      ST03
        BR       ST010
ST012:  MOV      #BUF1,R5        ;SET R5 TO BYTE POINTER
ST019:  CMPB     (R5)+,#204      ;CHECK FOR END OF TAPE
        BEQ      ST06
ST018:  CMP      R5,#BUF1E      ;CHECK FOR END OF BUFFER
        BLT      ST019
        BR       ST04
ST010:  .CLOSE #1              ;CLOSE FILES
        .CLOSE #0
        BIT      #FH,STATUS     ;CHECK FOR FEED HOLD
        BEQ      ST013
        BIS      #RH,CONTROL    ;RESET FEED HOLD SWITCH
        .EXIT
ST013:  CLR      LED
        MOV      #LSCH,DISPLAY
        .LOOKUP #AREA,#0,#DX0N
        BCC      ST026
        JMP      ST08
ST026:  JSR      PC,CUVT        ;CONVERT TO RADIX50
        .ENTER #AREA,#1,#DX1N,#-1
        BCC      ST016
        JMP      ST03
ST016:  CLR      R5
        CLR      R1
        .READW #LIST,#0,#BUF1,#1280.,R1
        BCC      ST014
        TSTB     ERKWD          ;ERROR CHECK
        BEQ      ST014
        JMP      ST08
ST014:  ADD      #5,R1          ;INCREMENT BUFFER POINTER
        MOV      #BUF2-22,R2
        MOV      #BUF1,R3
ST015:  ADD      #22,R2          ;INCREMENT BLOCK POINTER
ST025:  JSR      PC,HEAD        ;READ A CHARACTER
        CLR      XFLAG
        CLR      YFLAG
        CLR      CFLAG
        CLR      FFLAG
        CLR      (R2)          ;CLEAR MEMORY STORAGE
        CLR      2(R2)
        CLR      4(R2)
        CLR      6(R2)
        CLR      10(R2)
        CLR      12(R2)
        CLR      14(R2)
        CLR      16(R2)
        CLR      20(R2)
        ;/////////SKIP CHAIN TO CHECK FOR/////////
        ;/////////VALID CHARACTERS/////////
NCHK:   CMPB     #116,WORD      ;N?
        BEQ      NSTK          ;YES, STORE N
GCHK:   CMPB     #107,WORD      ;G?
        BEQ      GSTR          ;YES STORE G
XCHK:   CMPB     #130,WORD      ;X?
        BEQ      XSTR          ;YES, STORE X

```

```

YCHK:  CMPB    #131,WORD    ;Y?
      BEQ      YSTR        ;YES, STORE Y
CCHK:  CMPB    #103,WORD    ;C?
      BEQ      CSTR        ;YES, STORE C
FCHK:  CMPB    #106,WORD    ;F?
      BEQ      FSTR        ;YES, STORE F
MCHK:  CMPB    #115,WORD    ;M?
      BEQ      MSTR        ;YES, STORE M
CRCHK: CMPB    #15,WORD     ;CR?
      BEQ      CRSTR       ;YES, STORE CR
LFCHK: CMPB    #12,WORD     ;LF?
      BEQ      LFSTR       ;YES, STORE LF
PCHK:  CMPB    #45,WORD     ;X?
      BEQ      PSTOR       ;YES, STORE X
E1CHK: CMPB    #4,WORD ;E01?
      BEQ      E1STOR      ;YES, STORE E01
      JMP      ST08
NSTR:  JMP      NSTOR
XSTR:  JMP      XSTOR
YSTR:  JMP      YSTOR
CSTR:  JMP      CSTOR
FSTR:  JMP      FSTOR
MSTR:  JMP      MSTOR
CRSTR: JMP      CRSTOR
GSTR:  JMP      GSTOR
LFSTR: JMP      ST025
PSTOR: JSR      PC,READ
      JSR      PC,READ
      JMP      ST025
E1STOR: MOV     #1,LED      ;SET END FLAG
      JMP      DATOUT
;////////STORE SEQUENCE NUMBER////////////////////////////////////////
NSTOR: JSR      PC,READ      ;READ A CHARACTER
      JSR      PC,DIGCHK     ;VALID DIGIT?
      MOVB     WORD,N1       ;STORE A DIGIT
      JSR      PC,READ      ;READ A CHARACTER
      JSR      PC,DIGCHK     ;VALID DIGIT?
      MOVB     WORD,N2       ;STORE A DIGIT
      JSR      PC,READ      ;READ A CHARACTER
      JSR      PC,DIGCHK     ;VALID DIGIT?
      MOVB     WORD,N3       ;STORE A DIGIT
      JSR      PC,READ      ;READ A CHARACTER
      BIC      #177760,N3    ;STORE N CODE
      ROL      N2
      ROL      N2
      ROL      N2
      ROL      N2
      BIC      #177417,N2
      BIS      N2,N3
      SWAB     N1
      BIC      #170177,N1
      BIS      N3,N1
      MOV      N1,(R2)
      JMP      GCHK          ;RETURN TO SKIP CHAIN
;////////STORE X VALUE////////////////////////////////////////
XSTOR: BIS      #1,XFLAG     ;SET X FLAG
      MOV      #X1,R4       ;SETUP STORAGE
RDX:   JSR      PC,READ      ;READ A CHARACTER
      CMPB     #131,WORD     ;Y?
      BEQ      XFIN         ;YES,STORE X
      CMPB     #103,WORD     ;?
      BEQ      XFIN         ;YES,STORE,X
      CMPB     #106,WORD     ;F?
      BEQ      XFIN         ;YES,STORE X

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        CMPB    #115,WORD    ;M?
        BEQ     XFIN         ;YES,STORE X
        CMPB    #15,WORD     ;CR?
        BEQ     XFIN         ;YES, STORE X
        CMPB    #55,WORD     ;NEGATIVE X
        BNE     XDIG         ;NO,STORE DIGIT
        BIS     #100000,(R2) ;STORE SIGN
        JMP     RDX          ;READ A DIGIT
XFIN:   MOVB     #15,(R4)     ;STORE END BIT
        JMP     YCHK         ;RETURN TO SKIP CHAIN
XDIG:   JSR     PC,DIGCHK     ;VALID DIGIT?
        MOVB     WORD,(R4)+   ;STORE A DIGIT
        JMP     RDX          ;READ A CHARACTER
;////////STORE Y VALUE////////////////////////////////////////
YSTUR:  BIS     #1,YFLAG     ;SET Y FLAG
        MOV      #Y1,R4      ;SETUP STORAGE
RDY:    JSR     PC,READ       ;READ A CHARACTER
        CMPB    #103,WORD     ;C?
        BEQ     YFIN         ;YES, STORE Y
        CMPB    #106,WORD     ;F?
        BEQ     YFIN         ;YES, STORE Y
        CMPB    #115,WORD     ;M?
        BEQ     YFIN         ;YES, STORE Y
        CMPB    #15,WORD     ;CR?
        BEQ     YFIN         ;YES,STORE Y
        CMPB    #55,WORD     ;NEGATIVE Y
        BNE     YDIG         ;NO, STORE A DIGT
        BIS     #40000,(R2)   ;STORE SIGN
        JMP     RDY          ;READ A CHARACTER
YFIN:   MOVB     #15,(R4)     ;STORE END BIT
        JMP     CCHK         ;RETURN TO SKIP CHAIN
YDIG:   JSR     PC,DIGCHK     ;VALID DIGIT
        MOVB     WORD,(R4)+   ;STORE A DIGIT
        JMP     RDY          ;READ A CHARACTER
;////////STORE C VALUE////////////////////////////////////////
CSTOR:  BIS     #1,CFLAG     ;SET C FLAG
        MOV      #C1,R4      ;SETUP STORAGE
RDC:    JSR     PC,READ       ;READ A CHARACTER
        CMPB    #106,WORD     ;F?
        BEQ     CFIN         ;YES, STORE C
        CMPB    #115,WORD     ;M?
        BEQ     CFIN         ;YES, STORE C
        CMPB    #15,WORD     ;CR?
        BEQ     CFIN         ;YES, STORE C
        CMPB    #55,WORD     ;NEGATIVE C?
        BNE     CDIG         ;NO, STORE DIGIT
        BIS     #20000,(R2)   ;STORE SIGN
        JMP     RDC          ;READ A CHARACTER
CFIN:   MOVB     #15,(R4)     ;STORE END BIT
        JMP     FCHK         ;RETURN TO SKIP CHAIN
CDIG:   JSR     PC,DIGCHK     ;VALID DIGIT
        MOVB     WORD,(R4)+   ;STORE A DIGIT
        JMP     RDC          ;READ A CHARACTER
;////////STORE FEEDRATE////////////////////////////////////////
FSTUR:  MOV      #1,FFLAG     ;SET F FLAG
        MOV      #F1,R4      ;SETUP STORAGE
RDF:    JSR     PC,READ       ;READ A CHARACTER
        CMPB    #115,WORD     ;M?
        BEQ     FFIN         ;YES, STORE F
        CMPB    #15,WORD     ;CR?
        BEQ     FFIN         ;YES, STORE F
        JSR     PC,DIGCHK     ;VALID DIGIT
        MOVB     WORD,(R4)+   ;STORE A DIGIT
        JMP     RDF

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FFIN:  MOVb    #15,(R4)+      ;STORE END BIT
      JMP     MCHK           ;RETURN TO SKIP CHAIN
;////////STORE STOP CODE//////////
MSTOR: JSR     PC,READ        ;READ A CHARACTER
      JSR     PC,DIGCHK       ;VALID DIGIT?
      MOVb    WORD,M1        ;STORE A DIGIT
      JSR     PC,READ        ;READ A CHARACTER
      JSR     PC,DIGCHK       ;VALID DIGIT?
      MOVb    WORD,M2        ;STORE A DIGIT
      JSR     PC,READ        ;READ A CHARACTER
MEND:  BIC     #177760,M2     ;STORE STOP CODE
      ROL     M1
      ROL     M1
      ROL     M1
      ROL     M1
      BIC     #177417,M1
      BIS     M2,M1
      COM     M1
      MOVb    M1,2(R2)
      JMP     CRCHK           ;RETURN TO SKIP CHAIN
;////////INTP G CODE//////////
GSTOR: JSR     PC,READ        ;READ A CHARACTER
      JSR     PC,DIGCHK       ;VALID DIGIT?
      MOVb    WORD,G1        ;STORE A CHARACTER
      JSR     PC,READ        ;READ A CHARACTER
      JSR     PC,DIGCHK       ;VALID DIGIT?
      MOVb    WORD,G2        ;STORE A CHARACTER
      JSR     PC,READ        ;READ A CHARACTER
      BIC     #177760,G2     ;STORE G CODE
      ROL     G1
      ROL     G1
      ROL     G1
      ROL     G1
      BIC     #177417,G1
      BIS     G2,G1
      COM     G1
      MOVb    G1,3(R2)
      JMP     XCHK           ;RETURN TO SKIP CHAIN
;////////BUILD STACKED DATA TABLE//////////
CRSTOR: CMP     #1,FFLAG      ;FEEDRATE?
      BEQ     CKSR           ;YES, CALCULATE CLOCKSTORE
      JMP     DATOUT         ;OUTPUT DATA TO DISK
;////////BUILD THE FEEDRATE AND AXIS MOVEMENT//////////
;////////PORTION OF THE STACKED DATA TABLE//////////
CKSR:  CMP     #1,XFLAG      ;X VALUE PRESENT?
      BEQ     GETX           ;YES, GET X
      CMP     #1,YFLAG      ;Y VALUE PRESENT?
      BEQ     GETY           ;YES, GET Y
      CMP     #1,CFLAG      ;C VALUE PRESENT?
      BEQ     GETC           ;YES, GET C
      JMP     STOB
GETX:  JSR     PC,RSAVE
      MOV     #X1,R1
      JSR     PC,DIV25       ;DIVIDE BY 2500, MULT BY 16
      MOV     SUML,4(R2)
      MOV     SUMH,6(R2)
YTEST: CMP     #1,YFLAG      ;Y FLAG SET?
      BEQ     GETY           ;YES, GET Y
CTEST: CMP     #1,CFLAG      ;C FLAG SET?
      BEQ     GETC           ;YES, GET C
      JMP     ROTATE         ;TIME TO SHIFT
GETY:  JSR     PC,RSAVE
      MOV     #Y1,R1
      JSR     PC,DIV25       ;DIVIDE BY 2500, MULT BY 16

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      MOV      SUML,10(R2)
      MOV      SUMH,12(R2)
JMP      CTEST      ;C FLAG SET?
GETC:   JSR      PC,RSAVE
      MOV      #C1,R1
      MOV      R2,R0
      ADD      #14,R0
      JSR      PC,ATOI      ;BCD TO BINARY CONVERSION
      JSR      PC,RRET
      HALT
      JMP      ROTATE
DIV25:  MOV      #SUML,R0
      JSR      PC,ATOI      ;BCD TO BINARY
      CLR      R0
      CLR      R1
      CLR      R4
      MOV      #16.,R5
      JSR      PC,M.DPIM      ;MULT BY 16
      CLR      R4
      MOV      #25.,R5
      JSR      PC,M.DPID      ;DIV BY 2500
      MOV      R2,SUMH
      MOV      R3,SUML
      JSR      PC,RRET      ;RESTORE REGISTERS
      RTS      PC
;////////ROTATE DATA AND INSERT MARKER BIT////////////////////////////////////
ROTATE: MOV      #100000,NBUF2
      CLR      NBUF1
      ASL      4(R2)      ;COMBINED SHIFT LEFT ON X
      ROL      6(R2)
      INC      4(R2)      ;SET MARKER BIT
      ASL      10(R2)     ;COMBINED LEFT SHIFT ON Y
      ROL      12(R2)
      INC      10(R2)     ;SET MARKER BIT
      ASL      14(R2)     ;COMBINED LEFT SHIFT ON C
      ROL      16(R2)
      INC      14(R2)     ;SET MARKER BIT
MMTI:   BIT      #100000,6(R2) ;MAXIMUM X?
      BNE      STORXY      ;YES, SETUP TABLE
      BIT      #100000,12(R2) ;MAXIMUM Y?
      BNE      STORXY      ;YES, SETUP TABLE
      BIT      #100000,16(R2) ;MAXIMUM C?
      BNE      STORXY      ;YES, SETUP TABLE
MORROT: ASL      4(R2)
      ROL      6(R2)
      ASL      10(R2)
      ROL      12(R2)
      ASL      14(R2)
      ROL      16(R2)
      CLC
      ROR      NBUF2
      ROR      NBUF1
      JMP      MMTI      ;CHECK FOR END OF SHIFT
STORXY: JSR      PC,RSAVE
      MOV      #F1,R1
      MOV      #SUML,R0
      JSR      PC,ATOI      ;BCD TO BINARY CONVERSION
;////////CALCULATE CLOCKSTORE////////////////////////////////////
;////////((60*10**6)/F*(10**-4))/((2**N)*(.3))////////////////////////////////////
;////////APUL/CPUL=(((US/MIN)/(1/MIN)))/(US))/(MAX PUL)////////////////////////////////////
      MOV      SUML,R5
      MOV      SUMH,R4
      CLR      R0
      MOV      #677,R1

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      MOV      #4353,R2
      MOV      #1672,R3
      JSR      PC,M.DPID      ;192000000/F
      CLR      R0
      CLR      R1
      MOV      NBUF1,R5
      MOV      NBUF2,R4
      JSR      PC,M.DPID      ;(192000000/F)/2**N
      TST      R2
      BEQ      DOK            ;CLOCKSTORE TOO LARGE?
      JMP      ST08
DOK:   COM      R3
      MOV      R2,R2
      MOV      R3,20(R2)
      JSR      PC,RRET
      JMP      DATOUT          ;OUTPUT DATA TO DISK
;////////MULTIPLY TWO DOUBLE PRECISION INTERGERS////////
M.DPIM: CLR      R0            ;CLEAR HIGH ORDER WORDS
      CLR      R1
      MOV      #41,-(SP)      ;MOVE 32 DEC TO COUNTER
M.DP01: ROR      R0
      ROR      R1
      ROR      R2            ;SHIFT TO ADD
      ROR      R3
      BCC      M.DP02          ;NO CARRY NO ADD
      ADD      R5,R1
      ADC      R0            ;ADD DOUBLE PRECISION TO OBTAIN NEW PARTIAL
      ADD      R4,R0          ;PRODUCT
M.DP02: DEC      @SP          ;DECREMENT COUNTER
      BNE      M.DP01
      TST      (SP)+          ;REMOVE THE COUNTER
      RTS      PC            ;RETURN TO THE CALLER
;////////DIVIDE TWO DOUBLE PRECISION INTERGERS////////
M.DPID: MOV      #40,-(SP)      ;COUNTER FOR DIVISION CYCLES
      MOV      R4,-(SP)      ;HIGH ORDER
      MOV      R5,-(SP)      ;LOW ORDER DIVISOR TO THE STACK
      NEG      2(SP)          ;FORM NEGATIVE
      NEG      @SP            ;VERSION OF THE DIVISOR
      SBC      2(SP)
      ADD      @SP,R1
      ADC      R0            ;PERFORM THE INITIAL SUBTRACTION
      ADD      2(SP),R0
      BCS      M.DPS0          ;IF CARRY THEN OVERFLOW HAS OCCURRED
      CLR      -(SP)          ;THIS IS A LONGER LASTING CARRY BIT
M.DP40: ROL      R5
      ROL      R2
      ROL      R1
      ROL      R0
      TST      @SP            ;TEST "CARRY" INDICATOR
      BEQ      M.DP41          ;IF NO "CARRY" THEN ADD ELSE SUBTRACT
      CLR      @SP            ;CLEAR UP FOR NEXT TIME
      ADD      2(SP),R1
      ADC      R0            ;ADD -(DIVISOR)
      ADC      @SP            ;SET "CARRY" BIT
      ADD      4(SP),R0;<-
      BR       M.DP42
M.DP41: ADD      R5,R1
      ADC      R0            ;ADD +(DIVISOR)
      ADC      @SP            ;SET "CARRY" BIT
      ADD      R4,R0      ;<-
M.DP42: ADC      @SP            ;SET "CARRY" BIT
M.DP43: TST      @SP            ;TEST THE UPDATE INDICATOR
      BEQ      .+4            ;IF ZERO FORGET IT
      INC      R3            ;
      ;                      ;NO CARRY POSSIBLE HERE

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DEC      6(SP)      ;<-      ;DECREMENT COUNTER
BGT      M.DP40     ;BRANCH IF MORE TO DO
ROR      R3
BCS      M.DP44
ADD      R5,R1
AUC      R0
ADD      R4,R0
CLC
M.DP44:  ROL      R3
ADD      #10,SP      ;ADJUST STACK BY 5 WORDS
CLV      ;CLEAR OVERFLOW ON THE LARGE MACHINES
RTS      PC
M.DP50:  ADD      #6,SP      ;SET OVERFLOW BIT FOR THE USER
SEV
RTS      PC
;////////ASCII TO BINARY CONVERSION////////////////////////////////////////
ATOI:    MOV      R0,-(SP)    ;SAVE THE DEFA
CLC      -(SP)              ;THIS WORD IS FOR THE SWITCHES
CLC      R2                  ;EVENTUALLY THE NUMBER
CLC      R3                  ;WILL BE IN THIS REGISTER PAIR
MOV      #12,R5              ;DECIMAL TEN TO MULTIPLIER
CLC      R4                  ;A DOUBLE PRECISION TEN AT THAT
M.AINX:  MOV      (R1)+,R0     ;GET A CHARACTER FROM THE INPUT STREAM
BIC      #177600,R0          ;CLEAR ALL BITS NOT PART OF ASCII CODE
CMPB     #15,R0              ;COMPARE WITH <CR>
BEQ      M.AIXT              ;IF FOUND WE'RE ALL DONE
CMPB     #54,R0              ;COMPARE WITH A COMMA
BEQ      M.AIXT              ;A COMMA IS LIKE A <CR>
CMPB     #53,R0              ;IS IT A PLUS SIGN
BEQ      M.AIPL              ;BRANCH IF A PLUS
CMPB     #55,R0              ;IT COULD BE A MINUS SIGN
BEQ      M.AIMI              ;BRANCH IF A MINUS SIGN
CMPB     #40,R0              ;CHECK FOR A SPACE
BEQ      M.AISP              ;BRANCH IF A SPACE
CMPB     #60,R0              ;SEE IF IT IS IN THE RANGE FOR A DIGIT
BGT      M.AIVS              ;SET V AND EXIT IF TOO SMALL A VALUE
CMPB     #71,R0              ;UPPER BOUND TEST
BLT      M.AIVS              ;SET ERROR IF NOT IN GOOD SHAPE
SUB      #60,R0              ;REDUCE TO A BINARY VALUE
MOV      R1,-(SP)            ;SAVE THE SEFA FOR A WHILE
MOV      R0,-(SP)            ;SAVE THE CURRENT VALUE
JSR      PC,M.DP1M           ;GO AND MULTIPLY
BIS      R0,R1               ;CHECK FOR OVERFLOW
BNE      M.AIVT              ;IF ANY BITS ARE SET OVERFLOW
ADD      (SP)+,R3            ;ADD THE CURRENT DIGIT
AUC      R2                  ;NO OVERFLOW HERE
MOV      (SP)+,R1            ;PICK UP THE STORED SEFA
BIS      #1,@SP              ;SET THE SIGNIFICANCE SWITCH
BR       M.AINX              ;GO GET THE NEXT CHARACTER
M.AIMI:  RTS      #10,@SP     ;SET MINUS SIGN ENCOUNTERED
M.AIPL:  BIT      #5,@SP      ;TEST SIGNIFICANCE AND PREVIOUS SIGN
BNE      M.AIVS              ;IF ILLEGAL EXIT NOW
BIS      #4,@SP              ;SET SIGN ENCOUNTERED
BR       M.AINX              ;GO GET MORE
M.AISP:  BIT      #1,@SP      ;SPACE ENCOUNTERED TEST SIGNIFICANCE
BEQ      M.AINX
M.AIX1:  MOV      (R1)+,R0     ;<-
BIC      #177600,R0          ;      I
CMPB     #40,R0              ;      I
BEQ      #-12                ;>
CMPB     #15,R0              ;NOT BLANK SO CHECK FOR <CR> OR COMMA
BEQ      M.AIXT              ;OK IF A <CR>
CMPB     #54,R0              ;MAYBE A COMMA?
BEQ      M.AIXT              ;OK IF IT'S A COMMA

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M.A1VS: BIS      #2,@SP      ;SET THE V SWITCH
        BR       M.A1X1      ;SCAN FOR A <CR> OR COMMA
M.A1XT: IS1      @SP          ;IF NO SWITCHES THEN OK
        BEQ      .+10        ;->      ;SKIP THE SIGNIFICANCE TEST
        BIT      #1,@SP      ; I      ;TEST SIGNIFICANCE SWITCH
        BEQ      M.A1VV      ; I      ;EXIT WITH AN ERROR
        BIT      #10,@SP     ;<-      ;TEST FOR MINUS NUMBER
        BEQ      .+10        ;->
        NEG      R2          ; I
        NEG      R3          ; I
        SBC      R2          ; I
M.A1X2: MOV      (SP)+,R4;<-    ;SAVE THE SWITCHES FOR LATER
        MOV      (SP)+,R0      ;GET THE FORGOTTEN DEFA
        MOV      R3,(R0)+      ;STORE THE RESULT
        MOV      R2,@R0
        BIT      #2,R4
        BNE      .+4         ;->      ;CHECK FOR NORMAL OR ERROR RETURN
        RTS      PC          ; I      ;NORMAL RETURN
        SEV          ;<-
        RTS      PC          ;ERROR RETURN
M.A1VT: TST      (SP)+
        IS1      (SP)+        ;POP TWO WORDS OFF THE STACK
        BR       M.A1VS      ;AND SET THE ERROR RETURN
M.A1VV: BIS      #2,@SP      ;SET V
        BR       M.A1X2
DATOUT: TST      LED          ;CHECK FOR END OF TAPE
        BNE      D03
        CMP      #BUF2E-40,R2 ;END OF BUFFER CHECK
        BLT      D01
        JMP      ST015        ;BUFFER NOT FULL
D01:     .WRITW   #LIST,#1,#BUF2,#1280.,R5
        BCC      D02          ;ERROR CHECK
        JMP      ST03
D02:     ADD      #5,R5
        MOV      #BUF2,R2      ;RESET BUFFER POINTER
        JMP      ST025
D03:     .WRITW   #LIST,#1,#BUF2,#1280.,R5
        BCC      D04
        JMP      ST03
D04:     CLR      LED
        BIS      CL,CONTROL    ;RESET SYSTEM
        COM      DISPLAY      ;TURN OFF LIGHTS
        COM      LIGHTS
        .CLOSE   #0           ;CLOSE FILES
        .CLOSE   #1
        JMP      ST0RE
READ:    MOVW     (R3)+,WORD      ;READ A CHARACTER
        BICB     #200,WORD
        TSTB     WORD
        BEQ      READ
        CMP      #BUF1E-2,R3    ;END OF BUFFER CHECK
        BLT      R01
        RTS      PC
R01:     .READW   #LIST,#0,#BUF1,#1280.,R1
        BCC      R02          ;ERROR CHECK
        JMP      ST08
R02:     ADD      #5,R1
        MOV      #BUF1,R3      ;RESET BUFFER POINTER
        BR       READ
DIGCHK: CMPB     #55,WORD      ;NEGATIVE?
        BEQ      OKW
        CMPB     #60,WORD
        BEQ      OKW
        CMPB     #61,WORD

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      BEQ      OKW
      CMPB     #62,WORD
      BEQ      OKW
      CMPB     #63,WORD
      BEQ      OKW
      CMPB     #64,WORD
      BEQ      OKW
      CMPB     #65,WORD
      BEQ      OKW
      CMPB     #66,WORD
      BEQ      OKW
      CMPB     #67,WORD
      BEQ      OKW
      CMPB     #70,WORD
      BEQ      OKW
      CMPB     #71,WORD
      BEQ      OKW
      JMP      NOTOK
OKW:   RTS     PC
NOTOK: JMP      ST08
RSAVE: MOV      R0,TR0           ;SAVE ALL REGESTERS
      MOV      R1,TR1
      MOV      R2,TR2
      MOV      R3,TR3
      MOV      R4,TR4
      MOV      R5,TR5
      RTS     PC
RRET:  MOV      TR0,R0           ;RETURN ALL REGESTERS
      MOV      TR1,R1
      MOV      TR2,R2
      MOV      TR3,R3
      MOV      TR4,R4
      MOV      TR5,R5
      RTS     PC
;////////////////////////////////////
;THIS ROUTINE IS ENTERED WHEN THE MODE SWITCH
;IS IN THE PROGRAM SEARCH POSITION
;////////////////////////////////////
PSCH:  BIT      #PF,MODE         ;CHECK FOR PROGRAM SEARCH MODE
      BNE      PSCH1
      JMP      START
PSCH1: BIT      #SCH,STATUS      ;CHECK FOR SEARCH START
      BEQ      PSCH
      CLR      POUTER
      BIS      #RS,CONTROL      ;RESET SEARCH BUTTON
      MOV      #LSCH,DISPLAY    ;TURN ON SEARCH LIGHT
      JSR      PC,COVT          ;READ SEQNO AND CONVERT TO ASCII
      .LOOKUP #LIST,#1,#DX1N
      BCC      LDSCH            ;FILE WAS FOUND
      MOV      #SE,LIGHTS      ;TURN ON SEARCH ERROR LIGHT
      COM      DISPLAY          ;TURN OFF SEARCH LIGHT
      .CLOSE #1                 ;CLOSE FILE
      BR       PSCH
LDSCH: COM      LIGHTS          ;TURN OFF SEARCH ERROR LIGHT
      CLR      LIGHT
      COM      LIGHT
      COM      DISPLAY          ;TURN OFF SEARCH LIGHT
      .CLOSE #1                 ;CLOSE FILE
      BR       PSCH
;////////////////////////////////////
;ROUTINE TO CONVERT FOR SEQNO TO RADIX50
;////////////////////////////////////
COVT:  MOV      SEQNO,PRGNO      ;CONVERT TO RADIX50
      SWAB     PRGNO

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        BIC      #177760,PRGNO
        BIS      #60,PRGNO
        MOV      SEQNO,PRGNO+2
        ROL      PRGNO+2
        ROL      PRGNO+2
        ROL      PRGNO+2
        ROL      PRGNO+2
        BIC      #170377,PRGNO+2
        BIS      #30000,PRGNO+2
        BIS      PRGNO+2,PRGNO
        MOV      SEQNO,PRGNO+2
        BIC      #177760,PRGNO+2
        BIS      #60,PRGNO+2
        MOV      #PRG,R5
        JSR      PC,IRAD50      ;CONVERT TO RADIX50
        RTS      PC
;/////////////////////////////////////////////////////////////////
;THIS ROUTINE IS ENTERED WHEN THE MODE SWITCH IS
;IN THE SEQUENCE NUMBER SEARCH POSITION
;/////////////////////////////////////////////////////////////////
SEUSCH: BIT      #SNS,MODE      ;CHECK FOR SEQUENCE SEARCH MODE
        BNE      SEQ1
        JMP      START
SEQ1:   BIT      #SCH,STATUS    ;CHECK FOR SEARCH START
        BEQ      SEUSCH
        BIS      #RS,CONTROL   ;RESET SEARCH BUTTON
        MOV      #LSCH,DISPLAY ;TURN ON SEARCH LIGHT
        MOV      SEQNO,DSEQNO
        MOV      #BUF1,R1      ;RESET POINTER
        CLK      R3
        .LOOKUP #LIST,#1,#DX1N
SEQ4:   .READW #LIST,#1,#BUF1,#1280.,R3
        BCS      SEUER         ;READ ERROR
        ADD      #5,R3         ;SET R3 TO BLOCK POINTER
        MOV      #BUF1,R1
SEQ2:   MOV      (R1),R2
        BIC      #170000,R2
        CMP      R2,SEQNO      ;CHECK FOR SEQUENCE NUMBER FOUND
        BEQ      SEQ3
        ADD      #18.,R1
        CMP      R1,#BUF1E-20 ;CHECK FOR END OF BUFFER
        BLT      SEQ2
        BR       SEQ4
SEQ3:   MOV      R1,POINTER     ;STORE POINTER
        .READW #LIST,#1,#BUF2,#1280.,R3
        ADD      #5,R3
        MOV      R3,BLOCK      ;STORE BLOCK NUMBER
        .CLOSE #1              ;CLOSE FILE
        COM      LIGHTS        ;TURN OFF SEARCH ERROR LIGHT
        CLR      LIGHT
        COM      LIGHT
        COM      DISPLAY      ;TURN OFF SEARCH LIGHT
        JMP      SEUSCH
SEUER:  COM      DISPLAY        ;TURN OFF SEARCH LIGHT
        TSTB     ERRNO         ;END OF FILE CHECK
        BEQ      SEQ5
        MOV      #RE,LIGHTS    ;TURN ON READ ERROR LIGHT
        .CLOSE #1              ;CLOSE FILE
        JMP      SEUSCH
SEQ5:   MOV      #SE,LIGHTS    ;TURN ON SEARCH ERROR LIGHT
        .CLOSE #1              ;CLOSE FILE
        JMP      SEUSCH
;/////////////////////////////////////////////////////////////////
;THIS ROUTINE IS ENTERED WHEN THE MODE SWITCH IS IN THE

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;AUTOMATIC OR SINGLE BLOCK POSITION
;/////////////////////////////////////////////////////////////////
AUTO:  COM    DISPLAY      ;RESET LIGHTS
      CLR    LED
      CLR    TFEEDBK
      BIS    #CCT,TFEEDBK  ;TURN OFF CLOCK
      BIS    #INTRC,CONTROL ;RESET INTERPOLATION DONE FLAG
      JSR    PC,LASTAT
      BIT    #A,MODE        ;CHECK FOR AUTOMATIC MODE
      BNE    AUTO1
      BIT    #SB,MODE        ;CHECK FOR SINGLE BLOCK MODE
      BNE    AUTO1
      JMP    START
AUTO1:  BIT    #C,STATUS     ;CHECK FOR CLEAR
      BEQ    AUTO3
      BIS    #CL,CONTROL     ;CLEAR ALL
      CLR    LIGHT
      CUM    LIGHT
      CUM    LIGHTS
      CLR    POINTER
      CLR    BLOCK
AUTO3:  BIT    #CSI,STATUS    ;CHECK FOR CYCLE START BUTTON
      BEQ    AUTO
      MOV    #RG,CONTROL     ;RESET CYCLE START BUTTON
      MOV    #LCST,DISPLAY    ;TURN ON CYCLE START LIGHT
      JSR    PC,LASTAT        ;CHECK LASER STATUS
      .LOOKUP #LIST,#1,#0x1N  ;LOOKUP FILE
      BCC    AUTO4            ;FILE WAS FOUND
      MOV    #SE,LIGHTS       ;TURN ON SEARCH ERROR LIGHT
      MOV    #SE,LIGHT
      .CLOSE #1               ;CLOSE FILE #1
      JMP    AUTO
AUTO4:  TST    POINTER        ;CHECK FOR EMPTY BUFFER
      BNE    AUTO5
      MOV    #BUF1,POINTER    ;SET POINTER TO BUFFER 1
      .READW #LIST,#1,#BUF1,#1280.,BLOCK
      BCC    AUTO6            ;READ ERROR
      JMP    AUTO8
AUTO6:  ADD    #S,BLOCK        ;SET TO BLOCK POINTER
      .READW #LIST,#1,#BUF2,#1280.,BLOCK
      BCC    AUTO5            ;READ ERROR
AUTO8:  TSTB    ERRWD          ;END OF FILE
      BEQ    AUTO5
      MOV    #RE,LIGHTS       ;TURN ON READ ERROR LIGHT
      MOV    #RE,LIGHT
      JMP    AUTO
AUTO5:  MOV    POINTER,R4      ;SET R4 TO BUFFER POINTER
AUTO24: TSTB    3(R4)          ;CHECK FOR G CODE
      BEQ    AUTO10
      JSR    PC,GCODE         ;EXECUTE G CODE
AUTO10: MOV    #RN,LIGHTS      ;TURN ON RUN LIGHT
      MOV    #RN,LIGHT
      MOV    (R4),DSEQNO
      JSR    PC,LOAD          ;LOAD DDA
      BIS    #FL,CONTROL      ;OUTPUT FIRST LOAD
      BIC    #CCT,TFEEDBK     ;TURN CLOCK ON
      BIS    #IC,TFEEDBK      ;TURN INTERRUPT ON
      MOV    TFEEDBK,FEEDBK
      TSTB    -16.(R4)        ;CHECK FOR M CODE
      BEQ    AUTO9
      JMP    MCODE            ;EXECUTE M CODE
AUTO9:  CLR    LED
      BIT    #SB,MODE          ;CHECK FOR SINGLE BLOCK MODE
      BEQ    AUTO11

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      JMP      AUTO12
AUTO11: JSR      PC,BUFCK      ;CHECK FOR END OF BUFFER
      TSTB     3(R4)          ;CHECK FOR G CODE
      BEQ      AUTO22
      JSR      PC,GCODE       ;EXECUTE G CODE
AUTO22: JSR      PC,LOAD       ;LOAD ODA
      TSTB     -16.(R4)       ;CHECK FOR M CODE
      BEQ      AUTO23
      JMP      MCODE          ;EXECUTE M CODE
AUTO23: BIT      #LE,LMT       ;CHECK FOR LIMIT ERROR
      BEQ      AUTO28
      JMP      LIMIT
AUTO28: JSR      PC,LASTAT     ;CHECK LASER STATUS
      CMP      #1,LED
      BEQ      AUTO9
      CMP      #2,LED
      BNE      AUTO27
      JMP      FAULT
AUTO27: BIT      #FH,STATUS    ;CHECK FOR FEED HOLD
      BEQ      AUTO13
      MOV      #LFH,DISPLAY   ;TURN ON FEED HOLD LIGHTS
      MOV      #HD,LIGHTS
      MOV      #HD,LIGHT
      SUB      #22,R4
      JMP      AUTO12
AUTO13: BIT      #S,STATUS     ;CHECK FOR STOP SWITCH
      BEQ      AUTO15
AUTO19: MOV      R4,POINTER
      BIS      #CL,CONTROL    ;RESET ALL
      CLR      LIGHT
      COM      LIGHT
      COM      LIGHTS
      .CLOSE #1              ;CLOSE FILE
      JMP      AUTO
AUTO15: BIT      #A,MODE       ;CHECK FOR AUTOMATIC MODE
      BNE      AUTO23
      BIT      #SB,MODE        ;CHECK FOR SINGLE BLOCK MODE
      BEQ      AUTO19
AUTO12: BIC      #IC,TFEEDBK   ;TURN OFF INTERRUPT
      MOV      TFEEDBK,FEEDBK
      JSR      PC,LAST        ;LOAD STOP BLOCK
      BIT      #ID,MODE        ;CHECK FOR INTERPOLATION DONE
      BEQ      AUTO16
      BIT      #LE,LMT         ;CHECK FOR LIMIT ERROR
      BEQ      AUTO17
      JMP      LIMIT
AUTO17: BIT      #IF,MODE      ;CHECK FOR INTERPOLATION FAULT
      BNE      AUTO18
      JMP      FAULT
AUTO18: BIT      #S,STATUS     ;CHECK FOR STOP SWITCH
      BNE      AUTO19
      BIT      #A,MODE         ;CHECK FOR AUTOMATIC MODE
      BEQ      AUTO20
      JMP      AUTO12
AUTO20: BIT      #SB,MODE      ;CHECK FOR SINGLE BLOCK
      BNE      AUTO12
      JMP      AUTO19
AUTO16: BIS      #CCT,TFEEDBK  ;TURN OFF CLOCK
      MOV      TFEEDBK,FEEDBK
      MOV      #EB,LIGHTS     ;TURN ON END OF BLOCK LIGHT
      MOV      #EB,LIGHT
      COM      DISPLAY        ;TURN OFF CYCLE START LIGHT
      BIS      #INTRC,CONTROL  ;RESET INTERPOLATION DONE FLAG
      MOV      #2000,LED

```



```

////////////////////////////////////
LASTAT: BIS      #LAS,LIGHT      ;CLEAR LASER STATUS LIGHT
        BIT      #RF,LASER      ;CHECK FOR RETUNE ERROR
        BNE      LA1
        BIC      #RTE,LIGHT
LA1:    BIT      #RS,LASER      ;CHECK RETUNE STATUS
        BNE      LA2
        BIC      #RTS,LIGHT
LA2:    BIT      #LCS,LASER      ;CHECK FOR LASER HEAD STATUS ERROR
        BEQ      LA3
        BIT      #HE,LASER
        BEQ      LA3
        BIT      #R0K,LASER
        BNE      LA4
LA3:    BIC      #LSE,LIGHT
LA4:    BIT      #XE,LASER      ;CHECK FOR CONVERTER ERROR
        BNE      LA10
        BIT      #YE,LASER
        BEQ      LA6
LA10:   BIC      #PLE,LIGHT
LA6:    BIT      #RST,STATUS      ;CHECK FOR LASER RESTART
        BEQ      LA7
        BIS      #RP,CONTROL
LA7:    BIT      #RTU,STATUS      ;CHECK FOR LASER RETUNE
        BEQ      LA8
        BIS      #RR,CONTROL
        BIS      #CL,CONTROL      ;RESET SYSTEM
        BIC      #RTS,LIGHT      ;TURN ON LIGHT
        MOV      LIGHT,LIGHTS
        JSR      PC,RSAVE      ;SAVE REGISTERS
        MOV      #FDATA,-(SP)    ;STORE PARAMETER BLOCK
        MOV      #9,-(SP)
        MOV      SP,#5
        JSR      PC,COMP      ;GET COMPENSATION VALUE
        CMP      (SP)+,(SP)+    ;CLEANUP STACK
        JSR      PC,RRET      ;RESTORE REGISTERS
        ROLB     FDATA
        ROLB     FDATA
        ROLB     FDATA
        ROLB     FDATA
        BIC      #170017,FDATA
        BISB     FDATA,MFRG+1
        BISB     FDATA+1,MFRG+1
        ROLB     FDATA+2
        ROLB     FDATA+2
        ROLB     FDATA+2
        ROLB     FDATA+2
        BIC      #170017,FDATA+2
        BISB     FDATA+2,MFRG
        BISB     FDATA+3,MFRG
        ROLB     FDATA+4
        ROLB     FDATA+4
        ROLB     FDATA+4
        ROLB     FDATA+4
        BIC      #170017,FDATA+4
        BISB     FDATA+4,LFRG+1
        BISB     FDATA+5,LFRG+1
        ROLB     FDATA+6
        ROLB     FDATA+6
        ROLB     FDATA+6
        ROLB     FDATA+6
        BIC      #170017,FDATA+6
        BISB     FDATA+6,LFRG
        BISB     FDATA+7,LFRG

```

```

      MOV      MFRG,MFNU
      MOV      LFRG,LFNU
LAB:   BIT      #FU,MODE                      ;CHECK FOR FEEDBACK ON
      BEQ      LA9
      BIS      #LF,TFEEDBK                  ;TURN FEEDBACK ON
      MOV      TFEEDBK,FEEDBK
      MOV      LIGHT,LIGHTS
      RTS      PC
LA9:   BIC      #LF,TFEEDBK                  ;TURN FEEDBACK OFF
      MOV      TFEEDBK,FEEDBK
      MOV      LIGHT,LIGHTS
      RTS      PC
;////////////////////////////////////
;G CODE EXECUTE ROUTINE
;////////////////////////////////////
GCODE: CMPB    3(R4),#G00                    ;CHECK FOR POINT TO POINT INTERPOLATION
      BEQ      GC1
      BIC      #LF,TFEEDBK                  ;TURN FEEDBACK OFF
      BIC      #ER,TFEEDBK                  ;SET TO LIMITED RESOLUTION
      MOV      TFEEDBK,FEEDBK
      RTS      PC
GC1:   CMPB    3(R4),#G01                    ;CHECK FOR LINEAR INTERPOLATION
      BEQ      GC2
      BIS      #ER,TFEEDBK                  ;SET TO EXTENDED RESOLUTION
      MOV      TFEEDBK,FEEDBK
      RTS      PC
GC2:   BIS      #CL,CONTROL                  ;CLEAR SYSTEM
      MOV      #RE,LIGHTS                  ;SET READ ERROR LIGHT
      MOV      #RE,LIGHT
      .CLOSE #1                             ;CLOSE FILE
      JMP      AUTO
;////////////////////////////////////
;EXECUTE M CODE ROUTINE
;////////////////////////////////////
MCODE: BIC      #IC,TFEEDBK                  ;TURN OFF INTERRUPT
      JSR      PC,LAST                      ;LOAD LAST BLOCK
      MOV      TFEEDBK,FEEDBK
      BIT      #IO,MODE                      ;CHECK FOR INTERPOLATION DONE
      BEQ      MC1
      BIT      #LE,LMT                      ;CHECK FOR LIMIT ERROR
      BEQ      MC2
      JMP      LIMIT
MC2:   BIT      #IF,MODE                      ;CHECK FOR INTERPOLATION FAULT
      BNE      MC3
      JMP      FAULT
MC3:   BIT      #S,STATUS                    ;CHECK FOR STOP SWITCH
      BEQ      MCODE
MC6:   BIS      #CL,CONTROL                  ;RESET ALL
      .CLOSE #1                             ;CLOSE FILE
      JMP      AUTO19
MC1:   BIC      #CCT,TFEEDBK                  ;TURN OFF CLOCK
      MOV      TFEEDBK,FEEDBK
      BIS      #INTRC,CONTROL                ;RESET INTERPOLATION DONE FLAG
      BIS      #RG,CONTROL                  ;RESET START BUTTON
      MOV      -22(R4),DSEQNO
      CMPB    -16.(R4),#M00                  ;CHECK FOR PROGRAM STOP
      BNE      MC4
      MOV      #PS1,LIGHT
      MOV      #PS1,LIGHTS                  ;TURN ON PROGRAM STOP LIGHT
      JMP      MC14
MC4:   CMPB    -16.(R4),#M02                  ;CHECK FOR PROGRAM END
      BNE      MC5
      MOV      #PRE,LIGHT
      MOV      #PRE,LIGHTS                  ;TURN ON PROGRAM END LIGHT

```

```

COM      DISPLAY
CLR      POINTER
MOV      #2000,LED
MC15:    INC      LED
        BNE      MC15
        JMP      MC8
MC5:      CMPB    -16,(R4),#M01      ;CHECK FOR OPTIONAL STOP
        BNE      MC6
        BIT      #0S0,FEED          ;CHECK FOR OPTIONAL STOP ON
        BNE      MC7
        JMP      AUTO24
MC6:      JMP      GC2
MC7:      MOV      #0S,LIGHTS        ;TURN ON OPTIONAL STOP LIGHT
        MOV      #0S,LIGHT
MC14:     COM     DISPLAY
        MOV      #2000,LED
MC9:      INC      LED
        BNE      MC9
MC12:     JSR      PC,BUFCK          ;CHECK FOR END OF BUFFER
        BIT      #CST,STATUS        ;CHECK FOR CONTINUE
        BEQ      MC10
        MOV      #LCST,DISPLAY      ;TURN ON CYCLE START LIGHT
        TSTB     2(R4)
        BEQ      MC13
        ADD      #22,R4
        JMP      MC1
MC13:     JMP      AUTO24
MC10:     JSR      PC,LASTA1        ;CHECK LASER STATUS
        BIT      #A,MODE            ;CHECK FOR AUTOMATIC MODE
        BNE      MC11
        BIT      #SB,MODE          ;CHECK FOR SINGLE BLOCK MODE
        BNE      MC11
        JMP      AUTO19
MC11:     BIT      #C,STATUS        ;CHECK FOR CLEAR
        BEQ      MC12
        CLR      POINTER
        CLR      BLOCK
        CLR      LIGHT
        COM      LIGHT
        COM      LIGHTS
        JMP      AUTO
;////////////////////////////////////
;LOAD DDA
;////////////////////////////////////
LOAD:     BIT      #BXS,(R4)        ;CHECK FOR X SIGN
        BNE      LD1
        BIS      #SX,TFEEDBK
        BR       LD2
LD1:      BIC      #SX,TFEEDBK
LD2:      BIT      #BYS,(R4)        ;CHECK FOR Y SIGN
        BEQ      LD3
        BIS      #SY,TFEEDBK
        BR       LD4
LD3:      BIC      #SY,TFEEDBK
LD4:      BIT      #BCS,(R4)        ;CHECK FOR C SIGN
        BEQ      LD5
        BIS      #SC,TFEEDBK
        BR       LD6
LD5:      BIC      #SC,TFEEDBK
LD6:      MOV      TFEEDBK,FEEDBK
        MOV      (R4),NSEQNO
        ADD      #4,R4
        MOV      (R4)+,XLDDA        ;LOAD DDA
        MOV      (R4)+,XMDDA

```

```

MOV      (R4)+,YLDDA
MOV      (R4)+,YMDDA
MOV      (R4)+,CLDDA
MOV      (R4)+,CMDDA
MOV      (R4)+,IT
RTS      PC
;////////////////////////////////////
;LAST BLOCK LOAD ROUTINE
;////////////////////////////////////
LAST:    CLR      XMDDA
MOV      #1,XLDDA
CLR      YMDDA
MOV      #1,YLDDA
CLR      CMDDA
MOV      #1,CLDDA
MOV      #1,IT
RTS      PC
;////////////////////////////////////
;LIMIT ERROR ROUTINE
;////////////////////////////////////
LIMIT:   BIS      #CL,CONTROL      ;RESET SYSTEM
MOV      #LME,LIGHTS      ;TURN ON LIMIT ERROR LIGHT
MOV      #LME,LIGHT
        .CLOSE #1      ;CLOSE FILE
        JMP      EMI
;////////////////////////////////////
;INTERPOLATION FAULT ROUTINE
;////////////////////////////////////
FAULT:   BIS      #CL,CONTROL      ;RESET SYSTEM
MOV      #ITF,LIGHTS      ;TURN ON INTERPOLATION FAULT LIGHT
MOV      #ITF,LIGHT
        .CLOSE #1      ;CLOSE FILE
        JMP      START
;////////////////////////////////////
;THIS ROUTINE IS ENTERED WHEN THE MODE SWITCH
;IS IN THE MANUAL POSITION
;////////////////////////////////////
MANL:    JSR      PC,LASTAT
CLR      TFEEDBK
BIS      #CCI,TFEEDBK      ;TURN OFF CLOCK
BIS      #ER,TFEEDBK      ;SET TO LIMITED RESOLUTION
BIC      #IC,TFEEDBK      ;TURN OFF INTERRUPT
BIC      #LF,TFEEDBK      ;TURN OFF FEEDBACK
MOV      TFEEDBK,FEEDBK
BIS      #CL,CONTROL      ;RESET SYSTEM
MOV      MODE,TMODE
BIT      #M,TMODE          ;CHECK FOR MANUAL MODE
BNE      MAN
JMP      START
MAN:     BIT      #YU,TMODE      ;CHECK FOR Y OUT
BNE      YOUT
BIT      #XL,TMODE      ;CHECK FOR X LEFT
BNE      XLEFT
BIT      #XR,TMODE      ;CHECK FOR X RIGHT
BNE      XRIGHT
BIT      #YI,TMODE      ;CHECK FOR Y IN
BNE      YIN
BIT      #CC,TMODE      ;CHECK FOR C COUNTERCLOCKWISE
BNE      CCOUNT
BIT      #CW,TMODE      ;CHECK FOR C CLOCKWISE
BNE      CCLK
BIT      #C,STATUS      ;CHECK FOR CLEAR
BEQ      MANL
BIS      #CL,CONTROL      ;RESET SYSTEM

```

```

      CLR      LIGHT
      COM      LIGHT
      COM      LIGHTS
      JMP      MANL
XLEFT: BIS     #LXL,DISPLAY      ;TURN ON X LEFT LIGHT
      BIC     #SX,TFEEDBK      ;SET SIGN TO X LEFT
      BR
XRIGHT: BIS    #LXR,DISPLAY      ;TURN ON X RIGHT LIGHT
      BIS     #SX,TFEEDBK      ;SET SIGN TO X RIGHT
      BR
YIN:   BIS     #LYI,DISPLAY      ;TURN ON Y IN LIGHT
      BIC     #SY,TFEEDBK      ;SET SIGN TO Y IN
      BR
YOUT:  BIS     #LYO,DISPLAY      ;TURN ON Y OUT LIGHT
      BIS     #SY,TFEEDBK      ;SET SIGN TO Y OUT
      BR
CCOUNT: BIS    #LCC,DISPLAY      ;TURN ON C COUNTER-CLOCKWISE LIGHT
      BIS     #SC,TFEEDBK      ;SET SIGN TO C COUNTER-CLOCKWISE
      BR
CCLOCK: BIS    #LCH,DISPLAY      ;TURN ON C CLOCKWISE LIGHT
      BIC     #SC,TFEEDBK      ;SET SIGN TO C CLOCKWISE
      BR
XDRIVE: MOV     #XLDDA,R1        ;SET X SLIDE TO MOVE
      MOV     #YLDDA,R2
      MOV     #CLDDA,R3
      BR
YDRIVE: MOV     #YLDDA,R1        ;SET Y SLIDE TO MOVE
      MOV     #CLDDA,R2
      MOV     #XLDDA,R3
      BR
CDRIVE: MOV     #CLDDA,R1        ;SET C SLIDE TO MOVE
      MOV     #XLDDA,R2
      MOV     #YLDDA,R3
DRIVE: MOV     TFEEDBK,TFEEDBK
      MOV     MANUAL,TMANUAL    ;CHECK WHICH MANUAL INCREMENT
      BIT     #MI1,TMANUAL      ;OR RAPID FEED SELECTED
      BNE     SMI1
      BIT     #MI2,TMANUAL
      BNE     SMI2
      BIT     #MI3,TMANUAL
      BNE     SMI3
      BIT     #MI4,TMANUAL
      BNE     SMI4
      BIT     #MI5,TMANUAL
      BNE     SMI5
      BIT     #MI6,TMANUAL
      BNE     SMI6
      BIT     #MI7,TMANUAL
      BNE     SMI7
      BIT     #RF1,TMANUAL
      BNE     SRF1
      BIT     #RF2,TMANUAL
      BNE     SRF2
      BIT     #RF3,TMANUAL
      BNE     SRF3
      BIT     #RF4,TMANUAL
      BNE     SRF4
      BIT     #RF5,TMANUAL
      BNE     SRF5
      BIT     #RF6,TMANUAL
      BNE     SRF6
      BIT     #RF7,TMANUAL
      BNE     SRF7
      BR      DRIVE

```

```

SMI1:  MOV    #MI1L,R4      ;MANUAL INCREMENT FOR .001 MILS
      JMP     MILD
SMI2:  MOV    #MI2L,R4      ;MI .010 MILS
      JMP     MILD
SMI3:  MOV    #MI3L,R4      ;MI .100 MILS
      JMP     MILD
SMI4:  MOV    #MI4L,R4      ;MI .500 MILS
      JMP     MILD
SMI5:  MOV    #MI5L,R4      ;MI 1.00 MILS
      JMP     MILD
SMI6:  MOV    #MI6L,R4      ;MI 10.0 MILS
      JMP     MILD
SMI7:  MOV    #MI7L,R4      ;MI 100. MILS
      JMP     MILD
SRF1:  MOV    #RF1L,R4      ;RAPID FEED AT .001 IPM
      JMP     RFRUN
SRF2:  MOV    #RF2L,R4      ;RF .010 IPM
      JMP     RFRUN
SRF3:  MOV    #RF3L,R4      ;RF .100 IPM
      JMP     RFRUN
SRF4:  JSR    PC,RF8KF      ;RF .500 IPM
      MOV    #RF4L,R4
      JSR    PC,RFG0
      JMP     RF8KL
SRF5:  JSR    PC,RF16KF     ;RF 1.00 IPM
      MOV    #RF5L,R4
      JSR    PC,RFG0
      JMP     RF16KL
SRF6:  JSR    PC,RF32KF     ;RF 2.00 IPM
      MOV    #RF6L,R4
      JSR    PC,RFG0
      JMP     RF32KL
SRF7:  JSR    PC,RF80KF     ;RF 5.00 IPM
      MOV    #RF7L,R4
      JSR    PC,RFG0
      JMP     RF80KL
MILD:  JSR    PC,RFUP      ;LOAD ODA
      BIS    #FL,CONTROL   ;ISSUE FIRST LOAD
      BIC    #CCT,TFEEDBK  ;TURN CLOCK ON
      MOV    TFEEDBK,FEEDBK
      JSR    PC,LAST      ;SET TO STOP NEXT BLOCK
LMI:   BIT    #C,STATUS    ;CHECK FOR CLEAR
      BNE    EMI
      JSR    PC,LASTAT     ;CHECK LASER STATUS
      HIT    #ID,MODE      ;CHECK FOR INTERPOLATION DONE
      BEQ    EMI
      BIT    #LE,LMT       ;CHECK FOR LIMIT ERROR
      BEQ    FMI
      BIT    #XL,TMODE
      BEQ    AUTO40
      BIT    #LMXL,LMT
      BEQ    AUTO40
AUTO50: JMP    LIMIT
AUTO40: BIT    #XR,TMODE
      BEQ    AUTO41
      BIT    #LMXR,LMT
      BNE    AUTO50
AUTO41: BIT    #YI,TMODE
      BEQ    AUTO42
      BIT    #LMYI,LMT
      BNE    AUTO50
AUTO42: BIT    #YO,TMODE
      BEQ    FMI
      BIT    #LMYO,LMT

```

```

      BNE      AUT050
FMI:   BIT     #IF,MODE      ;CHECK FOR INTERPOLATION FAULT
      BNE
      JMP     FAULT
EMI:   BIS     #INTRC,CONTROL ;CLEAR INTERPOLATION DONE FLAG
      BIS     #CL,CONTROL    ;RESET SYSTEM
      BIS     #CCT,TFEEDBK   ;TURN OFF CLOCK
      MOV     TFEEDBK,FEEDBK
      MOV     #20000,LED
IMI:   INC     LED
      BNE     IMI
      CUM     DISPLAY        ;TURN OFF LIGHTS
      BIS     #CL,CONTROL
      JMP     MANL
RFRUN: JSR     PC,RFUP        ;LOAD ODA OUTPUT FIRST LOAD
      BIS     #FL,CONTROL    ;OUTPUT FIRST LOAD
      BIC     #CCT,TFEEDBK   ;TURN ON CLOCK
      MOV     TFEEDBK,FEEDBK
      SUB     #14.,R4
RFRUN1:JSR     PC,RFUP        ;LOAD ODA
HMI:   JSR     PC,LASTAT
      CMP     MANUAL,TMANUAL ;CHECK FOR MANUAL SWITCH IN SAME POSITION
      BNE     EMI
      CNPB    MODE,TMODE     ;CHECK FOR MODE SWITCH IN SAME POSITION
      BNE     EMI
      BIT     #10,MODE        ;CHECK FOR INTERPOLATION DONE
      BEQ     AMI
      BIT     #LE,LMT         ;CHECK FOR LIMIT ERROR
      BEQ     GMI
      JMP     LIMIT
GMI:   BIT     #1F,MODE      ;CHECK FOR INTERPOLATION FAULT
      BNE     HMI
      JMP     FAULT
AMI:   BIS     #INTRC,CONTROL
      SUB     #14.,R4        ;SET R4 TO POINTER
      BR      RFRUN1        ;DO IT AGAIN
RF8KF: MOV     #RF.15,R4     ;ACCELERATE TO 8K PPS
      JSR     PC,RF2KS
      MOV     #3.,R5
      JSR     PC,RFACC
      RTS     PC
RF16KF:MOV     #RF.15,R4     ;ACCELERATE TO 16K PPS
      JSR     PC,RF2KS
      MOV     #7.,R5
      JSR     PC,RFACC
      RTS     PC
RF32KF:MOV     #RF.15,R4     ;ACCELERATE TO 32K PPS
      JSR     PC,RF2KS
      MOV     #13.,R5
      JSR     PC,RFACC
      RTS     PC
RF80KF:MOV     #RF.15,R4     ;ACCELERATE TO 80K PPS
      JSR     PC,RF2KS
      MOV     #32.,R5
      JSR     PC,RFACC
      RTS     PC
RF8KL:  MOV     #RF.45,R4    ;DECELERATE FROM 8K PPS
      MOV     #3.,R5
      JMP     RFDEC
RF16KL:MOV     #RF1.05,R4    ;DECELERATE FROM 16K PPS
      MOV     #7.,R5
      JMP     RFDEC
RF32KL:MOV     #RF1.95,R4    ;DECELERATE FROM 32K PPS
      MOV     #13.,R5

```



```

      JMP      RFDEC
RF80KL: MOV     #RF4.95,R4      ;DECELERATE FROM 80K PPS
      MOV     #32.,R5
RFDEC: JSR     PC,RFDN
      BIS     #FL,CONTROL
ERF:   MOV     #174000,LED
ERF1:  INC     LED
      BNE     ERF1
      BIT     #C,STATUS      ;CHECK FOR CLEAR
      BEQ     ERF2
      JMP     EMI
ERF2:  BIT     #ID,MODE      ;CHECK FOR INTERPOLATION DONE
      BEQ     FRF
      BIT     #LE,LMT       ;CHECK FOR LIMIT ERROR
      BEQ     GRF
      JMP     LIMIT
GRF:   BIT     #IF,MODE      ;CHECK FOR INTERPOLATION FAULT
      BNE     ERF
      JMP     FAULT
FRF:   MOV     #INTRC,CONTROL ;CONTINUE INTERPOLATING
      DEC     R5
      BNE     RFDEC1
      JMP     EMI
RFDEC1: JSR    PC,RFDN
      JMP     ERF
RFACC: JSR     PC,RFUP
JRF:   MOV     #174000,LED
JRF1:  INC     LED
      BNE     JRF1
      BIT     #C,STATUS      ;CHECK FOR CLEAR
      BEQ     JRF2
      JMP     EMI
JRF2:  BIT     #ID,MODE      ;CHECK FOR INTERPOLATION DONE
      BEQ     HRF
      BIT     #LE,LMT       ;CHECK FOR LIMIT ERROR
      BEQ     IRF
      JMP     LIMIT
IRF:   BIT     #IF,MODE      ;CHECK FOR INTERPOLATION FAULT
      BNE     JRF
      JMP     FAULT
HRF:   MOV     #INTRC,CONTROL ;CONTINUE INTERPOLATING
      DEC     R5
      BNE     RFACC
      RTS     PC
RFG0:  JSR     PC,RFUP      ;LOAD DDA
ARF:   JSR     PC,LASTAT
      CMP     MANUAL,TMANUAL ;CHECK FOR MANUAL SWITCH IN SAME POSITION
      BNE     BRF
      CMPB    MODE,TMODE    ;CHECK FOR INTERPOLATION DONE
      BNE     BRF
      BIT     #ID,MODE      ;CHECK FOR INTERPOLATION DONE
      BEQ     CRF
      BIT     #LE,LMT       ;CHECK FOR LIMIT ERROR
      BEQ     DRF
      JMP     LIMIT
DRF:   BIT     #IF,MODE      ;CHECK FOR INTERPOLATION FAULT
      BNE     ARF
      JMP     FAULT
BRF:   MOV     #INTRC,CONTROL ;CONTINUE INTERPOLATING
      RTS     PC
CRF:   MOV     #INTRC,CONTROL
      SUB     #14.,R4      ;SET R4 TO POINTER
      BR      RFG0         ;DO IT AGAIN
RF2KS: JSR     PC,RFUP      ;LOAD DDA

```

```

      BIS      #FL,CONTROL      ;OUTPUT FIRST LOAD
      BIC      #CCT,TFEEDBK     ;TURN ON CLOCK
      MOV      TFEEDBK,FEEDBK
      RTS      PC
RFUP:  MOV      (R4)+,(R1)+      ;LOAD ODA
      MOV      (R4)+,(R1)
      MOV      (R4)+,(R2)+
      MOV      (R4)+,(R2)
      MOV      (R4)+,(R3)+
      MOV      (R4)+,(R3)
      MOV      (R4)+,IT
      TST      -(R1)
      IST      -(R2)
      TST      -(R3)
      RTS      PC
RFDN:  MOV      -(R4),IT        ;LOAD ODA
      TST      (R3)+
      MOV      -(R4),(R3)
      MOV      -(R4),-(R3)
      IST      (R2)+
      MOV      -(R4),(R2)
      MOV      -(R4),-(R2)
      TST      (R1)+
      MOV      -(R4),(R1)
      MOV      -(R4),-(R1)
      RTS      PC
PWRDN: MOV      R0,TR0          ;STORE REGISTERS ON POWER DOWN
      MOV      R1,TR1
      MOV      R2,TR2
      MOV      R3,TR3
      MOV      R4,TR4
      MOV      R5,TR5
      MOV      SP,TR6
      MOV      #PWRUP,24
      MOV      #340,26
      HALT
PWRUP: MOV      TR0,R0
      MOV      TR1,R1
      MOV      TR2,R2
      MOV      TR3,R3
      MOV      TR4,R4
      MOV      TR5,R5
      MOV      TR6,SP
      TST      (SP)+
      TST      (SP)+
      MOV      #100,177560
      MOV      #40,177170
      JMP      START1
XFLAG: 0
X1:     0
X2:     0
X3:     0
X4:     0
X5:     0
X6:     0
X7:     0
X8:     0
X9:     0
X10:    0
X11:    0
YFLAG:  0
Y1:     0
Y2:     0
Y3:     0

```

```

Y4:      0
Y5:      0
Y6:      0
Y7:      0
Y8:      0
Y9:      0
Y10:     0
Y11:     0
CFLAG:   0
C1:      0
C2:      0
C3:      0
C4:      0
C5:      0
C6:      0
C7:      0
C8:      0
C9:      0
C10:     0
C11:     0
FFLAG:   0
F1:      0
F2:      0
F3:      0
F4:      0
F5:      0
F6:      0
F7:      0
F8:      0
F9:      0
F10:     0
F11:     0
G1:      0
G2:      0
M1:      0
M2:      0
N1:      0
N2:      0
N3:      0
TR0:     0
TR1:     0
TR2:     0
TR3:     0
TR4:     0
TR5:     0
TR6:     0
TR7:     0
WORD:    0
SUML:    0
SUMH:    0
NSEQNO:  0
LED:     0
LIGHT:   0
BLOCK:   0
TMANUAL:      0
TMODE:      0
TFEEDBK:     0
POINTER:     0
NBUF1:      0
NBUF2:      0
MFRG:       0
LFRG:       0
FDATA:      .BLKW  9.
PAREA:      .BLKW  5

```

```

QAREA: .BLKW 7*5
SAREA: .WORD 0
      .WORD 0
      .WORD 0
      .WORD 0
      .WORD 1
      .WORD -1
      .WORD 0
PRG:   .WORD 3 ;BLOCK FOR MAXIX50 CONVERSION
      .WORD PRGNO-2
      .WORD PRGNO
      .WORD DX1N+6
      .WORD 3
PRGNO: 0
      0
LIST:  .BLKW 5 ;BLOCK FOR LOOKUP SUBROUTINE
DX1N:  .RAD50 "DX1"
      .RAD50 "PAD"
      .RAD50 "S "
      0
DXON:  .RAD50 "DX0"
      .RAD50 "PAD"
      .RAD50 "S "
      .RAD50 "000"
AREA:  .BLKW 10.
PRNAME: .RAD50 "PR "
      0
      0
MI1L:  0 ;OFFSET FOR MANUAL INCREMENT OF .001 MILS
      154000
      0
      2000
      0
      2000
      176647
MI2L:  0 ;MI .010 MILS
      100200
      0
      200
      0
      200
      176421
MI3L:  0 ;MI .100 MILS
      120020
      0
      20
      0
      20
      176126
MI4L:  0 ;MI .500 MILS
      144004
      0
      4
      0
      4
      177000
MI5L:  0 ;MI 1.00 MILS
      144002
      0
      2
      0
      2
      177750
MI6L:  20000 ;MI 10.0 MILS

```

```

175000
40000
0
40000
0
177742
MI7L: 2000 ;MI 100. MILS
116100
2000
0
2000
0
177755
RF1L: 177777 ;RAPID FEED AT .001 IPM
177777
1
0
1
0
150437
RF2L: 177777 ;RF .010 IPM
177777
1
0
1
0
175517
RF3L: 177777 ;RF .100 IPM
177777
1
0
1
0
177607
RF4L: 177777 ;RF .500 IPM
177777
1
0
1
0
177747
RF5L: 177777 ;RF 1.00 IPM
177777
1
0
1
0
177762
RF6L: 177777 ;RF 2.00 IPM
177777
1
0
1
0
177771
RF7L: 177777 ;RF 5.00 IPM
177777
1
0
1
0
177775
RF.00: 0
1

```

0
1
0
1
1
RF.15: 0
170040
0
40
0
40
177642
RF.3: 0
170020
0
20
0
20
177721
RF.45: 0
132010
0
10
0
10
177750
RF.6: 0
170010
0
10
0
10
177750
RF.75: 0
113004
0
4
0
4
177764
RF.9: 0
132004
0
4
0
4
177764
RF1.05: 0
151004
0
4
0
4
177764
RF1.2: 0
170004
0
4
0
4
177764
RF1.35: 0
103402
0

```
2
0
2
177772
RF1.5: 0
113002
0
2
0
2
177772
RF1.65: 0
122402
0
2
0
2
177772
RF1.8: 0
132002
0
2
0
2
177772
RF1.95: 0
141402
0
2
0
2
177772
RF2.1: 0
151002
0
2
0
2
177772
RF2.25: 0
160402
0
2
0
2
177772
RF2.4: 0
170002
0
2
0
2
177772
RF2.55: 0
177402
0
2
0
2
177772
RF2.7: 0
103401
0
1
```


0
1
177775
RF2.65: 0
107201
0
1
0
1
177775
RF3.0: 0
113001
0
1
0
1
177775
RF3.15: 0
116601
0
1
0
1
177775
RF3.3: 0
122401
0
1
0
1
177775
RF3.45: 0
126201
0
1
0
1
177775
RF3.6: 0
132001
0
1
0
1
177775
RF3.75: 0
135601
0
1
0
1
177775
RF3.9: 0
141401
0
1
0
1
177775
RF4.05: 0
145201
0
1
0

```

      1
      177775
RF4.2: 0
      151001
      0
      1
      0
      1
      177775
RF4.35: 0
      154601
      0
      1
      0
      1
      177775
RF4.50: 0
      160401
      0
      1
      0
      1
      177775
RF4.65: 0
      164201
      0
      1
      0
      1
      177775
RF4.80: 0
      170001
      0
      1
      0
      1
      177775
RF4.95: 0
      173601
      0
      1
      0
      1
      177775
BUF1: 0
      .=.+2560.
BUF1E: 0
BUF2: 0
      .=.+2560.
BUF2E: 0
HSPACE: 0
      .=.+200
EHSPC: 0
      .END      START1

```

```

SUBROUTINE COMP(FDATA)
DIMENSION FDATA(9)
TYPE 10
10  FORMAT (////////// ' ALL ENTRIES MUST BE FOLLOWED BY A RETURN')
TYPE 20
20  FORMAT (' TYPE 0 FOR METRIC AND 1 FOR ENGLISH: ', $)
ACCEPT 30, ME
30  FORMAT (I1)
TYPE 40
40  FORMAT (' RELATIVE HUMIDITY IN % = ', $)
ACCEPT 50, RH
50  FORMAT (F6.2)
IF (ME.EQ.1) GO TO 130
TYPE 60
60  FORMAT (' AIR TEMPERATURE IN C = ', $)
ACCEPT 50, TAC
TYPE 80
80  FORMAT (' BAROMETRIC PRESSURE IN MM = ', $)
ACCEPT 50, PM
TYPE 100
100  FORMAT (' PART TEMPERATURE IN C = ', $)
ACCEPT 50, TPC
TYPE 110
110  FORMAT (' COEFFICIENT OF EXPANSION IN PPM/C = ', $)
ACCEPT 50, CEC
CM1=0.3836391*PM
CM2=1.+(1.E-6)*PM*(0.817-0.0133*TAC)
CM3=1.+0.003661*TAC
CM4=3.033*(1.E-3)*RH*EXP(0.057627*TAC)
CM=CM1*(CM2/CM3)-CM4
COMPN=((1.E6)/(CM+1.E6)-(TPC-20.)*(1.E-6)*CEC)*15824785.47
TYPE 120, COMPN
120  FORMAT (' COMPENSATION = ', F9.0, 'E-8 NANUMETERS')
RETURN
TYPE 140
140  FORMAT (' AIR TEMPERATURE IN F = ', $)
ACCEPT 50, TAF
TYPE 150
150  FORMAT (' BAROMETRIC PRESSURE IN INCHES = ', $)
ACCEPT 50, PE
TYPE 160
160  FORMAT (' PART TEMPERATURE IN F = ', $)
ACCEPT 50, TPF
TYPE 170
170  FORMAT (' COEFFICIENT OF EXPANSION IN PPM/F = ', $)
ACCEPT 50, CEF
CE1=9.74443*PE
CE2=1.+(1.E-6)*PE*(26.7-0.167*TAF)
CE3=0.934915+0.0020388*TAF
CE4=1.089*(1.E-3)*RH*EXP(0.032015*TAF)
CE=CE1*(CE2/CE3)-CE4
COMPN=((1.E6)/(CE+1.E6)-(TPF-68.)*(1.E-6)*CEF)*62302305.
TYPE 210, COMPN
210  FORMAT (' COMPENSATION = ', F9.0, 'E-8 MICROINCHES')
ENCODE (9,220,FDATA)COMPN
220  FORMAT (F9.0)
RETURN
END

```

PROGRAM SECTIONS

NAME	SIZE	ATTRIBUTES
SCODE1	001512 421	RW,I,CON,LCL
SPDATA	000110 36	RW,D,CON,LCL
SIDATA	000776 255	RW,D,CON,LCL
SVARS	000122 41	RW,D,CON,LCL

TOTAL SPACE ALLOCATED = 002742 753

,LP:=OK1:COMP.FOR

APPENDIX F
HARDWARE DRAWINGS

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Figure F-1. LASER ERROR CORRECTION. (Cabinet Assembly)

Figure F-2. LASER ERROR CORRECTION. (System Block Diagram)

Figure F-6. LASER ERROR CORRECTION. (Laser Correct Logic Diagram)

Figure F-7. LASER ERROR CORRECTION. (Timing and Add Command Generator Logic Diagram)

Figure F-8. LASER ERROR CORRECTION. (32-Bit Adder Logic Diagram)

Figure F-10. LASER ERROR CORRECTION. (Output W/Buffer and Register Logic Diagram)

Figure F-11. LASER ERROR CORRECTION. (Input Receiver Logic Diagram)

Figure F-12. LASER ERROR CORRECTION. (Input Receiver W F/F Logic Diagram)

Figure F-13. LASER ERROR CORRECTION. (Programmable Clock Logic Diagram)

Figure F-14. LASER ERROR CORRECTION. (Counter W/Driver's Logic Diagram)

Figure F-16. LASER ERROR CORRECTION. (Reader Interface Schematic)

Figure F-17. LASER ERROR CORRECTION. (Control Panel Wiring Diagram)

Figure F-18. LASER ERROR CORRECTION. (Motor Drive Cabinet Interconnecting Cables)

Figure F-19. LASER ERROR CORRECTION. (Control Cabinet Interconnecting Cables)

Figure F-21. LASER ERROR CORRECTION. (Display PC/Board)

Figure F-23. LASER ERROR CORRECTION. (Input Receiver W F/F PC/Board)

Figure F-24. LASER ERROR CORRECTION. (Output W Buffer and Registers PC/Board)

Figure F-25. LASER ERROR CORRECTION. (Input Receiver PC/Board)

24" REF.

PROGRAM STATUS			LASER STATUS		MACHINE STATUS		
PROGRAM END +	PROGRAM STOP +	OPTIONAL STOP +	RETUNE STATUS +	RETUNE ERROR +	LIMIT ERROR +	INTRP FAULT +	
END OF BLOCK +	HOLD +	RUN +	PULSE ERROR +	LASER ERROR +	WRITE ERROR +	READ ERROR +	
					SEARCH ERROR +		

<h3 style="margin: 0;">X-AXIS</h3> <div style="border: 1px solid black; width: 150px; height: 40px; margin: 10px auto; position: relative;"> <div style="position: absolute; top: 0; bottom: 0; left: 50%; transform: translate(-50%, 0); border-left: 1px solid black;"></div> <div style="position: absolute; left: 0; right: 0; top: 50%; transform: translateY(-50%); border-top: 1px solid black;"></div> </div>	<h3 style="margin: 0;">Y-AXIS</h3> <div style="border: 1px solid black; width: 150px; height: 40px; margin: 10px auto; position: relative;"> <div style="position: absolute; top: 0; bottom: 0; left: 50%; transform: translate(-50%, 0); border-left: 1px solid black;"></div> <div style="position: absolute; left: 0; right: 0; top: 50%; transform: translateY(-50%); border-top: 1px solid black;"></div> </div>
<h3 style="margin: 0;">C-AXIS</h3> <div style="border: 1px solid black; width: 150px; height: 40px; margin: 10px auto; position: relative;"> <div style="position: absolute; top: 0; bottom: 0; left: 50%; transform: translate(-50%, 0); border-left: 1px solid black;"></div> <div style="position: absolute; left: 0; right: 0; top: 50%; transform: translateY(-50%); border-top: 1px solid black;"></div> </div>	<h3 style="margin: 0;">SEQ. NO.</h3> <div style="border: 1px solid black; width: 50px; height: 40px; margin: 10px auto; position: relative;"> <div style="position: absolute; top: 0; bottom: 0; left: 50%; transform: translate(-50%, 0); border-left: 1px solid black;"></div> <div style="position: absolute; left: 0; right: 0; top: 50%; transform: translateY(-50%); border-top: 1px solid black;"></div> </div>

+ $\frac{1}{8}$ " (.250) DRILL, 16 HOLES

MAT'L: $\frac{1}{8}$ " ALUM. METAL PHOTO

Figure F-26. LASER ERROR CORRECTION. (Status Display Panel)

Figure F-27. LASER ERROR CORRECTION. (Programmable Clock PC/Board)

Figure F-28. LASER ERROR CORRECTION. (Cable PC/Board)

Figure F-29. LASER ERROR CORRECTION. (32-Bit Adder PC/Board)

Figure F-30. LASER ERROR CORRECTION. (Timing and Add Command Generator PC/Board)

Figure F-31. LASER ERROR CORRECTION. (Optical Isolator PC/Board)

Figure F-33. LASER ERROR CORRECTION. (Counter W Driver PC/Board)

Figure F-34. LASER ERROR CORRECTION. (Laser Correct PC/Board)

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