To the Graduate Council:

I am submitting herewith a thesis written by Richard Earl Neal entitled "A Programmable Control System for Scanning Cylindrical Parts." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Electrical Engineering.

Robert E Bodenheimer
Major Professor

We have read this thesis
and recommend its acceptance:

E J Kennedy

D. R. Peterson

Accepted for the Council:

Hilton A. Smith
Vice Chancellor
Graduate Studies and Research

A PROGRAMMABLE CONTROL SYSTEM FOR SCANNING CYLINDRICAL PARTS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

Richard Earl Neal

December 1974

ACKNOWLEDGEMENTS

The author wishes to thank Dr. Robert Bodenheimer for his guidance in the preparation of this thesis.

1176345

ABSTRACT

As an alternative to Numerical Contouring Control, a programmable control system has been designed and implemented for scanning cylindrical parts. The system provides the advantage of low cost and eliminates the delays associated with part tape production. The system operates by enabling an axis drive motor and continuously monitoring the accumulated output from an encoder mounted on the shaft. The accumulated counts are continuously compared to a number representing the required motion and, when the two are equal, the desired motion has been executed.

There are seven variables that must be specified for scanning a particular sized cylinder. In this system, they are all inputted via switches.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	A PROGRAMMABLE CONTROL SYSTEM FOR SCANNING CYLINDRICAL PARTS	1
	Introduction	1
II.	CONTROL ALTERNATIVES	7
	NC Assets and Liabilities	7
	Alternative Systems	7
	System Selection	12
III.	THE PROGRAMMABLE CONTROL SYSTEM	13
	Input	13
	Control Logic (MCU)	15
	Analog Axis Drive Systems	22
	Other Design Considerations	23
IV.	CONCLUSIONS AND RECOMMENDATIONS	25
LIST OF REFERENCES		26
APPENDIX A		29
APPENDIX B		32
APPENDIX C		37
APPENDIX D		41
VITA		45

LIST OF FIGURES

FIGURE		PAGE
1.	Single-Axis Digital Numerical Control System	2
2.	Single-Axis Phase Analog Numerical Control System	4
3.	Basic Motions Required for Scanning a Cylinder	6
4.	Motions Required for Scanning a Conical Part	8
5.	Open-Loop Stepping-Motor Control System	9
6.	One-Axis Analog Drive System	11
7.	Special-Purpose Scan Control Unit	14
8.	Control Panels of the Programmable System For Scanning Cylindrical Parts	16
9.	Flow Chart Showing Logic Decisions Made by Hardwired Control System	17
10.	Block Diagram of Hardwired Control System	18
11.	Machine Axes Configuration	19

CHAPTER I

A PROGRAMMABLE CONTROL SYSTEM FOR SCANNING CYLINDRICAL PARTS

I. INTRODUCTION

The modern automatic control system can be said to have evolved from the desire of primitive man to simplify his existence. He soon learned that by applying his strength to mechanical devices, such as wheels and levers, he could more readily accomplish his objectives. Years later his descendents learned to utilize external power sources such as the wind and water. Inventions like the steam engine and the harnessing of electrical power led to the development of manual machines that required very little power input from the operator. The desire to free the operator from the monotonous tasks of controlling processes, and the inability of man to duplicate certain machine functions led to the development of the technology of automatic control systems.

Often in industry automatic controllers are called upon to guide a machine tool or other device repeatedly over the part surface until the operation is complete. Such devices fall into the general category of numerical control (NC) which is defined as the operation of processing equipment by a series of coded instructions comprised mostly of numbers.[1] For purposes of this discussion, the term NC system will apply only to the conventional closed loop, industrially produced machine.

Commercial NC systems fall into two basic categories depending on the feedback method employed. They are the digital feedback system most often used for inspection applications, and the phase-analog system usually used for machining. A basic block diagram of a single-axis digital system is shown in Figure 1. The machine control unit (MCU) accepts input and provides command signals to the servo-system. For each motion required, the

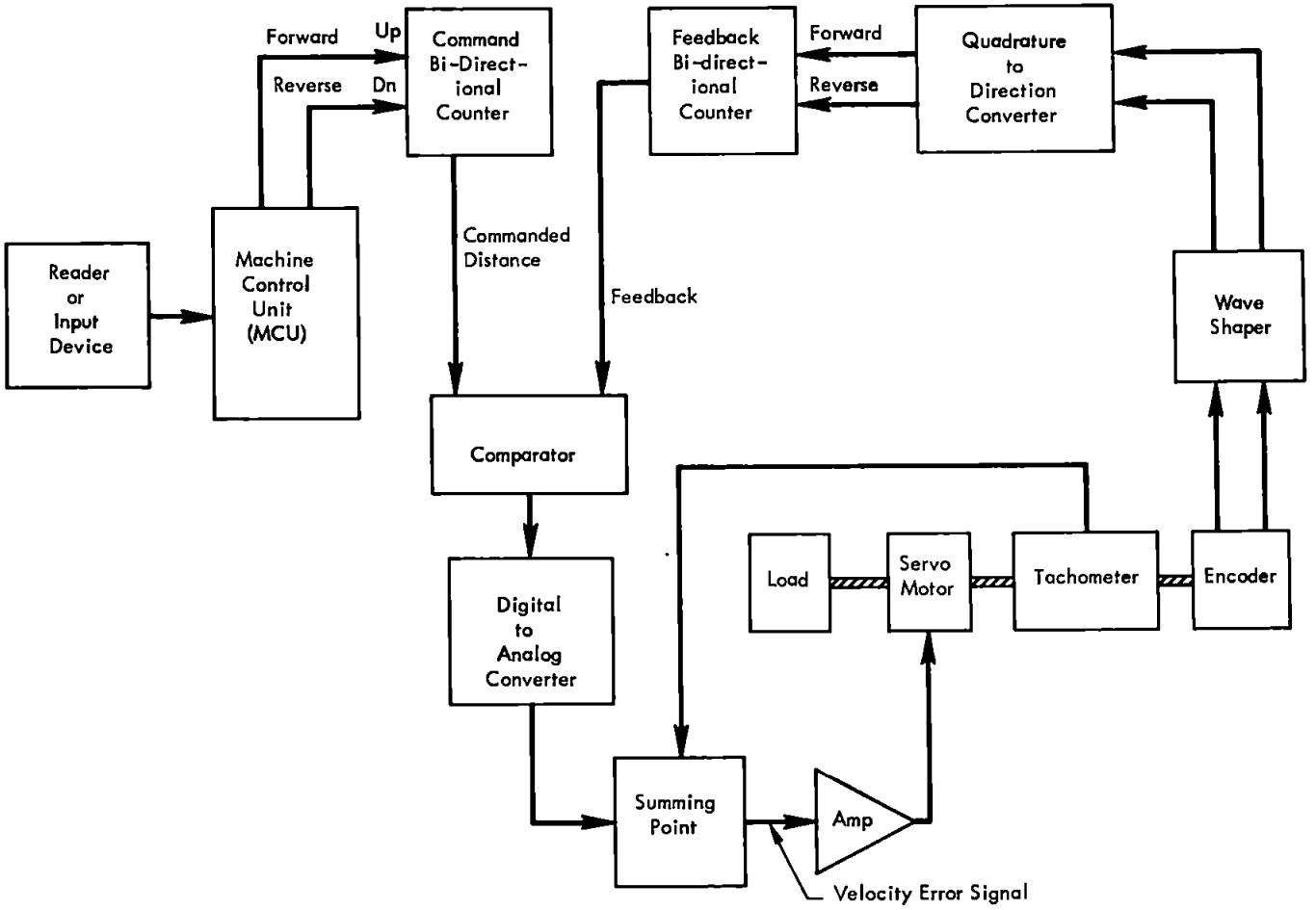


FIGURE 1

SINGLE-AXIS DIGITAL NUMERICAL CONTROL SYSTEM

distance, speed, and direction must be specified. The commanded distance is defined by the number of pulses issued to the bidirectional counter; the speed is defined by the frequency of the pulses, and the direction is controlled by choosing the proper input line. The comparator is essentially a subtractor whose output is a digital signal proportional to the difference in the two inputs. This difference is converted to an analog signal and added to the tachometer output creating a velocity error signal which serves as the input to the amplifier that drives the axis motor (for linear motion the motor turns a lead screw which converts turns to distance at a defined ratio). An encoder mounted on the motor shaft provides quadrature pulses to an up-down converter. Each pulse either increments (forward) or decrements (reverse) the feedback counter whose output is compared with the output of the command counter. When no difference exists, the required motion is complete.

A single-axis phase-analog system is depicted in Figure 2. In order to make this system operate, two phase-analog voltages must be produced: one to indicate commanded position, and the other to indicate feedback position. To generate the feedback signal, the resolver is excited by a two-phase source at the reference frequency (a few hundred cycles). This induces in the output winding a single-phase sinusoidal voltage which shifts in phase relative to the reference as a function of resolver shaft position. The output is converted to a square wave which serves as the position feedback signal. The commanded position signal is produced by feeding the output of the clock oscillator to the command phase counter which divides the clock signal down to the same frequency as the reference. The relative phases of the position feedback signal and the command phase counter output are compared by the phase discriminator, thereby producing a position error signal whose magnitude and polarity are a function of the relative phase displacement of the inputs. This signal, after amplification, is used to drive the motor and the resolver in the direction required to reduce the error signal. The system thus far described would simply hold the axis at a fixed

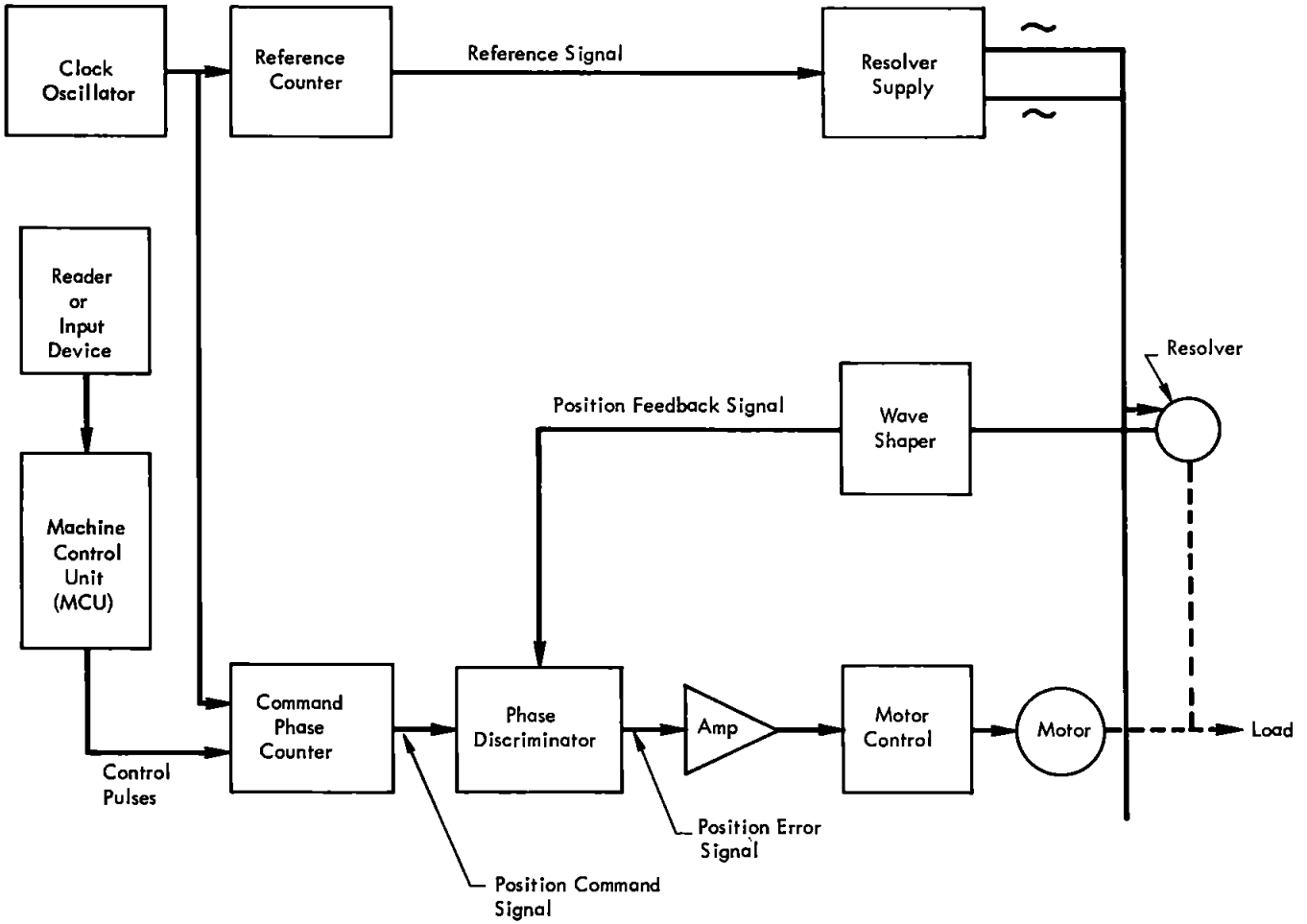


FIGURE 2

SINGLE-AXIS PHASE ANALOG NUMERICAL CONTROL SYSTEM

position. In order to produce motion, the position command signal must be phase shifted so that the rate of phase shift and the total phase shift are proportional to the desired velocity and displacement. To accomplish this motion, the command phase counter is designed to accept input from the MCU. For each control pulse produced, a certain phase shift results that causes a calibrated displacement, the amount of which is a characteristic of machine design. The velocity is proportional to the frequency of the control pulses and the total displacement to the number of pulses. The direction of the phase shift at the position command signal with respect to the reference dictates the direction of machine motion.[2]

Both types of NC systems are usually quite capable, expensive machines. For any operation they are to perform, several steps must be taken to convert a designer's conception of a part into a finished product. A drawing must first be made from which a programmer can convert every required movement or action into a series of coded instructions. These instructions must then be transformed into a mode acceptable to the reader of the MCU. The acceptable mode may be through perforated tape, magnetic tape, tabulating cards, or direct from a computer storage (disk, magnetic tape, core memory or read only memory). The required transition from designer's concept to acceptable input produces a significant delay in obtaining the desired result. After the information is loaded into the reader, and the cycle is initiated, the MCU issues the data required to cause the desired actions to occur.

In performing a particular operation, a head must be translated parallel to the axis of rotation of either the inside or outside wall of cylinders of various sizes a required number of times. The axes must also retrace their path to an unimposing home position when the operation is complete. As illustrated in Figure 3, three basic motions are required for such performance. First, from home, the head must move perpendicular to the axis of rotation a sufficient distance to obtain proper orientation with the part diameter (X length). Motion must then occur parallel to the rotational axis the distance required to allow the

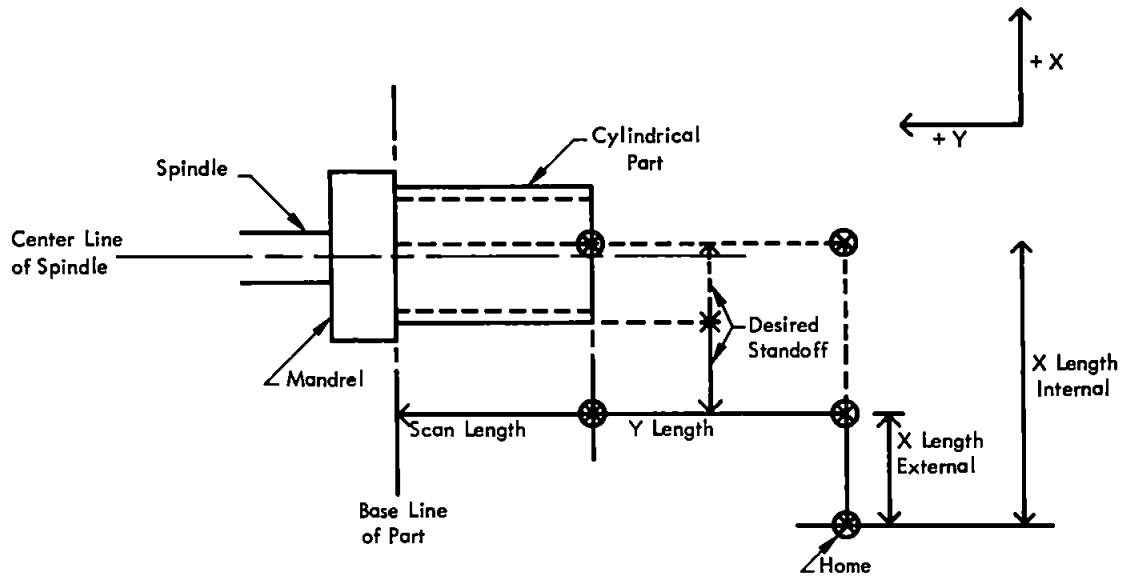


FIGURE 3

BASIC MOTIONS REQUIRED FOR SCANNING A CYLINDER

start of each scan to occur near the front of the part (Y length). The final motion is executed parallel to the part the number of times required for the completion of the process after which the path is retraced to home. This is a simple operation that wastes the capabilities of an NC system.

In order to more efficiently scan various sized cylinders, a system is required that eliminates the delays associated with making new part tapes every time part dimensions change (several hours in this case). The length of the three required motions and the number of scans should be entered directly by the operator at the control console. The system should be as simple to operate as possible and very reliable, since only one of its kind will be available and schedules must be met. The need for a system capable of meeting these requirements forms the basis for the work described in this thesis.

CHAPTER II

CONTROL ALTERNATIVES

NC Assets and Liabilities

Numerical control systems possess many features that make them attractive for the solution of control problems. Standard systems are available that can be adapted to fill the need in most control applications. They are very accurate and produce better repeatability in that human interaction is minimized. This lack of interaction downgrades the quality of employee required to perform a machining operation from a skilled craftsman to trained operator. Management therefore has better control over both the machining operation itself and the quality of the finished product.

The impressive credentials of NC systems have led to their almost universal acceptance as the answer to control problems, but certain other factors should be taken into consideration before decisions are reached. In the first place, the scope of the project for which NC is being considered must be large enough to justify the costs. A large initial capital outlay is required to purchase the equipment, and a highly trained technical staff must be employed to program and maintain the systems. In the second place, the job should be of sufficient complexity to require the capabilities of an NC system. Certain operations are so simple that they waste the flexibility and accuracy of a sophisticated machine.

Alternative Systems

Programmable Controllers. For many control applications, alternatives exist which provide the desired control more economically and efficiently. For example, programmable controllers are available in various degrees of sophistication that can solve many control problems. They are special purpose devices with core and/or read only memories (ROM). Such controllers coupled with the required axes drive motors can replace

NC as an alternative to manually manipulated machine tools. If a particular pattern is to be followed repeatedly and no flexibility is required, the part description can be permanently stored in a ROM and upon initiation of the cycle (most machining operations are initiated by depressing a cycle start button) the programmable controller issues the commands that cause the axes motors to turn. Each turn produces a translation of that particular axis an amount depending upon the axis lead screw.

Stepping Motor Drive Systems. Another control alternative is an open loop stepping motor drive system. As an example of how such a system operates, suppose that cones of various sizes are to be scanned in much the same fashion as the cylinder depicted in Figure 3. The same three basic motions are required with the exception of the fact that the scan motion must be executed by both the X and Y axes as shown in Figure 4. A block diagram of how the system would operate is shown in Figure 5. When the cycle is initiated

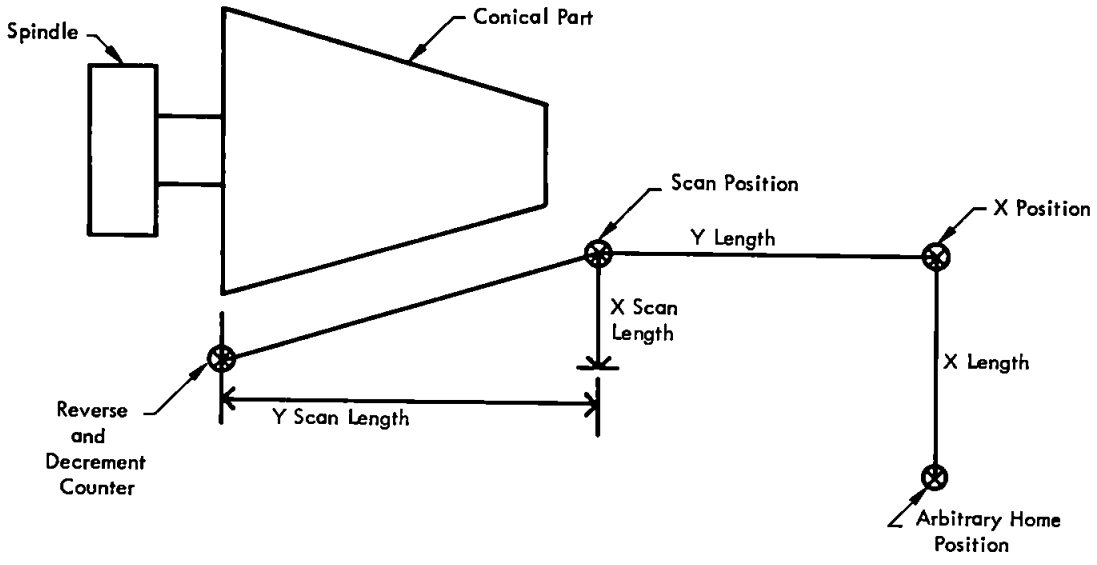


FIGURE 4

MOTIONS REQUIRED FOR SCANNING A CONICAL PART

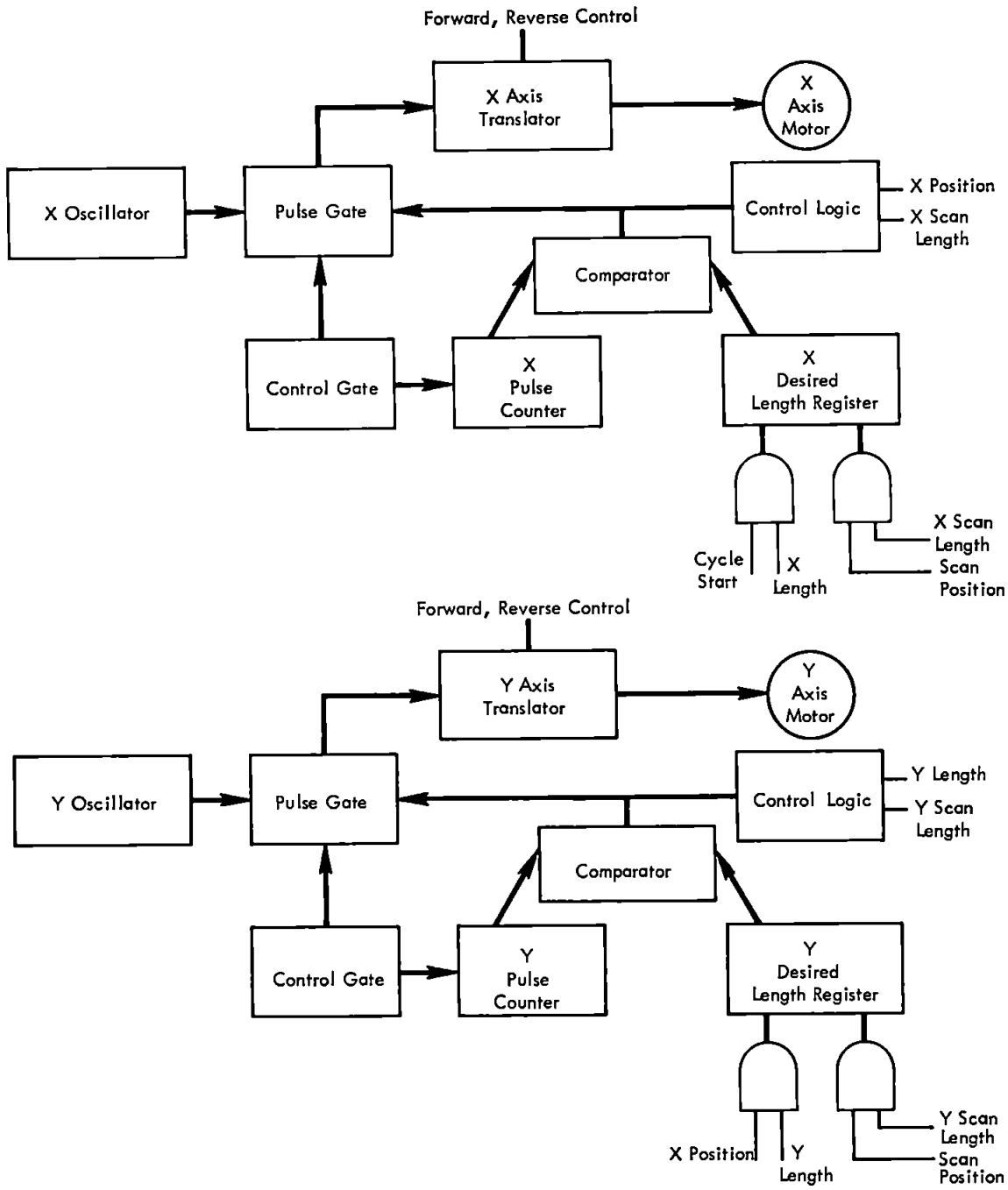


FIGURE 5

OPEN-LOOP STEPPING-MOTOR CONTROL SYSTEM

and X length is read into the desired travel register, a pulse is applied to the control gate allowing pulses from the oscillator to be fed to the translator circuits. These logic circuits convert each pulse into the correct sequence to drive the motor one step. The pulse counter, initially reset by the start pulse, increments itself each time a pulse is applied to the translator. When the accumulated total in the counter equals the number required for the X motion (X length) the control circuitry closes the pulse gate, resets the decade counters, allows Y length to be read into the Y desired length register, and issues a start pulse for the Y axis motion. This motion is executed in like manner and is discontinued when the contents of the Y decade counter equal the desired motion (Y length). A clear pulse then resets both counters, allows X scan and Y scan to be read into the desired length registers, and issues a start command for motion in both the forward X and Y directions. Pulses applied to the translator are accumulated until both the X and Y counters contain the numbers representing the required length. Both axes operate independently of each other so if X scan length is reached before Y scan length, X motion is disabled until Y is complete. When both X and Y counters contain the desired numbers, the scan counter is decremented, both counters are zeroed, and motion is initiated in the reverse direction. The direction of travel is reversed by changing the input level of the direction control in the translator. Again both counters are incremented until X scan length and Y scan length are reached. This reversal process is repeated until the operation is complete. If no scans are remaining when the axes return to Y length position, both counters are zeroed, Y length is read into the Y desired length register, and motion is enabled in the Y reverse direction. After this motion is executed, X travel is enabled in the negative direction until the axes return to the original home position. In this operation there are six variables that can be either programmed or hardwired. They are: X length, Y length, X scan length, Y scan length, X axis velocity (oscillator frequency), and Y axis velocity. A logic system can be designed that allows all these variables to be inputted via switches, or if the same scanning motion is to be repeated

continuously, the inputs can be hardwired. The system represents an open loop method of performing a control operation. There is no velocity or position feedback, but the reliability of stepping motor systems has been well established.[3,4]

Special Purpose Hardwired Controllers. An alternative remains that could be called a special purpose programmable controller. Commercially available controllers are designed with flexibility that allows them to be adapted to meet the customers' requirements. In certain applications, a hardwired logic system can be constructed to perform the control function more economically and efficiently. For example, let us consider a process that requires only one axis to be driven at a time. A block diagram of a single axis analog drive system is shown in Figure 6. When the cycle is initiated, the axis is enabled providing power to the axis motor through a relay closure. As motion continues, pulses from an encoder mounted on the motor shaft are counted by a hardwired controller.

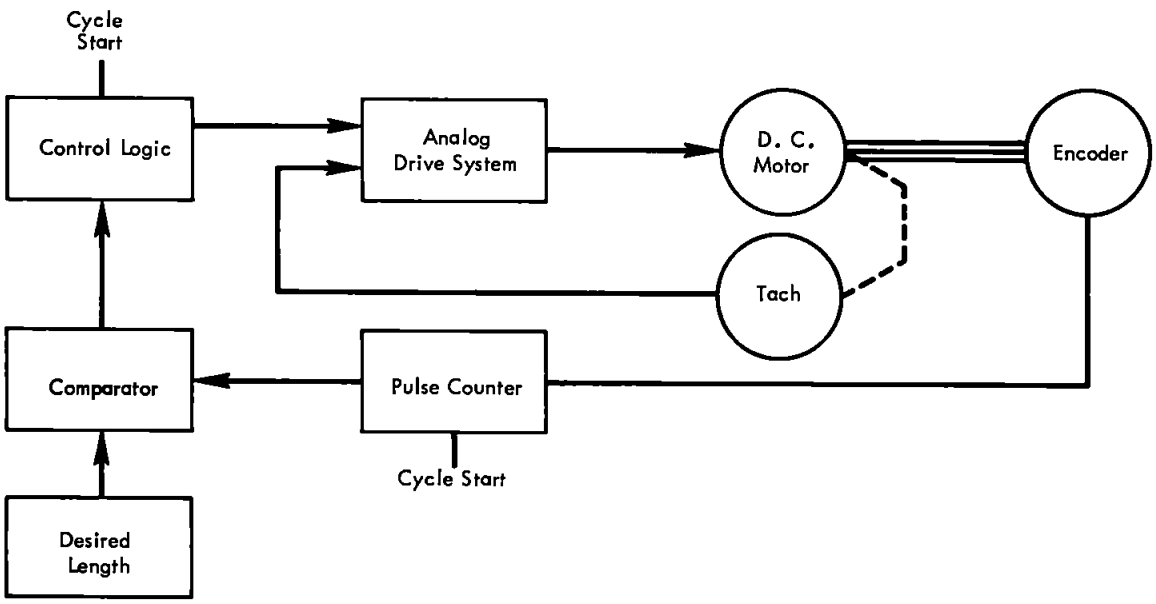


FIGURE 6

ONE-AXIS ANALOG DRIVE SYSTEM

When the number of accumulated counts is equal to the number corresponding to the desired travel length (desired travel length may be programmed or hardwired by switches), the relay is de-energized breaking the path, and the next motion is initiated. Position feedback is provided by the encoders, but no velocity position feedback is built into the system. The velocity for each motion is programmed by changing the input gain of the amplifier system that drives that axis motor.

System Selection

The scanning of a cylinder previously described and illustrated in Figure 3 (Page 6) presents several requirements. First, the spindle must be rotated at various speeds that the operator selects at the console. Second, two axes must be independently controlled (neither moves while the other is moving) in such a way as to execute the three required motions, and finally, the scan parameters (X length, Y length, scan length, X axis velocity, Y axis velocity, and required scans) must be inputted by the operator at the console. All the control alternatives discussed were considered for accomplishing this task. The decision was reached that on the basis of simplicity, reliability, cost and the availability of components, a special purpose controller for an analog drive system represented the best selection.

CHAPTER III

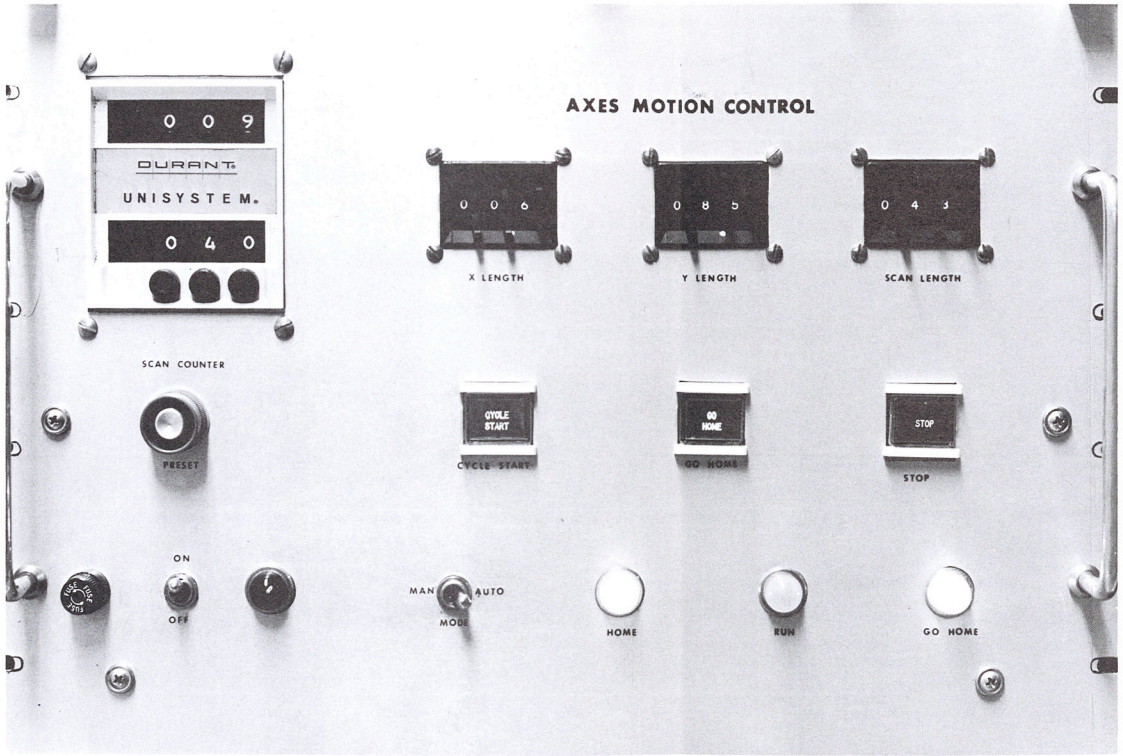
THE PROGRAMMABLE CONTROL SYSTEM

All the control alternatives discussed consist of three fundamental sections. They are the input, the MCU, and the axes drive system. Each of the sections of the programmable control system for scanning cylinders will be discussed separately.

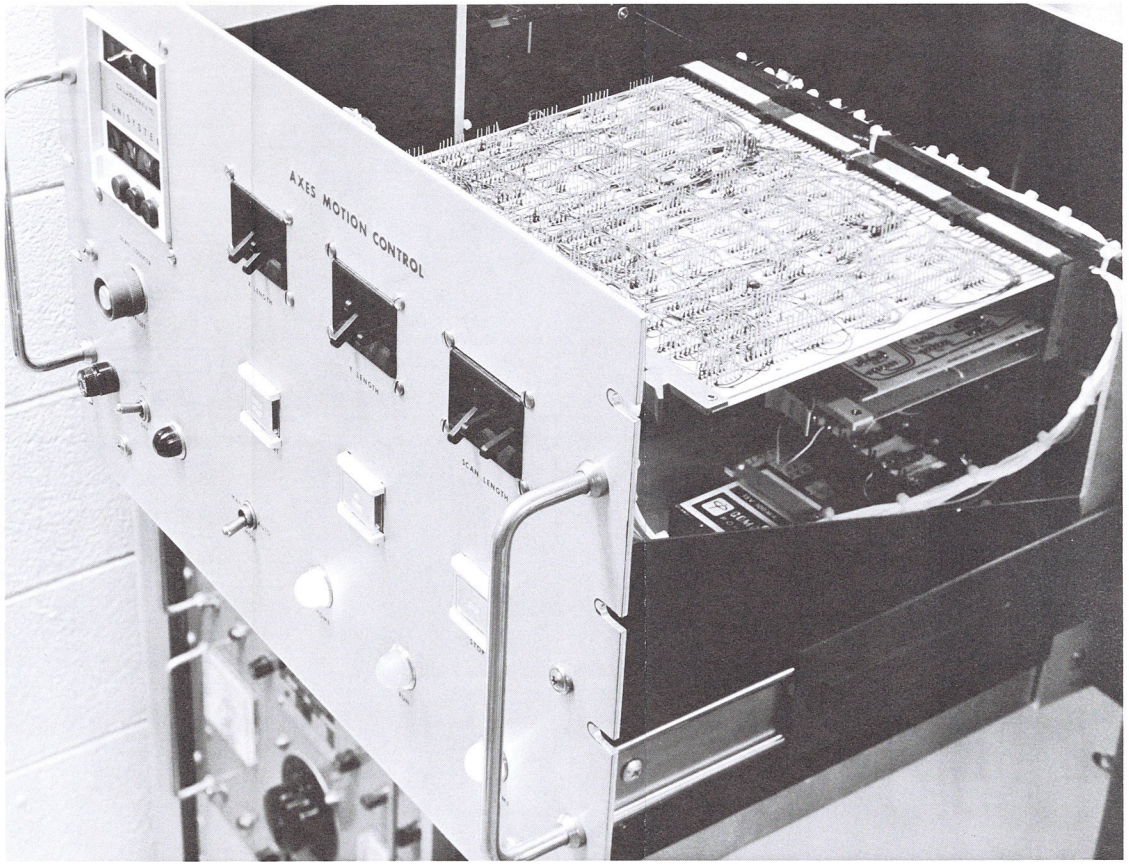
Input

There are several input modes that could be incorporated into the programmable control system. Possible alternatives include a teletype, ROM, or switches since all of these modes meet the basic design requirement of immediate parameter change by the operator at the console. Of the alternatives, switch input is easier to implement from the design standpoint and is probably more convenient for operator interaction. For these reasons, switches were chosen as the input mode for all scanning parameters.

There are four control parameters that define the contour scanning of a cylindrical part. They are: (1) X length, (2) Y length, (3) scan length, and (4) the number of scans required (Figure 3, Page 6). In order to calculate X length for external scanning, the operator adds the desired standoff to the cylinder radius and subtracts the sum from the distance from home position to the centerline of the part (distance to centerline minus standoff minus radius). For internal scanning, X length equals distance to centerline minus radius plus standoff. Y length is obtained by subtracting the part length from the Y distance from home to the baseline of the part. Scan length is usually the part length, but for certain applications, overtravel is allowed at both turnaround points. The number of scans is simply a function of the process and is inputted through a commercial predetermining counter at the operator's discretion. As shown in Figure 7, the required lengths are specified via lever switches. Three decades are provided for each motion with the least significant digit representing tenths of an inch. These binary coded decimal outputs are converted to binary and inputted to the



(a) CONTROLS AND INDICATORS (156993)



(b) CONFIGURATION OF THE REQUIRED LOGIC (156992)

FIGURE 7

SPECIAL-PURPOSE SCAN CONTROL UNIT

comparator of the control logic. The input conversion logic is illustrated schematically in Appendix A.

The three remaining parameters that must be specified are Y axis velocity, X axis velocity, and spindle speed. The pushbutton switches on the control panel (Figure 8) control by voltage division the input to operational amplifiers that drive the axis motors. No velocity-position error signals are generated in the system.

Control Logic (MCU)

The purpose of the MCU is to accept input commands and create an output that properly describes the required sequences. In the case of the cylinder, the MCU must accept the four control parameters previously described and sequentially enable and disable the axes motors when required to properly execute the cycle. A flow chart of the logic decisions necessary for scanning a cylinder is shown in Figure 9, and a block diagram of the implementation of these decisions is presented in Figure 10.

After the operator has entered the four control parameters, he pushes the cycle start button. This sets the output of all the counters in the MCU to zero and enables X axis forward motion by applying a logical "1" (+ 3 volt) input to a relay driver (Appendix C, Page 37). As the motor turns, the quadrature output of the X axis encoder is converted to up-down pulses at a rate of 200 per revolution. The X axis lead is 0.25 inch per revolution (Figure 11); therefore, when 80 encoder pulses have occurred, the X axis has moved 0.1 inch. Their occurrence is detected by "anding" the 2^4(16) and 2^6(64) binary outputs. Each 80 pulse event resets the X divider to zero and increments the X length counter. The contents of the counter are continuously compared with the binary X length input. When the two are equal, X position is asserted disabling X forward motion and enabling Y forward motion.

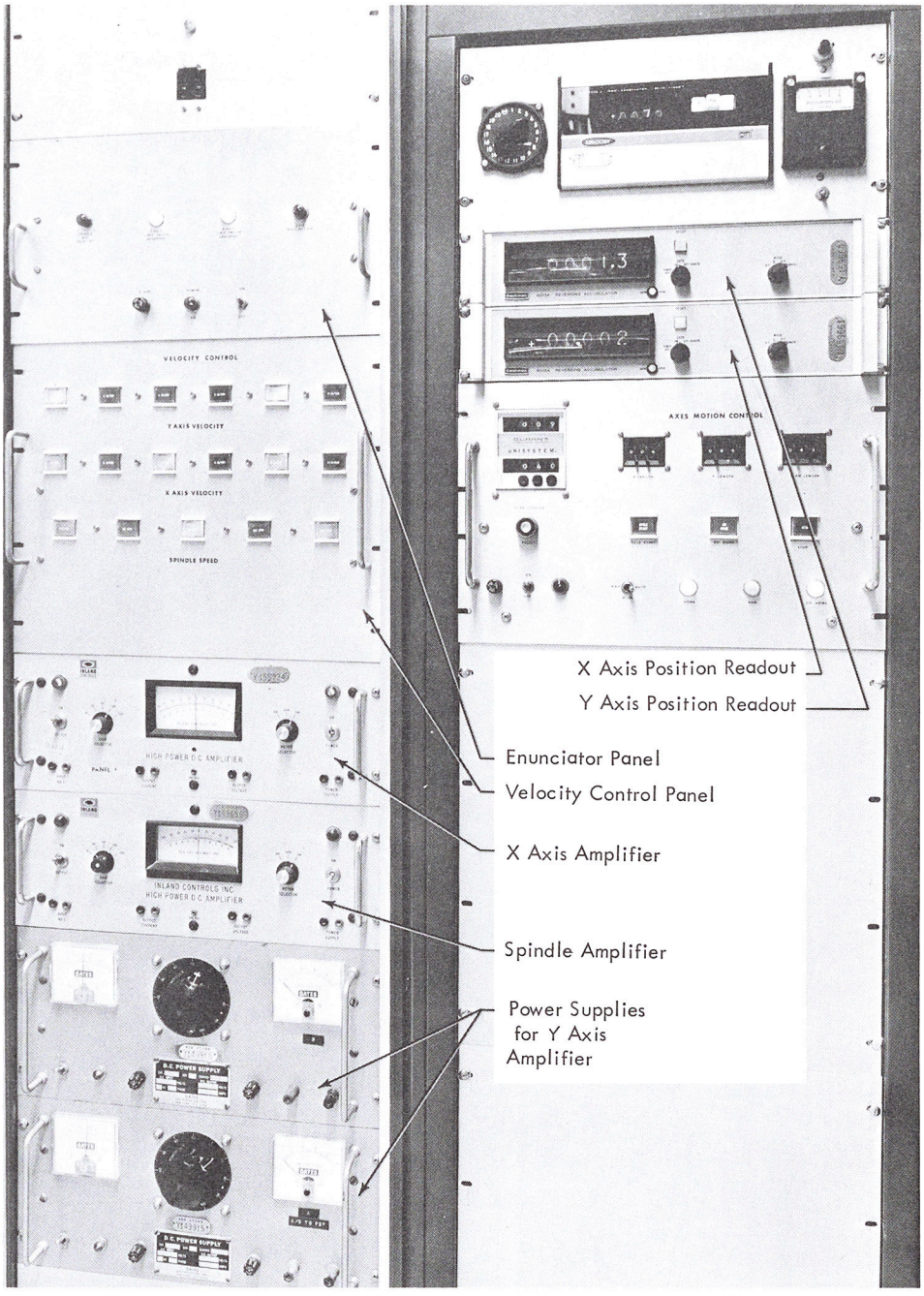


FIGURE 8

CONTROL PANELS OF THE PROGRAMMABLE SYSTEM
FOR SCANNING CYLINDRICAL PARTS

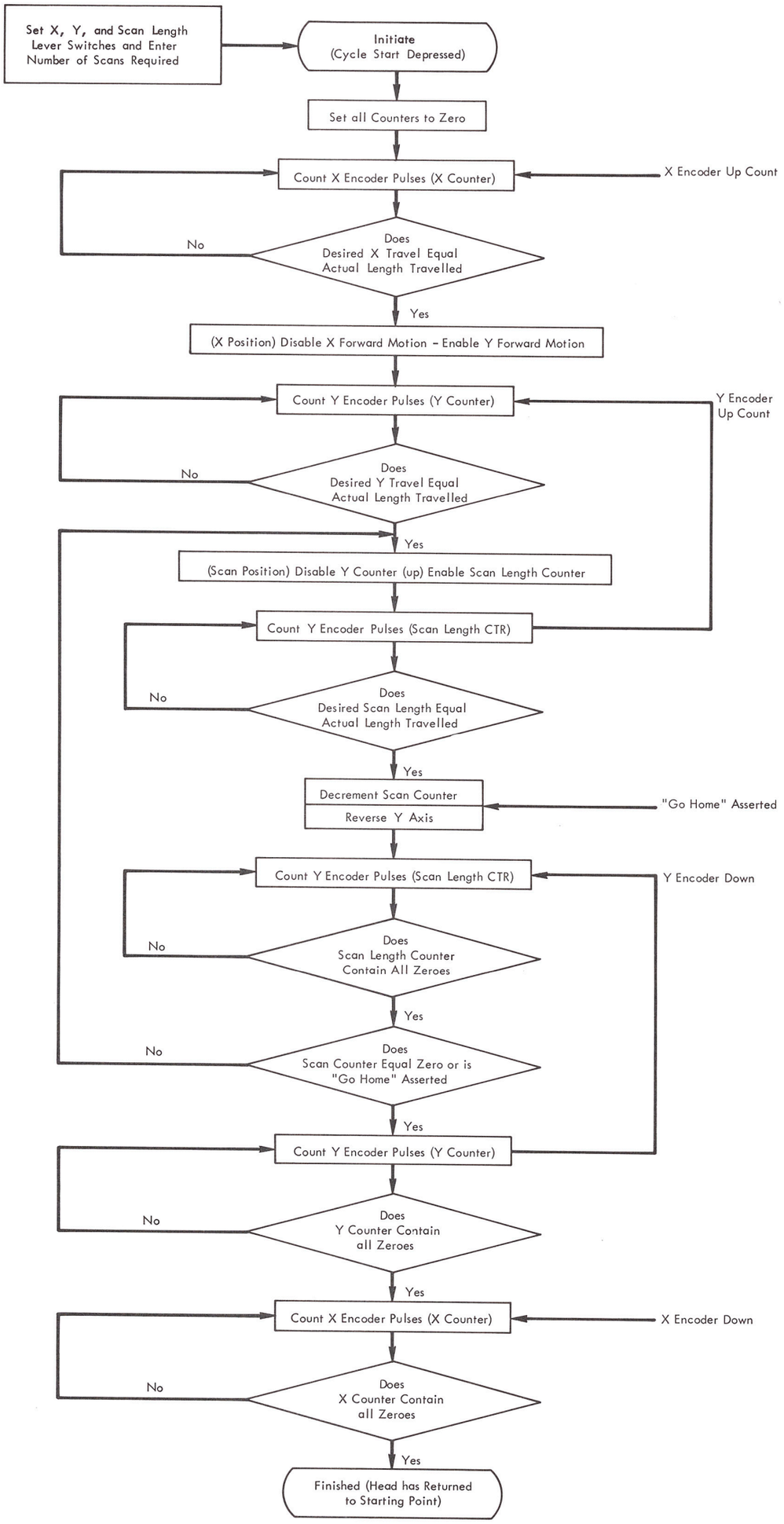


FIGURE 9

FLOW CHART SHOWING LOGIC DECISIONS MADE BY HARDWIRED CONTROL SYSTEM

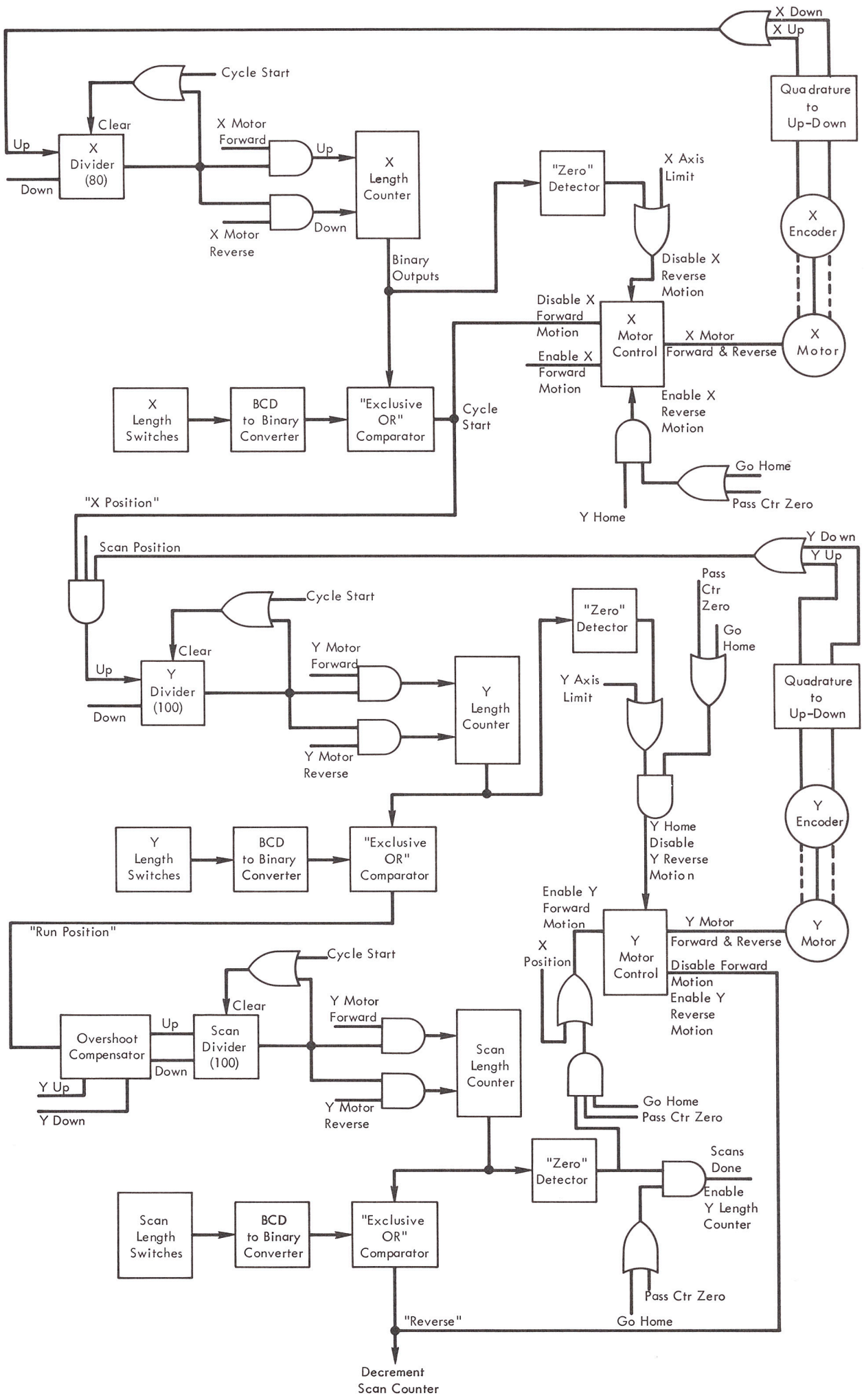


FIGURE 10

BLOCK DIAGRAM OF HARDWIRED CONTROL SYSTEM

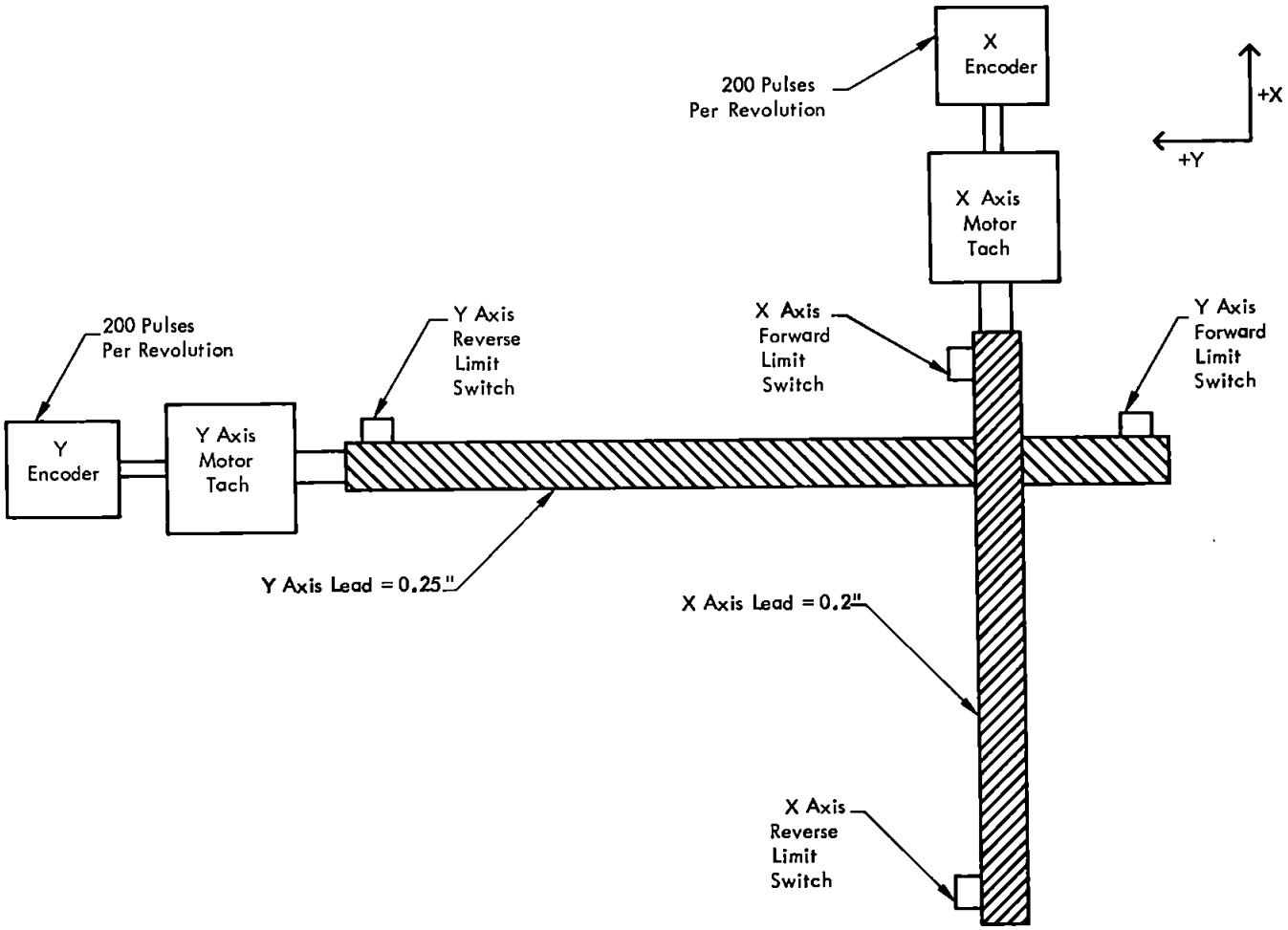


FIGURE 11

MACHINE AXES CONFIGURATION

The Y axis lead is 0.2 inch per revolution. Therefore, with an encoder output of 200 pulses per revolution, the Y axis travels 0.1 inch for every 100 pulses. For every 100 pulses accumulated by the Y divider, the Y counter is incremented and the Y divider is reset. As shown in Appendix B, Page 33, the 2^2, 2^5, and 2^6 outputs are not simply "anded." The additional circuitry is necessitated by timing considerations. During the Y motion, the contents of the Y length counter are continuously compared with the binary Y length register, and, when the two are equal, run position is asserted. This disables the Y divider and allows encoder pulses to be applied to the scan circuitry through the overshoot compensator which will be discussed in a succeeding section. The Y encoder pulses applied to the scan divider accumulate as previously described (Appendix B, Page 34), and the scan length counter is incremented for every 100 counts. When the counter contents equal the scan length input, reverse is asserted disabling forward motion, decrementing the scan counter, and enabling reverse Y motion. The reverse counts from the Y axis encoder are then accumulated (by incrementing the divider) until 100 pulses have been counted. This occurrence decrements the scan length counter, since the Y axis is moving in the reverse mode (the input is gated into the up or down counter input depending on the direction of motion), and clears the scan divider. The output of the scan length counter is continuously monitored by the zero detector, and when all zeroes are present, one complete scan has been accomplished. If additional scans are required (scan counter does not contain zero) or "go home" is not asserted (Figure 7, Page 14), reverse motion is disabled and forward motion is enabled. This process continues until one of the previously mentioned scan termination signals is asserted. Such assertion allows the Y axis motor to continue to run in the reverse mode with the encoder pulses incrementing the Y divider and each 100 count overflow decrementing the Y length and resetting the divider until all zeroes are contained in the Y length counter or the Y axis limit switch is asserted. When one of these conditions is met, the Y axis has returned to the Y home position and motion is disabled. Motion is

then initiated in the X reverse direction and continues until the X length counter contains all zeroes or the X limit switch is asserted. When such is the case, the required scanning has been completed, and the axes have returned to the home position.

The use of the overshoot compensator was alluded to in the previous discussion. For both X and Y length motion, the up and down encoder pulses are fed into an "OR" gate and are used to increment the divider. The direction of axis motion controls the incrementing or decrementing of the length counter. This method is adequate for the X and Y length motions, but with many repetitions of the scan motion, inertial overshoot of the Y axis can result in an appreciable error if the overshoot is not equal for both reversals. The circuitry required to solve this problem is illustrated in Appendix B, Page 36. Every time a forward pass is executed, and the turnaround point is reached, some counts are accumulated in the scan divider before the reversal is executed. The overshoot compensator allows encoder pulses to decrement the scan divider until it contains all zeroes. After this is accomplished, the scan divider accumulates encoder pulses and decrements the scan length counter for every 0.1 inch of reverse motion. When the scan length counter contains all zeroes, motion is reversed, but, as before, some overshoot occurs. The scan divider is again decremented to zero before the next scan counting begins.

The MCU of the controlled analog drive system essentially consists of a repetition of three control segments. By specifying a resolution of 0.1 inch and counting pulses at a rate of 100 pulses for 0.1 inch, a theoretical accuracy of 0.001 inch is realized for any of the Y motions. A theoretical accuracy of 0.00125 inch is realized for X axis motion. This far exceeds the accuracy requirements of the process for which the machine was designed ($\pm$ 0.100 inch).

Analog Axis Drive Systems

In discussing the function of the MCU, mention was made of the fact that the application of a + 3 volt signal to a relay driver enables motion. For the purposes of explanation, one scan will be traced from initiation to return to home. When the operator presses the cycle start button, a + 3 volt signal is applied to the base of the X forward relay driver transistor (Appendix C, Page 37). This saturates the transistor and energizes relay K2. The relay closure (Appendix C, Page 38) allows a negative input to be applied to the preamplifier the magnitude of which depends on the axis velocity selected. The amplified signal drives an 800-watt power amplifier which causes the X axis lead screw to rotate clockwise creating motion in the X forward direction (Figure 11, Page 19). When X position is reached, the signal is removed from the X forward driver and + 3 volts are applied to the base of the Y forward driver. This enables closure of relay K22 allowing motion in the Y forward direction. Such motion continues until reverse is asserted. Then the "1" signal is removed from Y forward and applied to Y reverse changing the sign of the input and reversing the direction of Y travel. When Y home is reached, the signal is removed from the Y reverse driver and applied to the base of the X reverse transistor enabling return to home position. The velocities of all the axes motions are calibrated by adjusting the loop gains of the amplifier system and the voltage applied at the input. Periodic checks of the velocities reveal that accuracies of ± 5 percent are maintained over an extended period of time with no short-term fluctuations. This is more than adequate for the particular application considered. Tachometer feedback is used only to provide stability and interacts in no way with machine positioning. No control is exercised over the spindle except manual on-off and rotational speed (Appendix C, Page 40).

Other Design Considerations

Limit Switch Closures. Limit switch closures at the travel extreme of both the X and Y axes serve a dual purpose on this machine. In the first place, they prevent overtravel and, therefore, protect against tooling damage in the event of a machine malfunction. Appendix C, Pages 37 and 38, illustrate how this is accomplished. For example, if the X forward limit switch is asserts relay K5 is energized. Further forward motion is now impossible since no voltage is available to the K2 relay coil.

The limit switch closures also provide input to the control logic preventing overtravel during the automatic operation and serving as a convenient and repeatable home position. Such utilization presents a problem since a very noisy relay closure must serve as an input to a noise-sensitive logic system. The circuitry used to solve this problem is shown in Appendix D, Page 41. These circuits convert a switch closure at + 24 volts into an isolated signal at + 5 volts via optical isolators. These isolators are four terminal devices that convert an electrical input signal into photon energy (via a light source) and reverse the conversion process through a photosensor producing an electrical output. Such isolation prevents the introduction of high frequency noise into the MCU.

Part Protection Interlocks. In any operation, there are certain malfunctions that must disable machine operations in order to prevent part destruction. For example, in a machining operation, if the spindle should cease to rotate or if the axes should stop, the part might be grooved. In order to protect against such occurrence, spindle rotation and axes motion interlocks are installed on the cylinder scanning system. The spindle rotation interlocks simply monitor the output of the tachometer. When it falls below a preset level, a transistor is saturated, energizing a relay coil and disabling process continuation.

The axis motion interlock incorporates more complex switching circuits. The control relay is driven by three circuits in a wired "OR" configuration (Appendix D, Page 42). The Y axis tachometer is monitored continuously, and the process is allowed to continue

when: (1) the Y axis is moving forward with a velocity above the threshold (positive voltage feedback), (2) the Y axis is moving in the reverse mode with the feedback above the threshold level, or (3) the machine is not executing the scan cycle. If none of these conditions are met, a relay closure discontinues process operation.

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

The system just described meets the design requirements with minimum complexity. The machine capability is to scan any size cylinder within the limits of machine travel with all inputs immediately accessible. No claim of added flexibility is made. Due to the minimum complexity, the system provides maximum reliability since no unnecessary parts disable machine performance. For these reasons, the programmable control system can be said to represent the best alternative for scanning cylinders.

The imposition of additional requirements would necessitate a reevaluation of alternative selection. For example, if the requirements were changed to demand simultaneous motion of the two axes, the MCU would have to be modified extensively. Instead of providing just an axis drive signal, a digital command signal would have to be generated essentially creating the system depicted in Figure 1 (Page 2). As the requirements of the process become more demanding, the trend toward justification of an NC system is evident.

The programmable control system for scanning cylinders was fabricated and has operated for about a year. Accuracies of $\pm$ 0.005 inch are realized from the start of an operation to its conclusion. The difference in theoretical and observed accuracies can be attributed to mechanical uncertainty of the limit switch closures and to random noise signals from relay closures. Whatever the source, the error is of no significance. Maintenance problems have been few and those that have occurred have been readily alleviated due to the simplicity of the system.

LIST OF REFERENCES

LIST OF REFERENCES

1. Gettelman, K. M., Editor; 1971 NC Guidebook and Directory; Gardner Publishing, Incorporated, Cincinnati, Ohio (1970).

2. Mark Century[a] Numerical Contouring Control; General Electric Company, Waynesboro, Virginia.

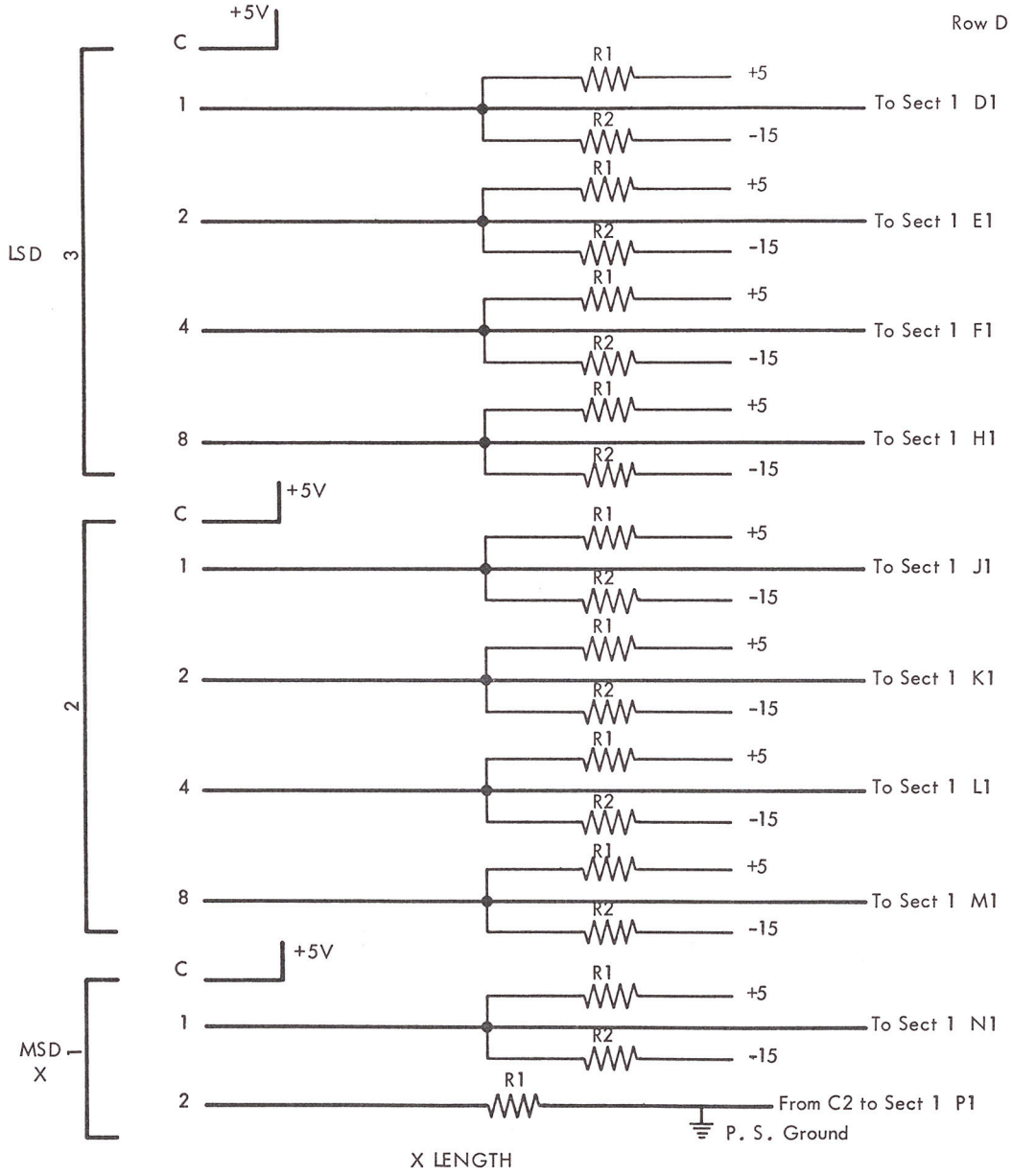
3. Bowers, G. L.; "Minicomputer Implementation of a Pulse-Train Generator for Two-Axis Contouring Control of a Machine Tool," Masters Thesis, The University of Tennessee, Knoxville, Tennessee; March 1973.

4. Kuo, B. C.; Theory and Applications of Step Motors; West Publishing Company, St. Paul, Minnesota (1974).

[a]Trademark of General Electric.

APPENDICES

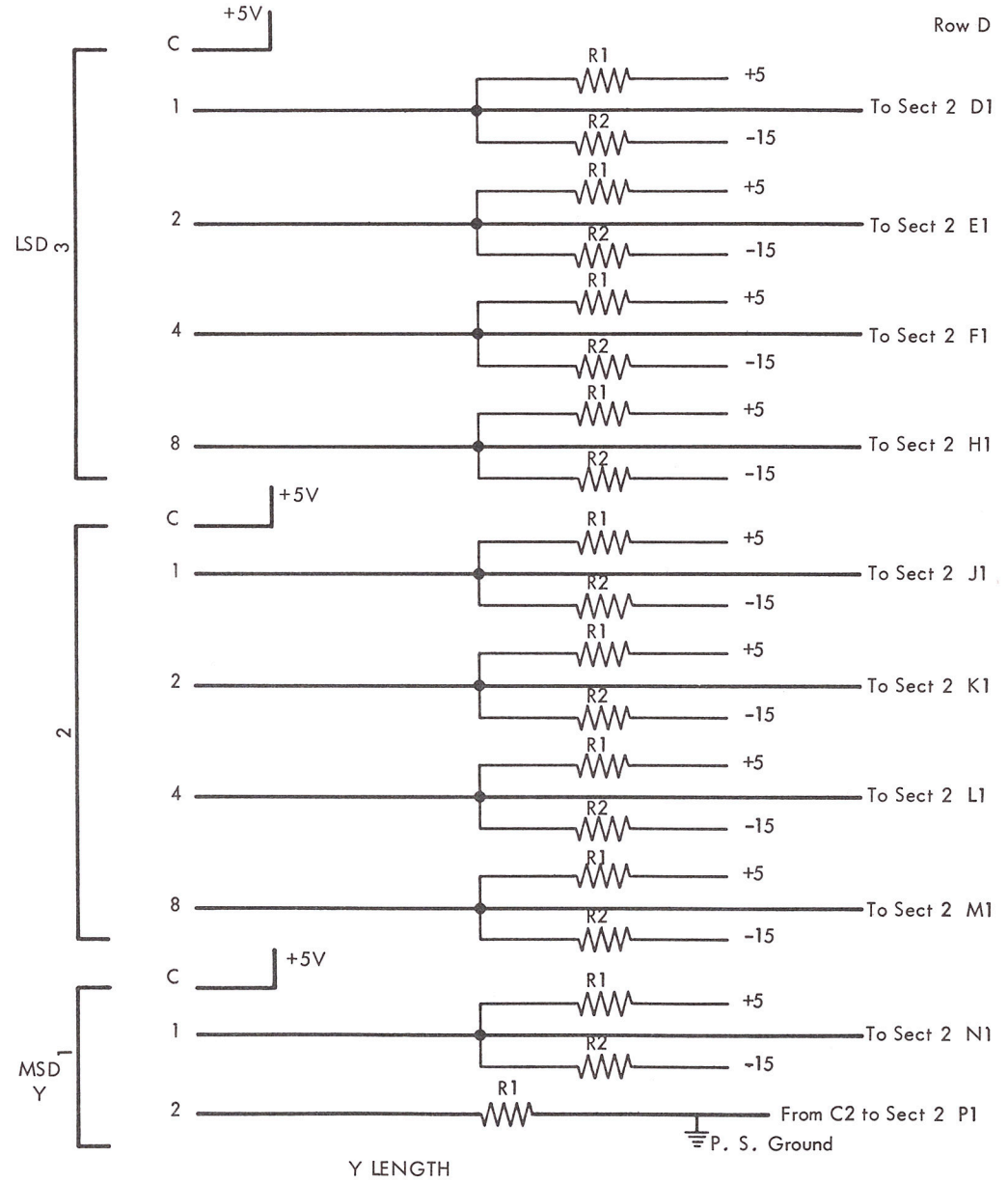
APPENDIX A



X LENGTH

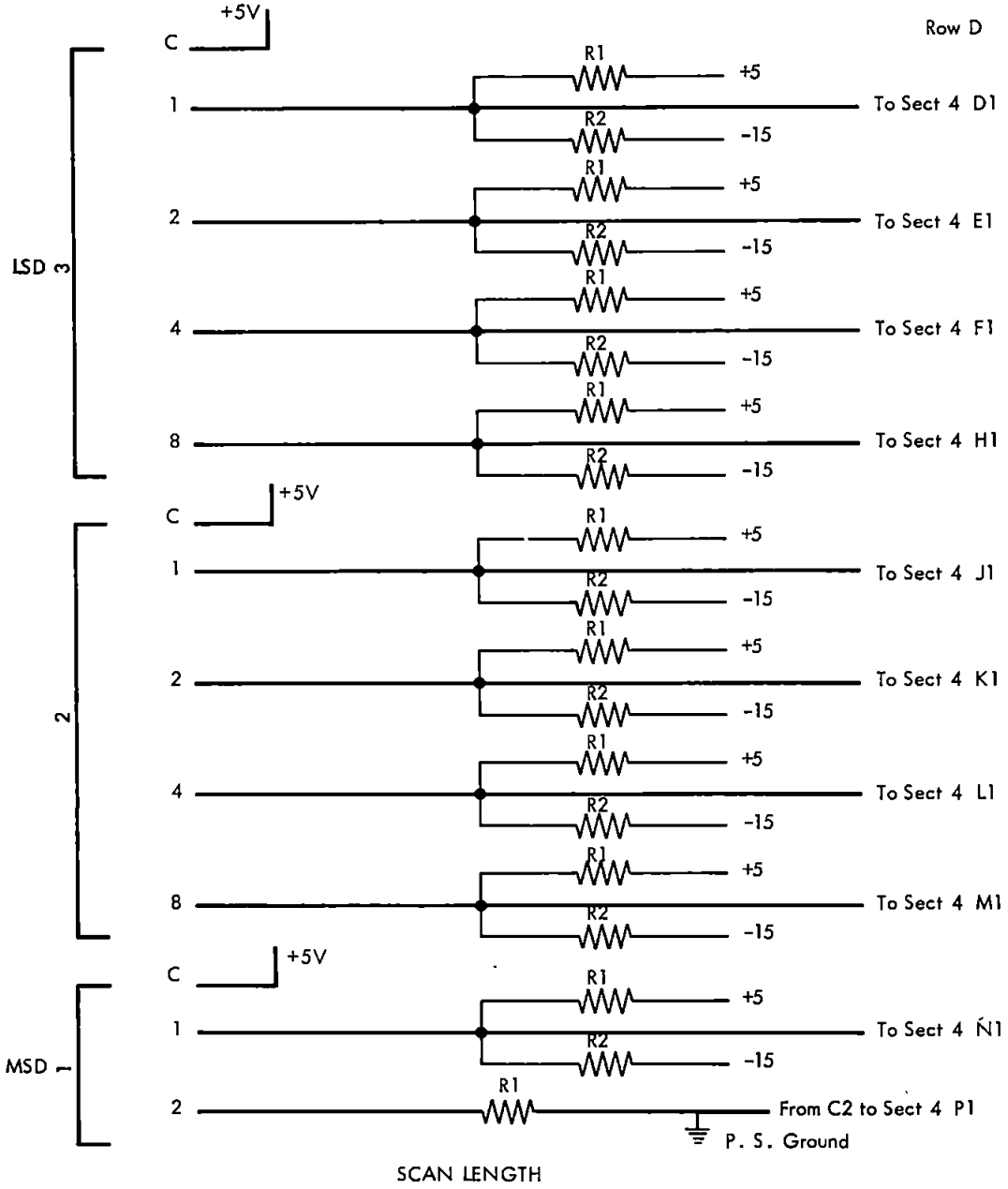
R1 and R2 to be 1/4 watt 1% Resistors
R1 = 3.3K
R2 = 6.2K

SWITCH INPUT



Y LENGTH

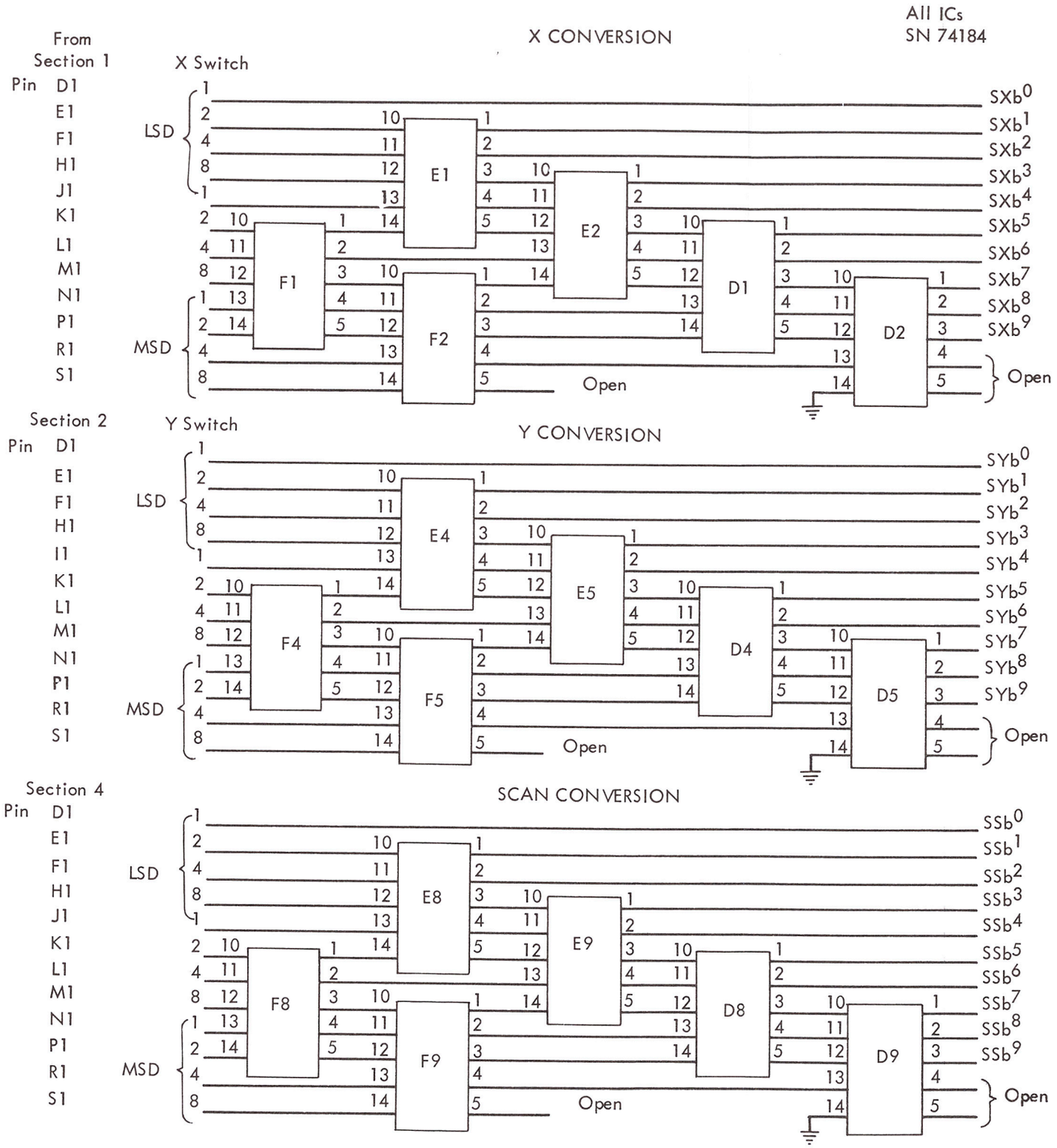
R1 and R2 to be 1/4 watt 1% Resistors
R1 = 3.3K
R2 = 6.2K



SCAN LENGTH

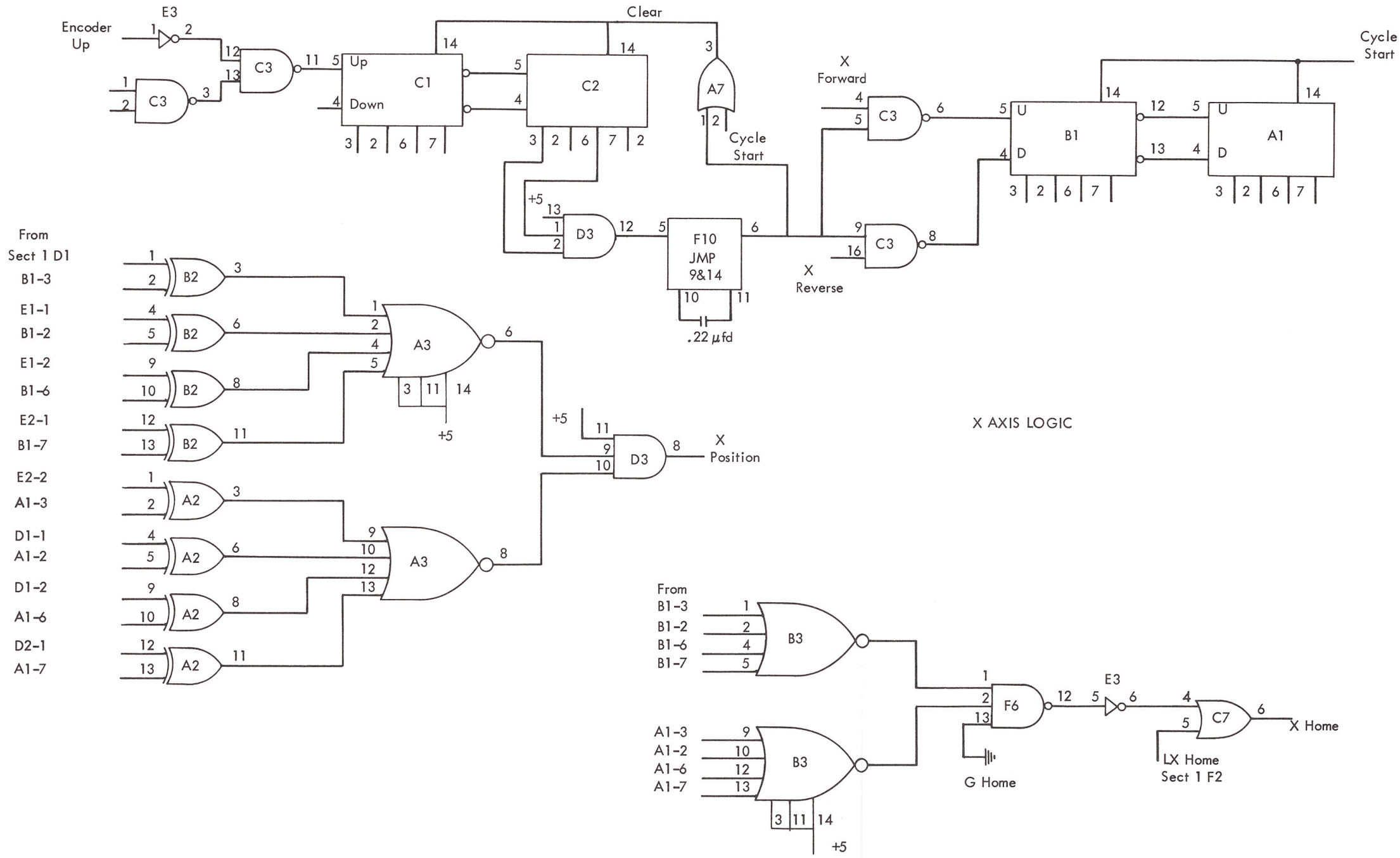
R1 and R2 to be 1/4 watt 1% Resistors
R1 = 3.3K
R2 = 6.2K

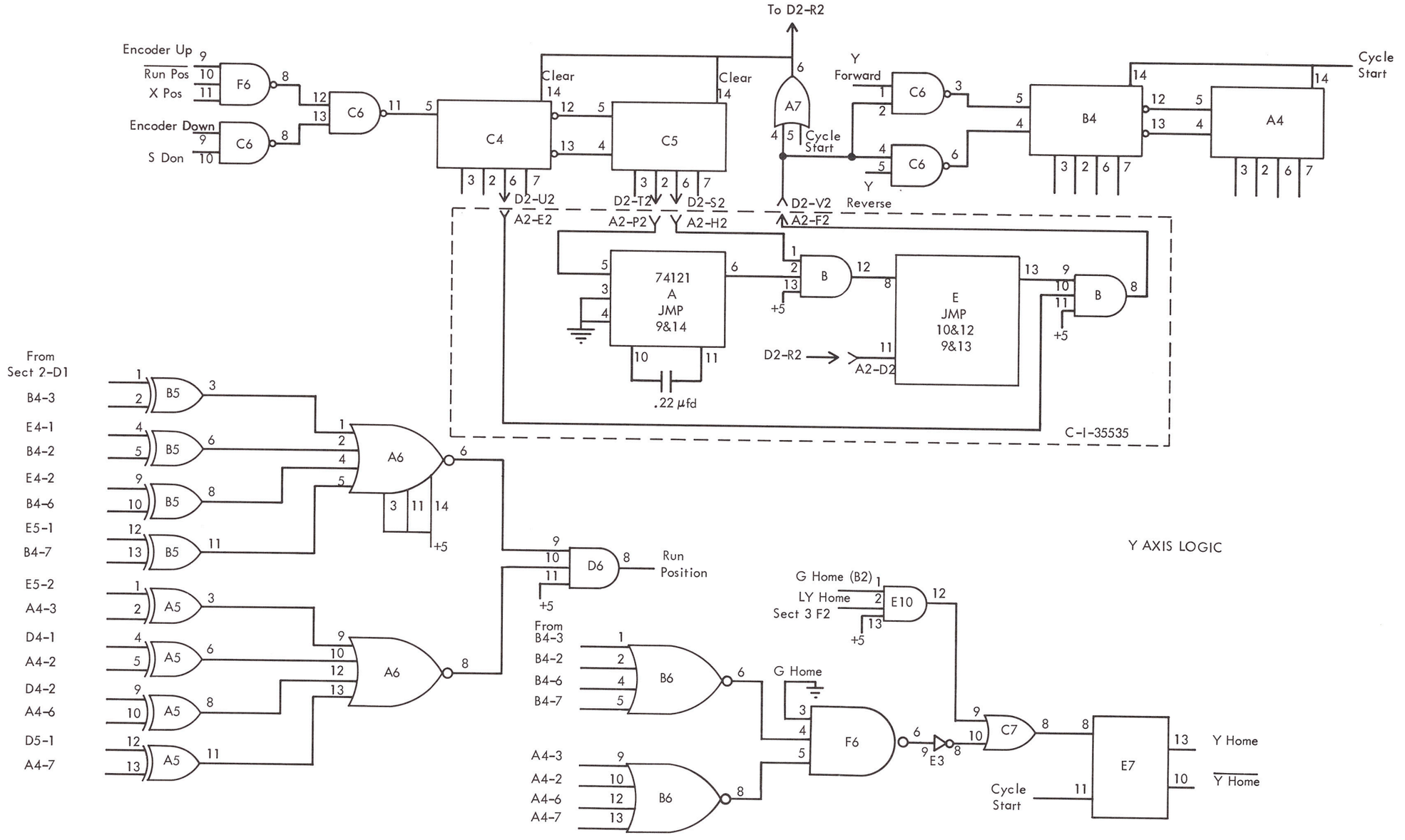
All ICs
SN 74184

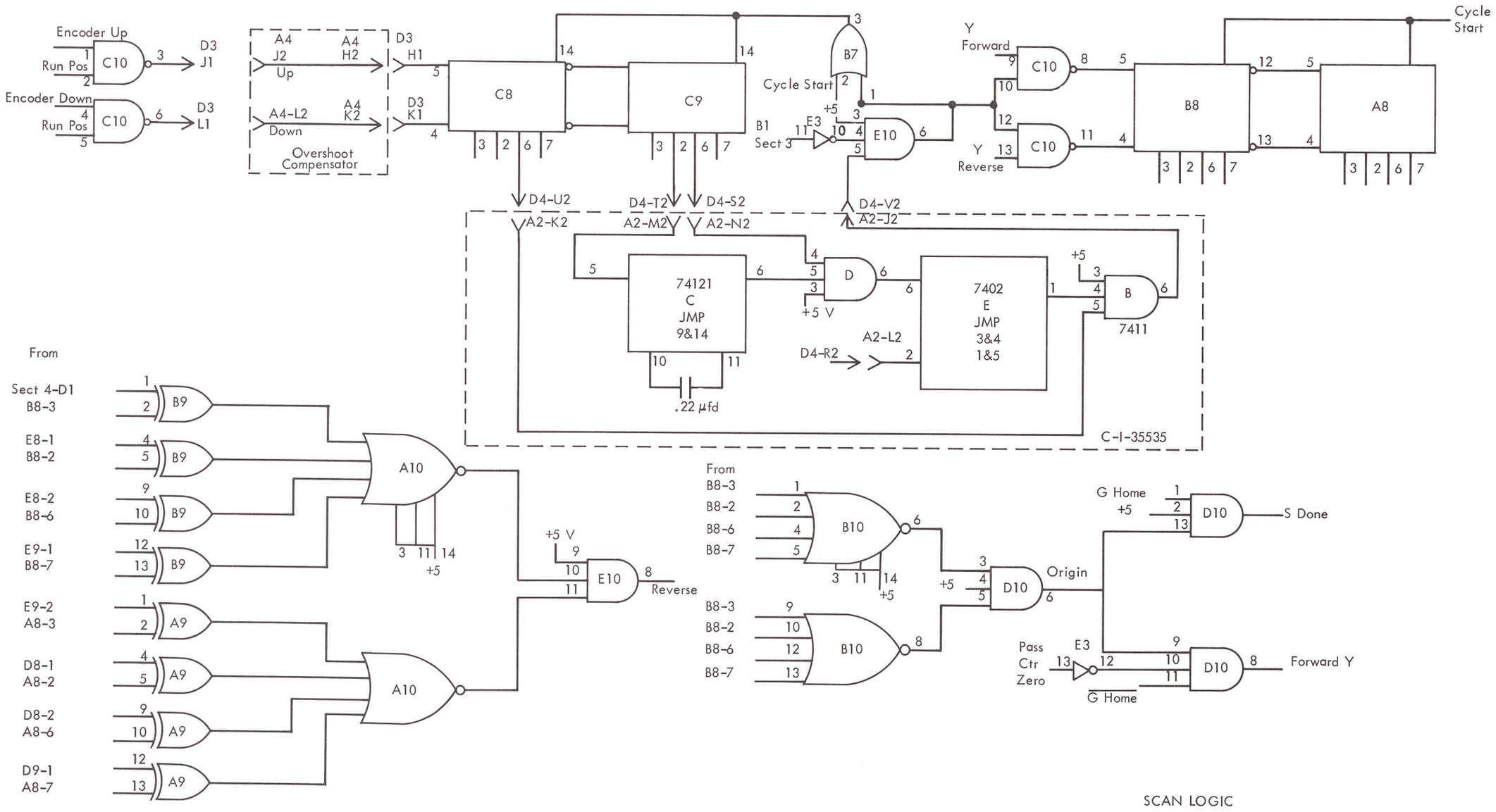


INPUT CONVERSION - BCD TO BINARY

APPENDIX B

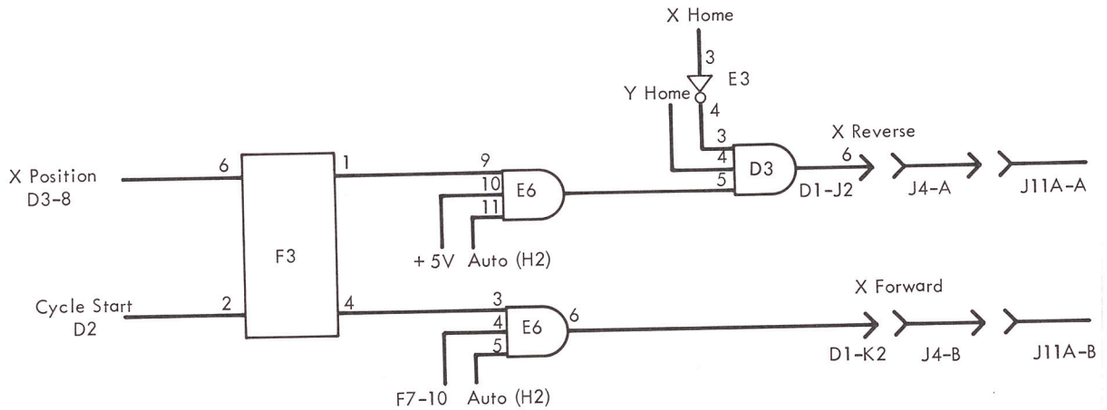

Encoder Up
E3
C3
C3
C1
Up
Down
C2
Clear
A7
Cycle Start
X Forward
C3
B1
A1
Cycle Start
+5
D3
F10 JMP 9&14
.22 µfd
X Reverse
C3
From Sect 1 D1
B1-3
E1-1
B1-2
E1-2
B1-6
E2-1
B1-7
E2-2
A1-3
D1-1
A1-2
D1-2
A1-6
D2-1
A1-7
B2
A2
A3
+5
D3
X Position
X AXIS LOGIC
From
B1-3
B1-2
B1-6
B1-7
A1-3
A1-2
A1-6
A1-7
B3
F6
E3
C7
G Home
LX Home
Sect 1 F2
X Home

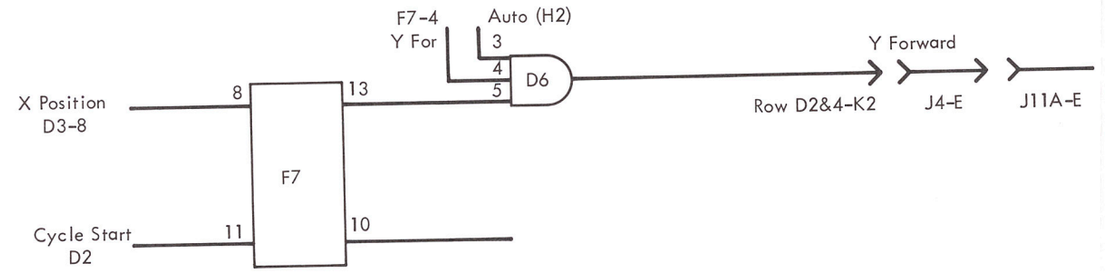

To D2-R2
Encoder Up
Run Pos
X Pos
Encoder Down
S Don
F6
C6
C6
C4
C5
Clear
Clear
A7
Cycle Start
Y Forward
C6
C6
Y Reverse
B4
A4
Cycle Start
D2-U2
A2-E2
D2-T2
A2-P2
D2-S2
A2-H2
D2-V2
A2-F2
74121 A JMP 9&14
.22 µfd
B
B
+5
+5
E JMP 10&12 9&13
D2-R2
A2-D2
C-I-35535
From Sect 2-D1
B4-3
E4-1
B4-2
E4-2
B4-6
E5-1
B4-7
E5-2
A4-3
D4-1
A4-2
D4-2
A4-6
D5-1
A4-7
B5
B5
B5
B5
A6
A5
A5
A5
A5
A6
+5
D6
Run Position
+5
Y AXIS LOGIC
From
B4-3
B4-2
B4-6
B4-7
A4-3
A4-2
A4-6
A4-7
B6
B6
G Home
G Home (B2)
LY Home
Sect 3 F2
E10
+5
F6
E3
C7
E7
Cycle Start
Y Home
Y Home

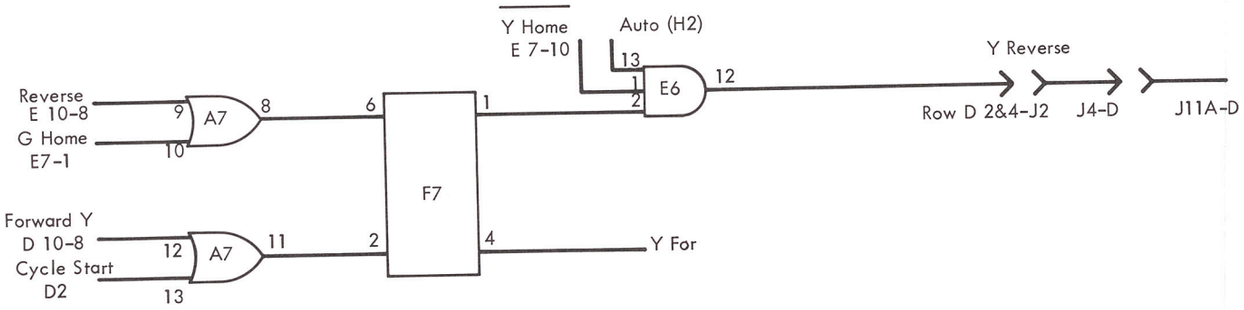

Encoder Up
Run Pos
C10
D3 J1
Encoder Down
Run Pos
C10
D3 L1
A4 J2 Up
A4 H2
D3 H1
A4-L2 Down
A4 K2
D3 K1
Overshoot Compensator
C8
C9
B7
Cycle Start
B1 Sect 3
E3
E10
Y Forward
Y Reverse
C10
C10
B8
A8
Cycle Start
D4-U2
D4-T2
D4-S2
D4-V2
A2-K2
A2-M2
A2-N2
A2-J2
74121 C JMP 9&14
.22 µfd
D
+5 V
7402 E JMP 3&4 1&5
A2-L2
D4-R2
B
7411
C-I-35535
From
Sect 4-D1
B8-3
E8-1
B8-2
E8-2
B8-6
E9-1
B8-7
E9-2
A8-3
D8-1
A8-2
D8-2
A8-6
D9-1
A8-7
B9
A9
A10
A10
+5 V
E10
Reverse
From
B8-3
B8-2
B8-6
B8-7
B8-3
B8-2
B8-6
B8-7
B10
B10
D10
Origin
G Home
+5
D10
S Done
Pass Ctr Zero
E3
D10
Forward Y
G Home

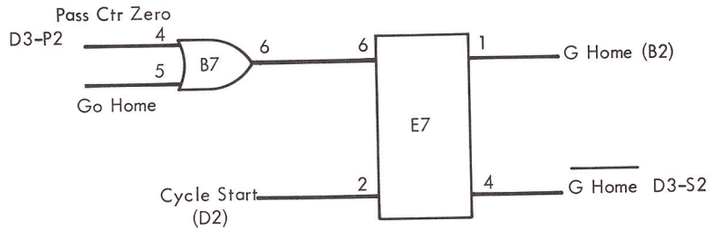
SCAN LOGIC

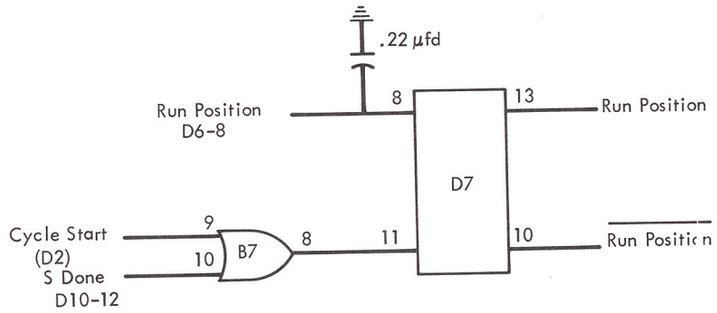
All Flops 7402 Jmpr. 3&4 and 1&5
on Each Chip

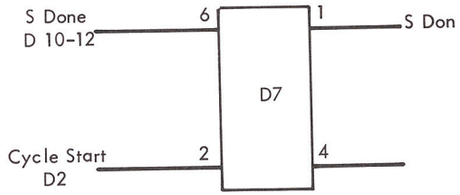


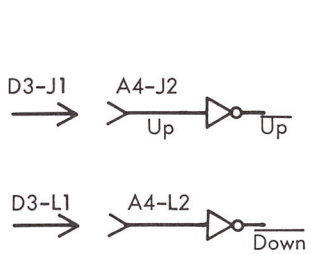


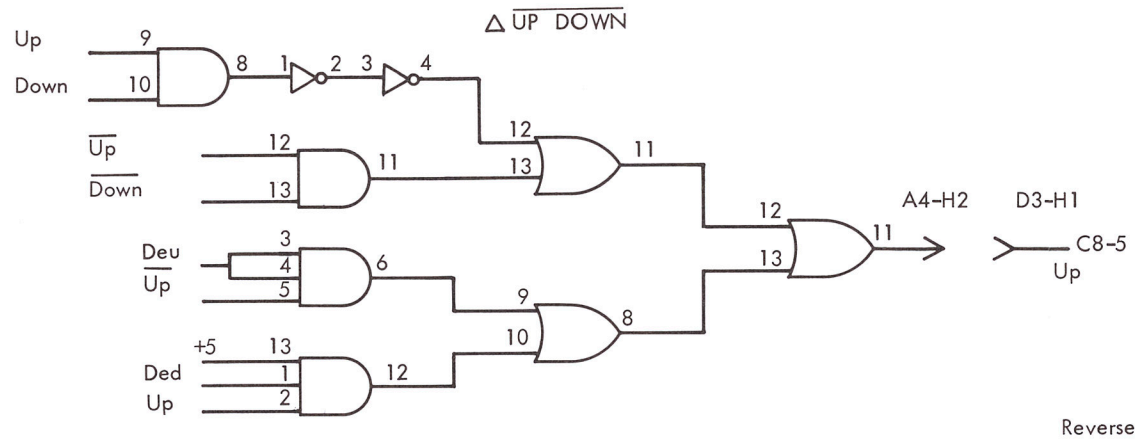


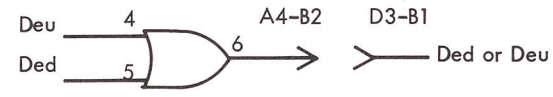


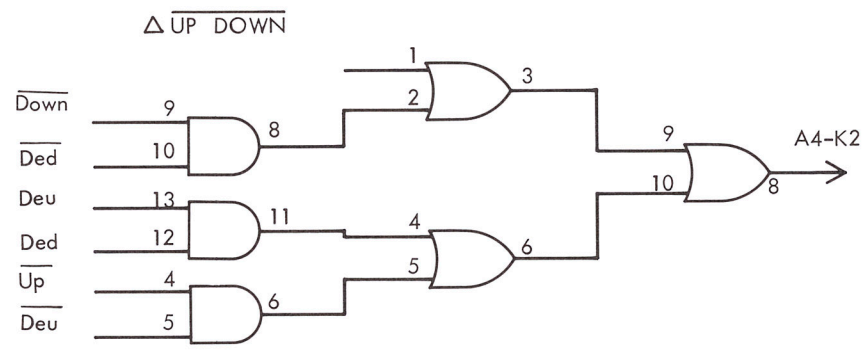


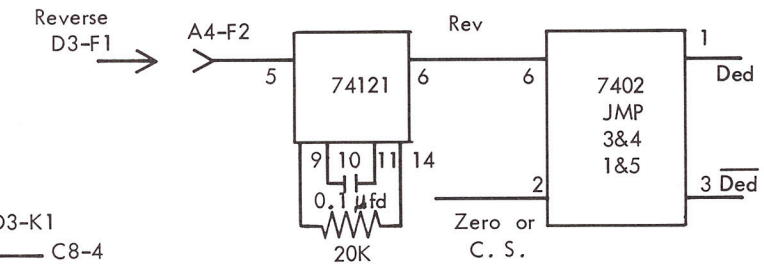


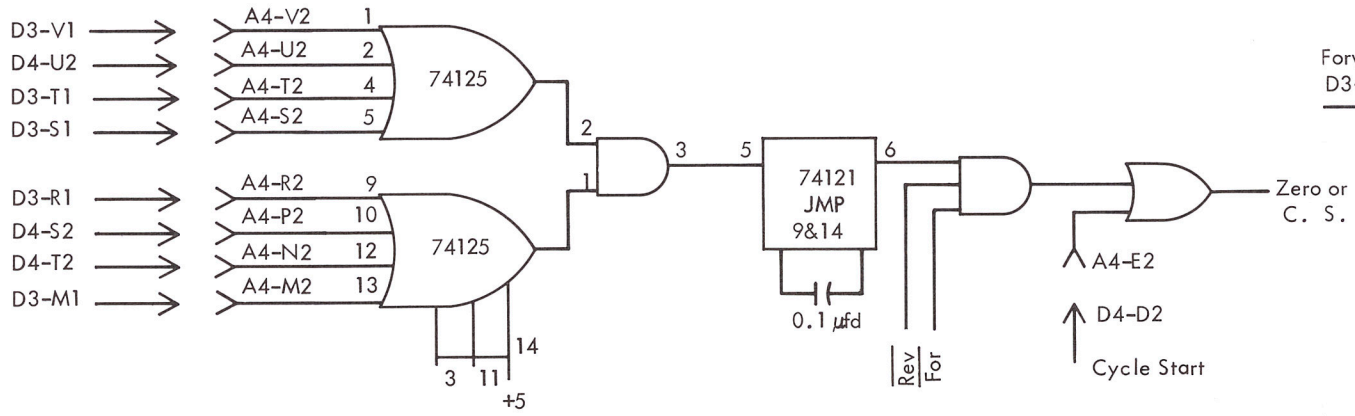


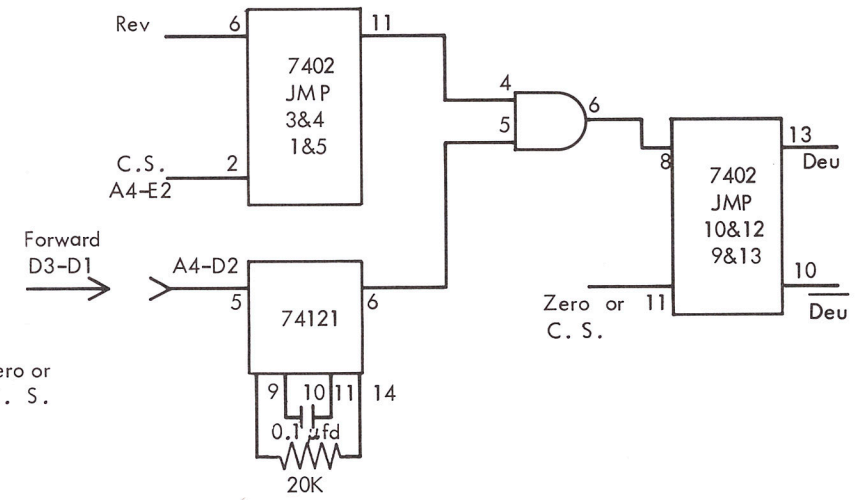










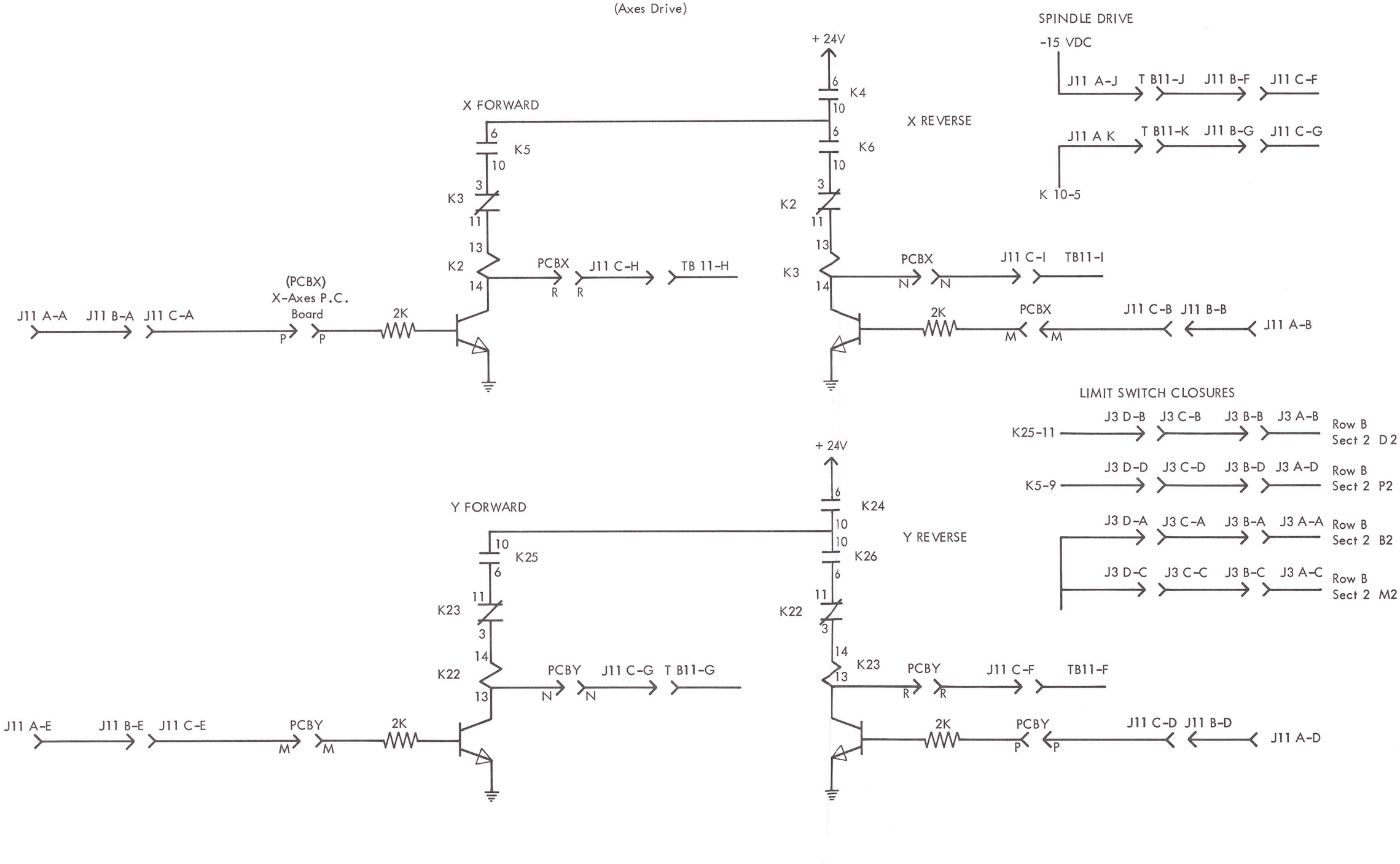


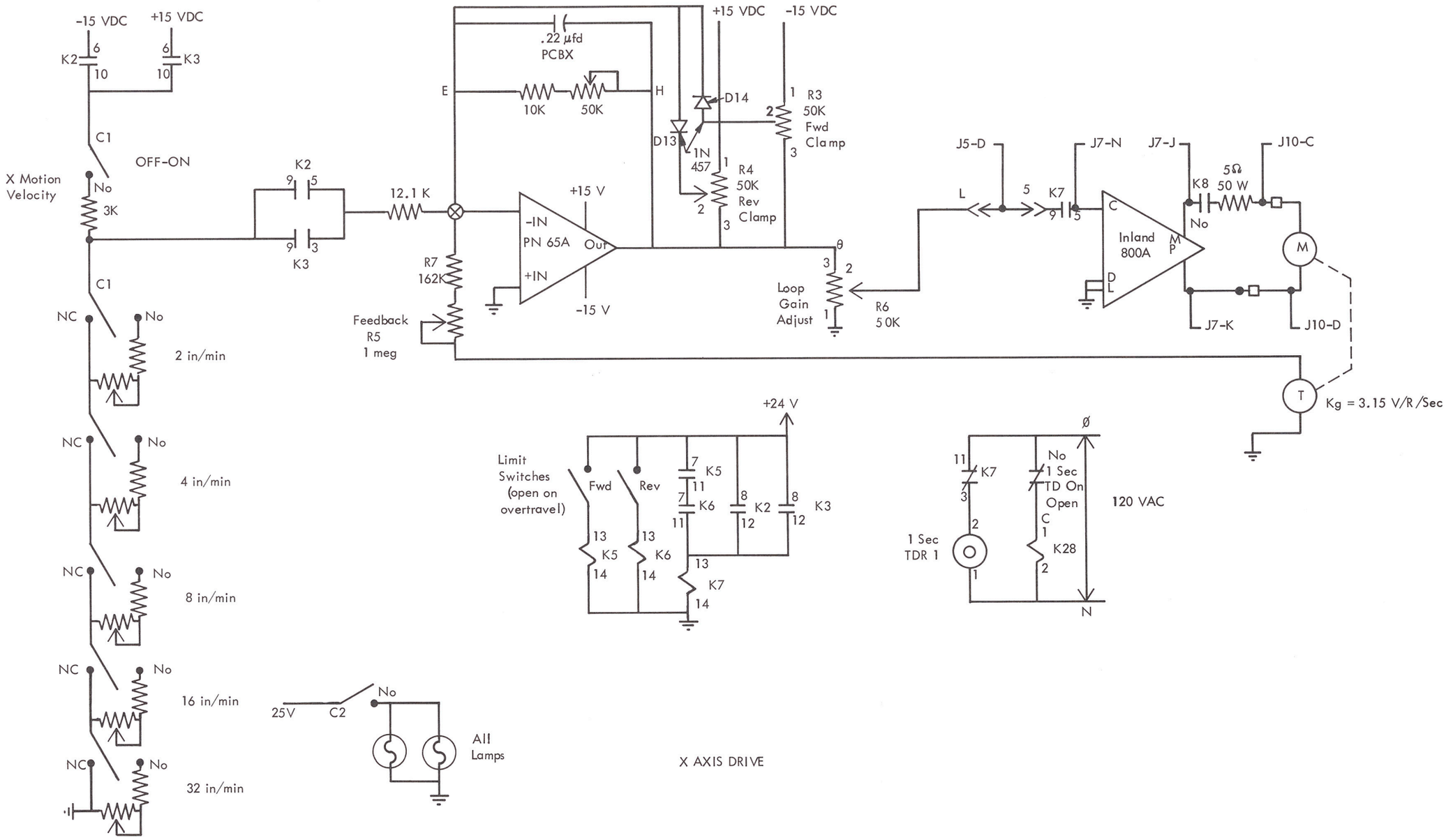
OVERSHOOT COMPENSATOR

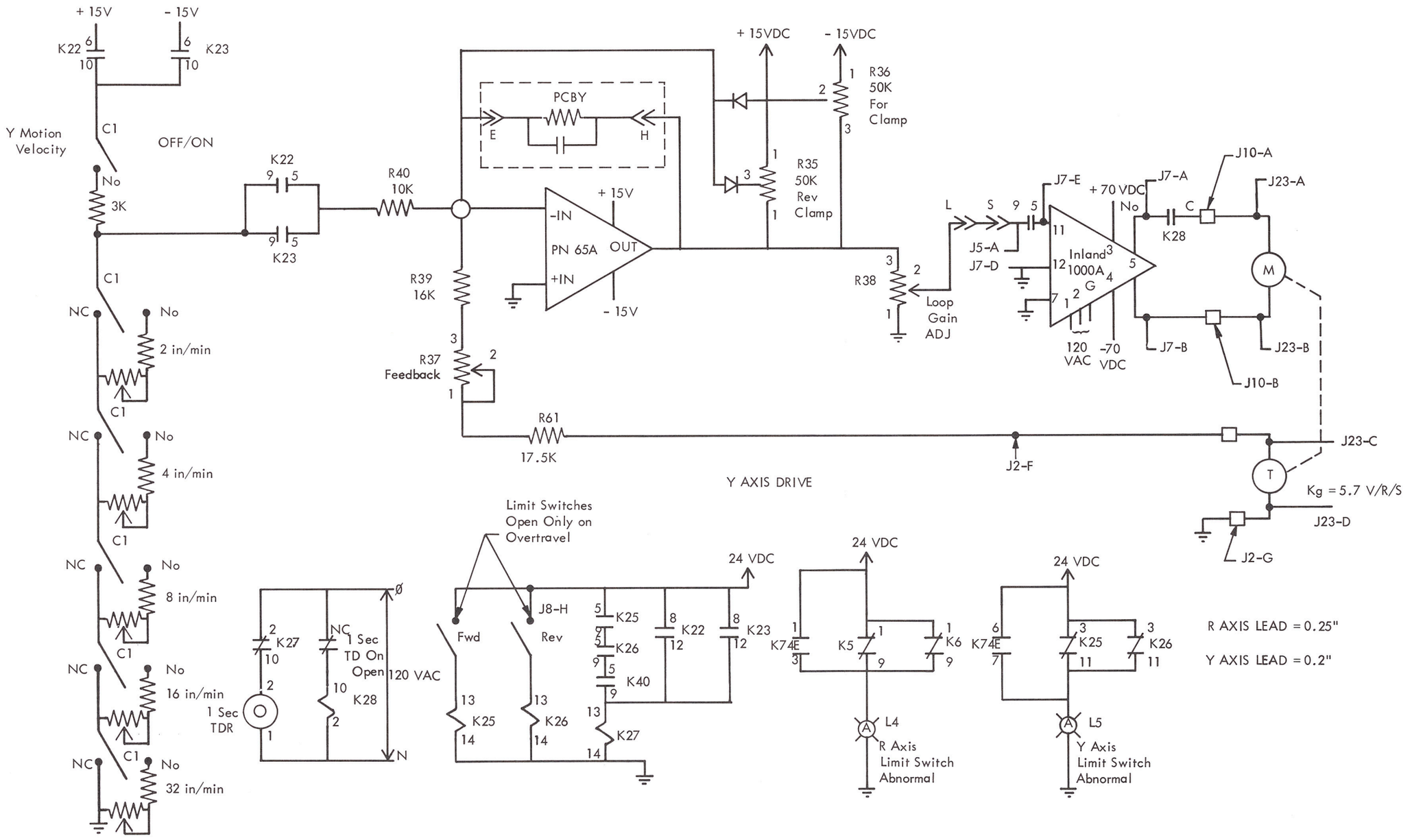
D-I-50850

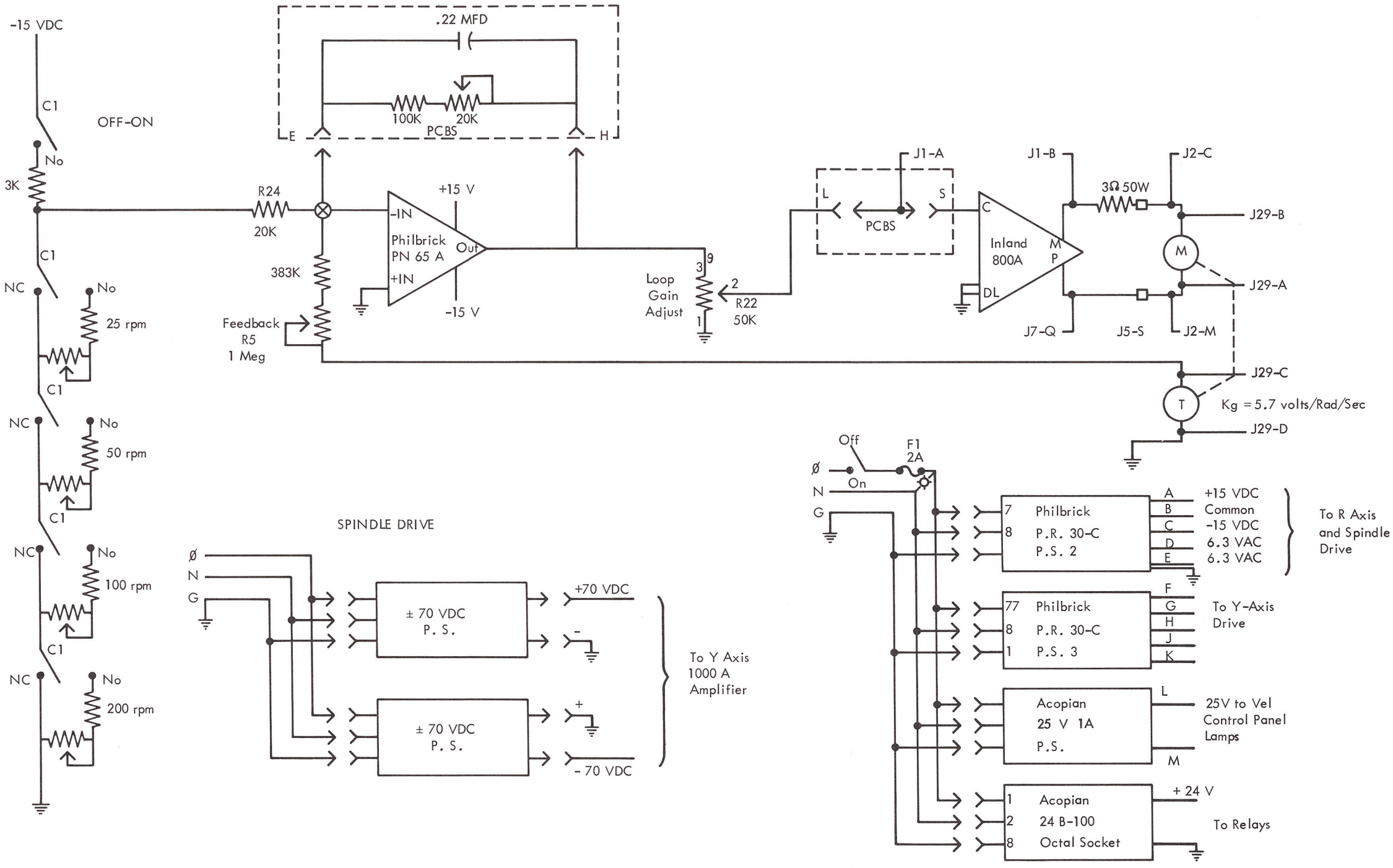
APPENDIX C

MODIFICATIONS TO RELAY CONTROL PANEL
(Axes Drive)

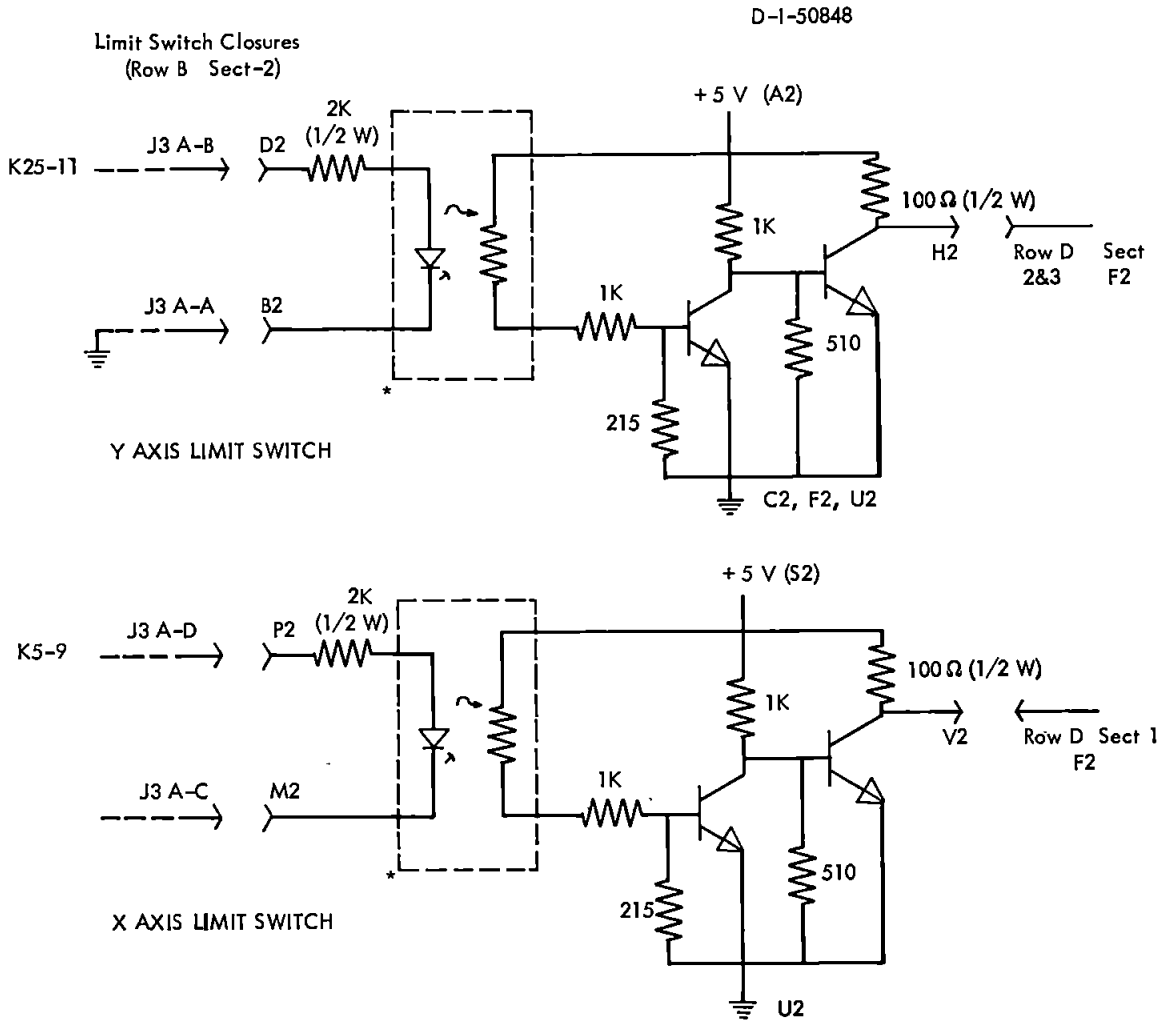



-15 VDC
+15 VDC
K2
K3
C1
OFF-ON
X Motion Velocity
No
3K
K2
K3
12.1 K
.22 µfd
PCBX
E
H
10K
50K
+15 V
-15 V
-IN
+IN
PN 65A
Out
R7
162K
Feedback
R5
1 meg
D13
1N
457
D14
R4
50K
Rev
Clamp
R3
50K
Fwd
Clamp
Loop
Gain
Adjust
R6
50K
J5-D
J7-N
J7-J
J10-C
L
K7
K8
5Ω
50 W
Inland
800A
M
P
D
L
J7-K
J10-D
M
T
Kg = 3.15 V/R/Sec
NC
No
2 in/min
4 in/min
8 in/min
16 in/min
32 in/min
+24 V
Limit
Switches
(open on
overtravel)
Fwd
Rev
K5
K6
K2
K3
K7
1 Sec
TDR 1
K28
No
1 Sec
TD On
Open
120 VAC
Ø
N
25V
C2
All
Lamps
X AXIS DRIVE


+ 15V
- 15V
K22
K23
Y Motion Velocity
OFF/ON
C1
No
3K
NC
2 in/min
4 in/min
8 in/min
16 in/min
32 in/min
1 Sec TDR
K27
1 Sec TD On
Open
120 VAC
K28
R40
10K
PCBY
E
H
R39
16K
R37
Feedback
R61
17.5K
-IN
+IN
PN 65A
OUT
+ 15VDC
- 15VDC
R36
50K
For
Clamp
R35
50K
Rev
Clamp
R38
Loop
Gain
ADJ
J5-A
J7-D
J7-E
J7-A
J7-B
J10-A
J10-B
J23-A
J23-B
J23-C
J23-D
+ 70 VDC
Inland
1000A
120
VAC
-70
VDC
K28
M
T
Kg = 5.7 V/R/S
J2-F
J2-G
Y AXIS DRIVE
Limit Switches
Open Only on
Overtravel
J8-H
Fwd
Rev
K25
K26
K40
K22
K23
K27
24 VDC
K5
K6
K74E
L4
R Axis
Limit Switch
Abnormal
L5
Y Axis
Limit Switch
Abnormal
R AXIS LEAD = 0.25"
Y AXIS LEAD = 0.2"


-15 VDC
C1
OFF-ON
No
3K
C1
NC
No
25 rpm
C1
NC
No
50 rpm
C1
NC
No
100 rpm
C1
NC
No
200 rpm
.22 MFD
100K
20K
PCBS
E
H
R24
20K
383K
Feedback
R5
1 Meg
+15 V
-IN
Philbrick
PN 65 A
Out
+IN
-15 V
Loop
Gain
Adjust
3
2
1
R22
50K
J1-A
L
PCBS
S
C
Inland
800A
M
P
DL
J1-B
3Ω 50W
J2-C
J29-B
M
J29-A
J7-Q
J5-S
J2-M
J29-C
T
Kg = 5.7 volts/Rad/Sec
J29-D
SPINDLE DRIVE
ø
N
G
± 70 VDC
P. S.
+70 VDC
-
± 70 VDC
P. S.
+
- 70 VDC
To Y Axis
1000 A
Amplifier
Off
On
F1
2A
ø
N
G
7
8
Philbrick
P.R. 30-C
P.S. 2
A
B
C
D
E
+15 VDC
Common
-15 VDC
6.3 VAC
6.3 VAC
To R Axis
and Spindle
Drive
77
8
1
Philbrick
P.R. 30-C
P.S. 3
F
G
H
J
K
To Y-Axis
Drive
Acopian
25 V 1A
P.S.
L
M
25V to Vel
Control Panel
Lamps
1
2
8
Acopian
24 B-100
Octal Socket
+ 24 V
To Relays

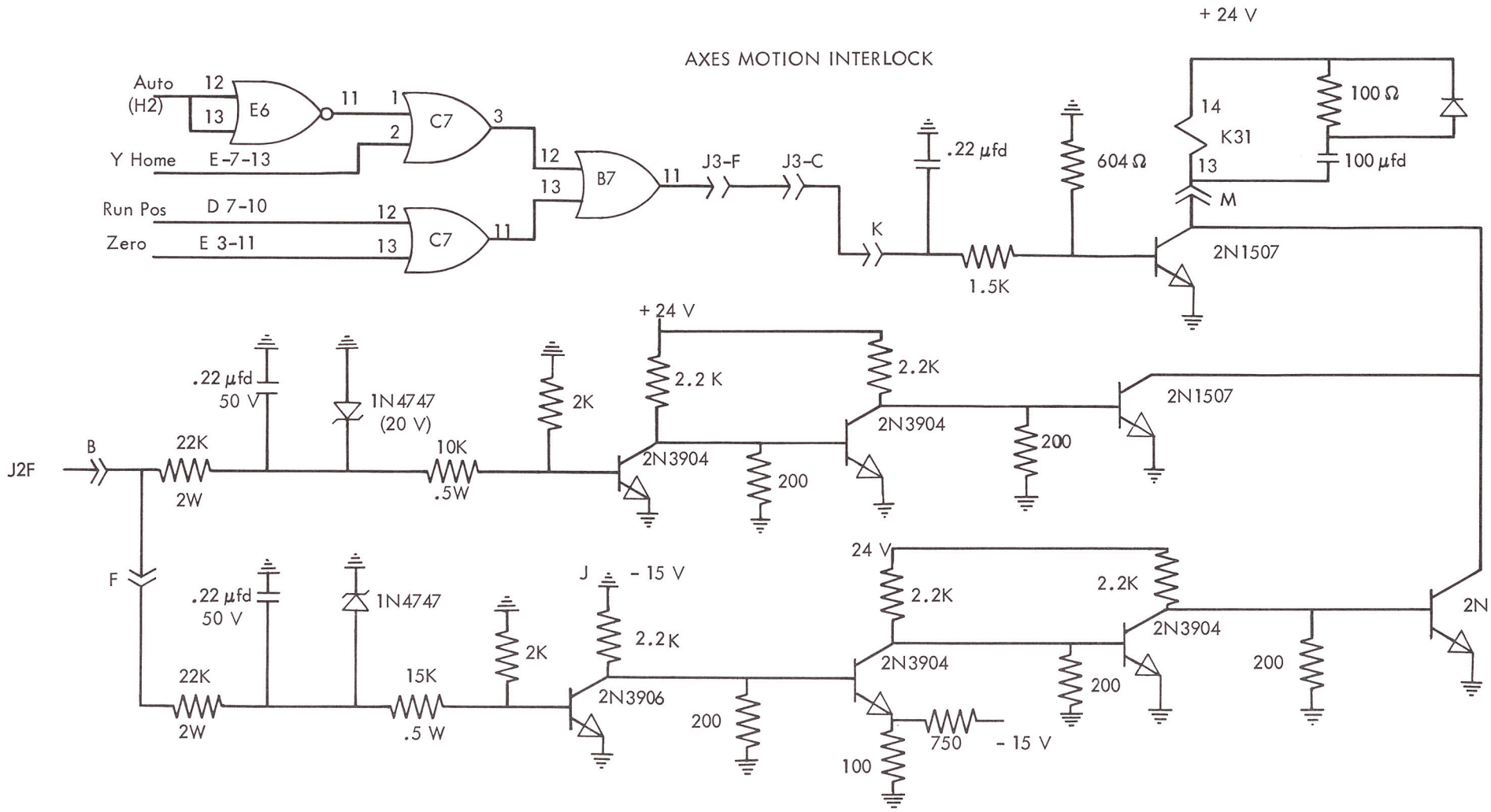
APPENDIX D



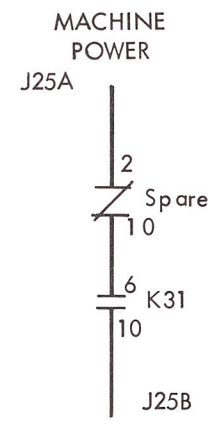
*Allen Bradley Type PT001 Led Optical Isolators.

All Resistors 1/4 Watt Except Where Specified
All Transistors 2N3904

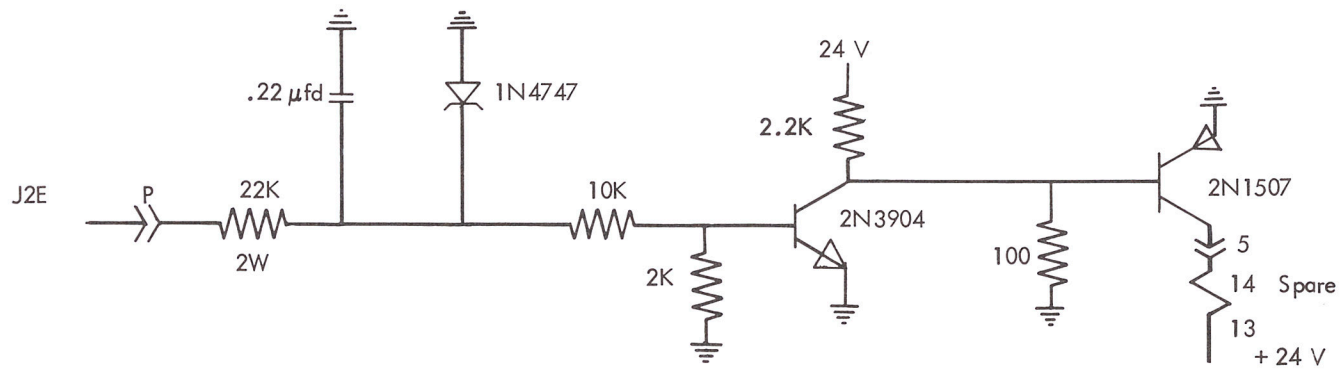
AXES MOTION INTERLOCK



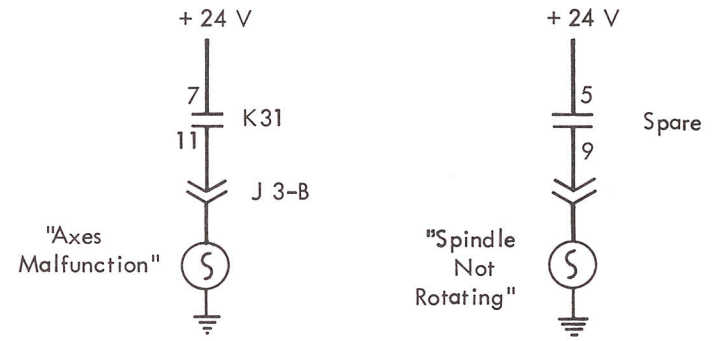
MACHINE POWER



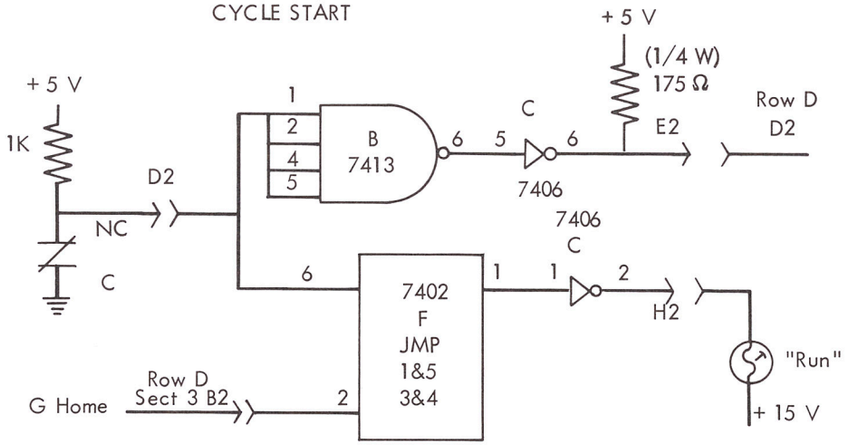
SPINDLE ROTATION INTERLOCK



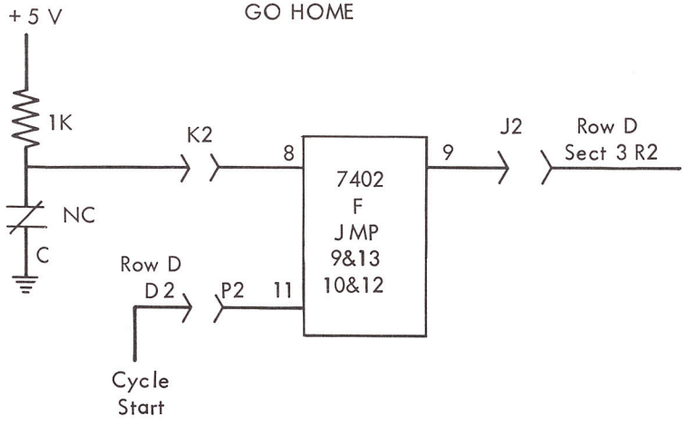
LIGHTS



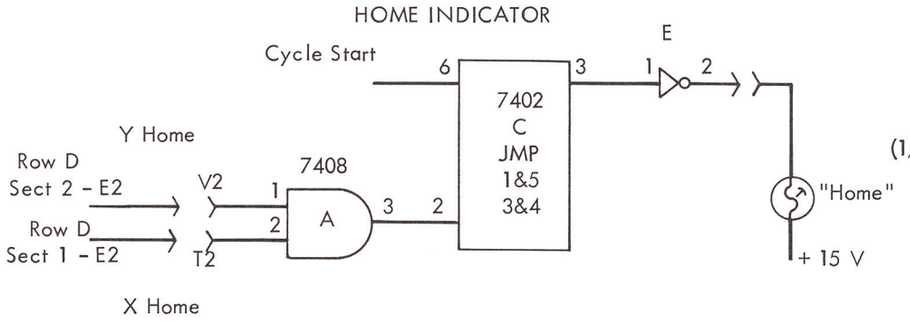
CYCLE START



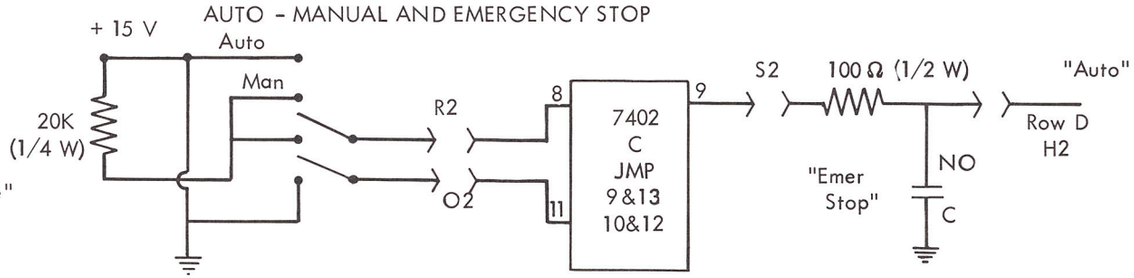
GO HOME



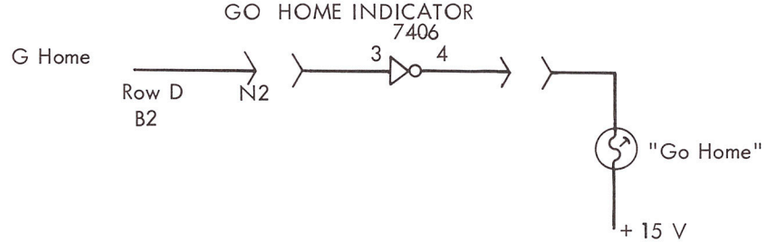
HOME INDICATOR



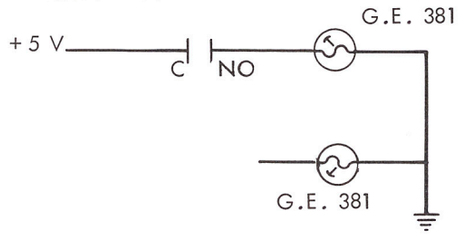
AUTO - MANUAL AND EMERGENCY STOP



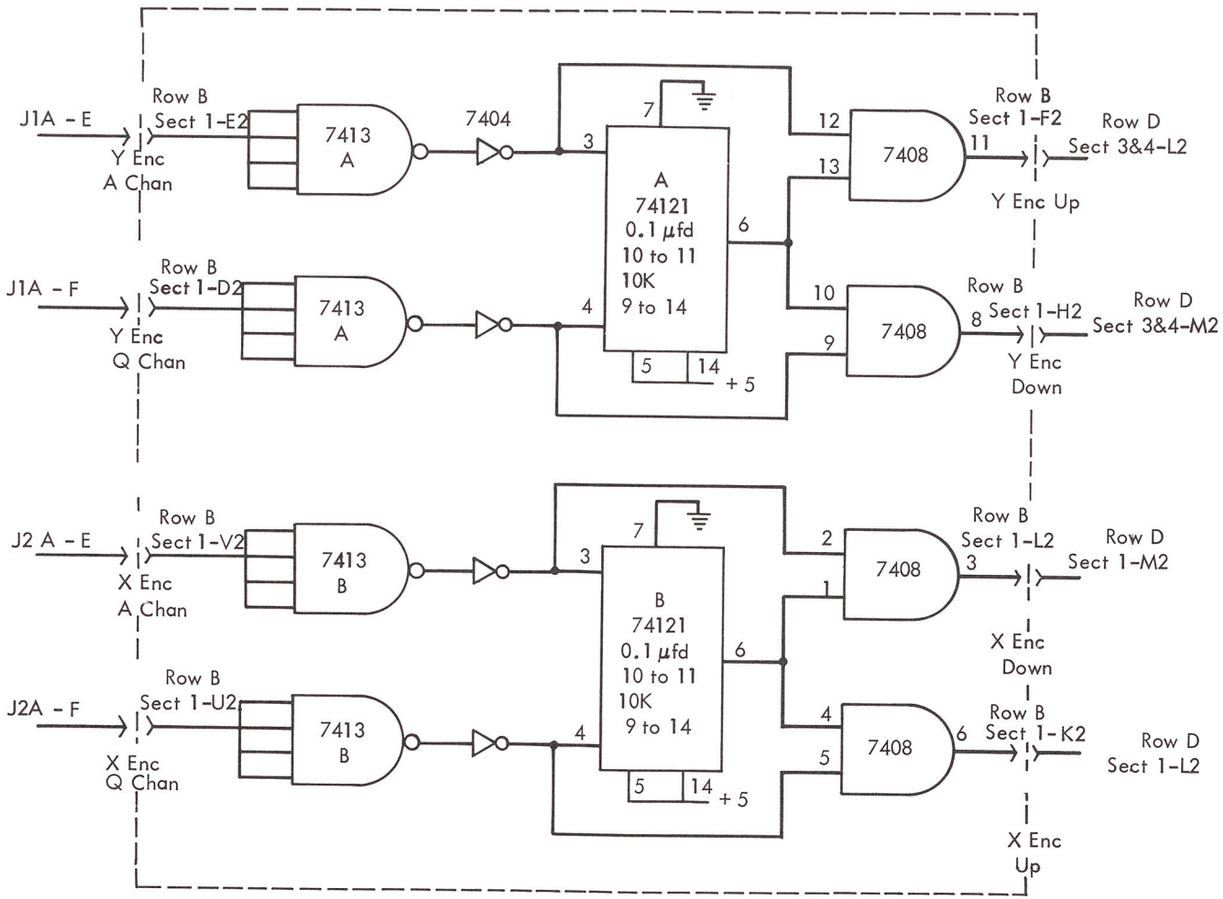
GO HOME INDICATOR



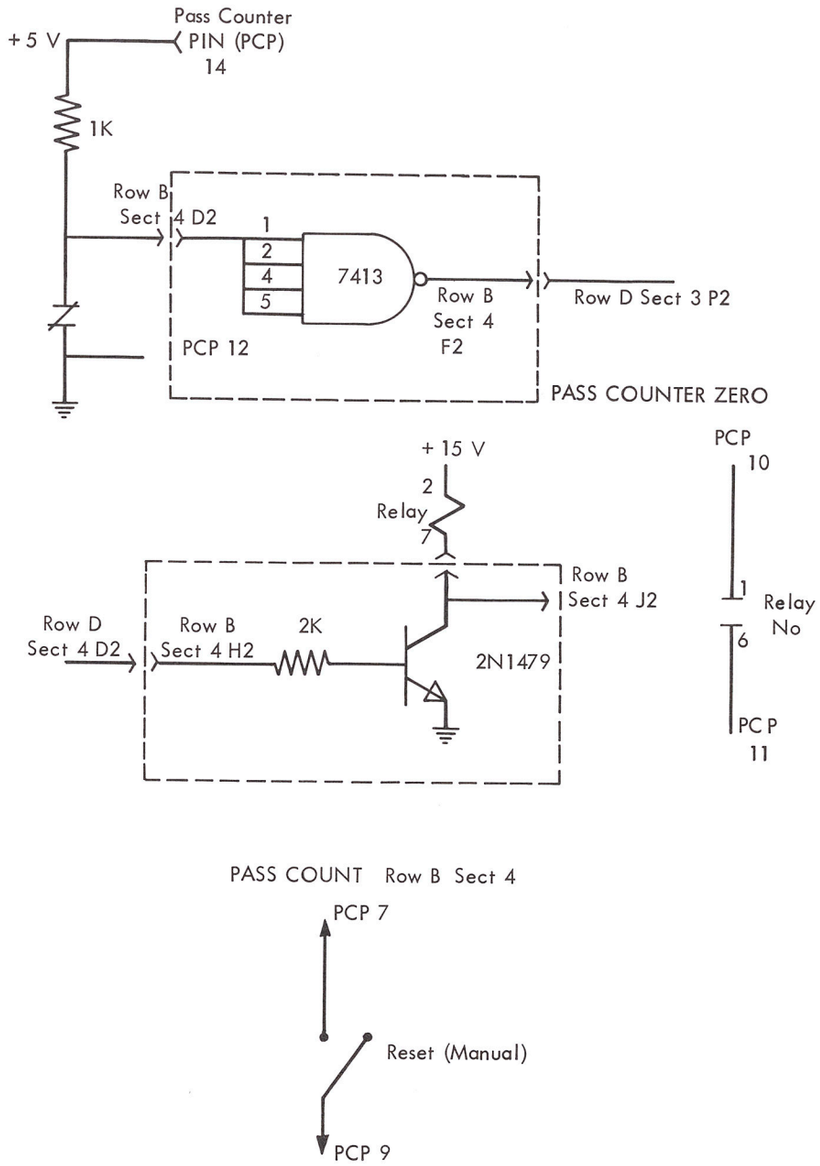
SWITCH LIGHTS



QUADRATURE CONVERTERS



PASS COUNTER CONNECTIONS



VITA

Richard Earl Neal was born in Shelbyville, Tennessee on September 2, 1946. He attended Tech Training Elementary School in Cookeville, Tennessee and was graduated from Fulton High School in Knoxville, Tennessee in 1964.

In March 1967 he entered The University of Tennessee and received a Bachelor of Science degree in Electrical Engineering in June 1970. He then accepted employment with Union Carbide Nuclear Division in Oak Ridge, Tennessee and began part time study on a Master of Science Degree in Electrical Engineering. He is a member of Tau Beta Pi.

He is married to the former Brenda Kay Scarbrough of Harriman, Tennessee.