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# HYBRID COMPUTER SIMULATION FOR THE INVESTIGATION OF THE AUTOMATIC STEERING OF A TWIN DRUM COAL SHEARER BY MICROCOMPUTER

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## ABSTRACT

The process by which a single drum longwall coal-cutting system is steered vertically through an undulating coal seam has been previously investigated. This work demonstrated initially that several discrepancies existed between theoretical models and actual performance. It was shown theoretically that the delay between the coal thickness measurement by nucleonic sensor and the actual cutting action contributes to system instability. Analysis of the process has demonstrated that by storing the previous pass data on a remote computer the system can be stabilised and this has been substantiated by the use of a $\frac{1}{4}$-scale physical model.

Recently the possibility of the automatic steering of a twin-drum shearer cutting simultaneously the roof and floor of the coal seam has been considered. From theoretical considerations it seems possible that a local microcomputer can achieve the required optimum control of the twin-drum shearer dispensing with the remote computer.

For the purposes of analytical studies, a hybrid computer simulation of the process allowing for bi-directional cutting and the associated microcomputer control system have been constructed and is described in this report. The model and controller have been constructed to represent realistically the operation required in the difficult environment at the coal face.

Hybrid Computer Simulation for the Investigation of the Automatic Steering of a Twin Drum Coal Shearer by Microcomputer


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## 1. INTRODUCTION

Evolving from the mechanisation of coal mining since the Second World War, the longwall face cutter now accounts for over 85% of the total annual production of coal in Britain. As a natural development, attempts have been made to automatically control the vertical steering of the cutter along the coal face.

In 1972 Bogdadi[1] investigated the problems that had arisen and showed theoretically that, due to the distance lag between the cutter and the nucleonic coal seam thickness sensor, the system was unstable. Based upon this theory, Bogdadi showed that by employing data storage in a remote computer, the system could be stabilised and an optimum control algorithm produced.

However, some discrepancies between control behaviour in practise and theory existed and these were investigated with the aid of a ¼-scale model resulting in suggestions being offered for their cause and partial elimination.

Further papers by Edwards and Bogdadi[2-3], and Edwards[4] developed the theory associated with instability arising in multipass processes similar to the coal cutter considered here.

Some of the discrepancies between theory and practise are explained in a paper by Edwards and Greenberg[5] by considering the effect of the semi-flexible conveyor and geometrical offset of the cutter upon system stability, and a further paper[6] by the same authors extends analysis a little further.

The knowledge gained in the analysis of the single-drum cutter is now being used in considering the automatic control of a twin-drum cutter. From theoretical considerations it appears that this system can be stabilised by a local controller not requiring the extensive data storage, and hence a remote computer, as for the single-drum system. However this will be covered in another research report.

This present report is concerned with the hybrid simulation model of the twin-drum process and the associated local controller. The whole system is constructed with due consideration of the actual operating conditions existing at the coal face and also for ease of system analysis. The simulation allows for uni-directional or bi-directional cutting of the coal.

The hybrid computer installation employed for the simulation is an Electronic Associates 500 hybrid computer comprising a 581 analogue computer linked through a control and data interface to a Pacer 100 digital computer with disc store, V.D.U., teletype and high speed paper tape station. The Pacer 100 possesses 16K words of 16 bits and the disc has a storage capacity of 2.2M words. The data interface consists of a 16 channel ADC and 8 D.A.C.'s. Further details of the hybrid hardware are available in EAI documentation.

System software for the installation comprises a disc operating system handling Fortran IV, Assembler, Hybrid Operations Interpreter (HOI), Library routines and Diagnostics.

The process controller is based upon an Intel MCS4 Microcomputer with the necessary interface cards. Development of the controller software is undertaken using an Assembler on an Intellec 4 development system.

A description of the coal cutter simulation and the associated controller design is given in the remainder of this report.

## 2. DESCRIPTION OF THE COAL CUTTER

### 2.1 Mathematical Model of the Coal Cutter

Figure 2.1 shows diagramatically the Twin Drum Coal Shearer proceeding along the coal face.

The positions of the two cutting heads are determined by the along face and face advance tilts of the cutting machine, the conveyor position above the datum and the positions of the two jacks.

The direction of rotation of the cutting heads are such as to force the machine on to the skids at the rear of the direction of movement. So when the cutter is moving to the right the face advance tilt is determined by the left hand skids and vice-versa.

The height of the bottom of the lower or left drum at the next cut i.e. cut (n+1) is given by

$$\begin{aligned} Y_L(n+1,\ell) + Z(n+1,\ell) = {} & e(n,\ell+R) \\ & + \text{FACE ADVANCE TILT} \\ & + (\text{ALONG FACE TILT})\ R/F \\ & + J_L\ (n,\ell) \end{aligned} \qquad (2.1)$$

assuming that the conveyor width and drum width W are identical and

where FACE ADVANCE TILT either

$$= |e(n,\ell+R)-e(n-1,\ell+R)| \text{ cutter moving right}$$

$$\text{or} \quad = |e(n,\ell+R+F)-e(n-1,\ell+R+F)| \text{ cutter moving left} \qquad (2.2)$$

and ALONG FACE TILT is either

$$|e(n, \ell +R)-e(n,\ell+F+R) \qquad (2.3a)$$

$$\text{or} \quad |e(n-1,\ell+R)-e(n-1,\ell+F+R)| \qquad (2.3b)$$

determined as follows.

When moving to the right, it is the smallest of (2.3a) and (2.3b)

When moving to the left, it is the largest of (2.3a) and (2.3b).

Similarly the height of the bottom of the right hand drum at the next cut i.e. cut (n+1) is given by

$$\begin{aligned} Y_R(n+1,\ell+F+2R) + Z(n+1,\ell+F+2R) = {} & e(n,\ell+R) \\ & + \text{FACE ADVANCE TILT} \\ & - (\text{ALONG FACE TILT})\ \frac{R+F}{F} \\ & + J_R\ (n,\ell+F+2R) \end{aligned} \qquad (2.4)$$

where FACE ADVANCE TILT and ALONG FACE TILT are defined in equations (2.2) and (2.3).

When required for roof cutting information, the height of the top of the drum above the coal seam floor is given by

$$Y_L'(n+1,\ell) = Y_L(n+1,\ell) + D_m \quad (2.5)$$

and $$Y_R'(n+1,\ell+F+2R) = Y_R(n+1,\ell+F+2R) + D_m \quad (2.6)$$

For simulation purposes, therefore, it is necessary to store conveyor heights along the whole coal face both for the front and rear of the conveyor pans. This data is derived from the floor cut data allowing for the positioning of the semi-flexible conveyor pans as they are jacked over on to the freshly cut floor coal.

From equations (2.5) and (2.6) it is possible to derive the thickness of coal left at the roof after cutting.

At the left hand cutter this is given by,

$$V_L(n+1,\ell) = D_s(n+1,\ell) - Y_L'(n+1,\ell) \quad (2.7)$$

and the right hand cutter

$$V_R(n+1,\ell+F+2R) = D_s(n+1,\ell+F+2R) - Y_L'(n+1,\ell+F+2R) \quad (2.8)$$

## 2.2 Design for Bi-directional Cutting

To allow for bi-directional cutting, the mechanical design of the cutting heads and nucleonic sensors must allow for the sensor to pass over its associated cutting head to ensure that it always lags the cutting head when the cutter is moving.

In addition to moving the sensor or probe arm, the sensor can be retracted from the coal face or positioned for reading. When retracted the nuclear source is shielded.

For simulation purposes it is assumed that on demand from the controller the probe arm will change position with a small time delay before acknowledging to the controller that the movement is completed.

In the case of the probe positioned or retracted it is assumed in the simulation model that upon controller demand, the sensor movement is always completed instantaneously.

A sketch of the suggested sensor arrangement is shown in figure 2.2.

### 2.3 Machine Protection

In practise, devices to check successful start of cutting heads etc would be incorporated. In the simulation model it is assumed that these protection devices would trip the cutter master supply relay. Under these conditions the controller is arranged to take safety action, the master supply relay being simulated by a manually operated switch.

## 3. HYBRID COMPUTER SIMULATION OF THE PROCESS

### 3.1 Simulation System Design

In order to produce a theoretical control study that exhibits some usefulness in its application it is necessary to inject some realism, as well as the underlying mathematics, into the mode of operation of the simulation model. Since the continuous nature of the coal cutting process has previously been converted into a discrete nature by sampling process variables at specific intervals along the coal face, the simulation model can be conveniently arranged in the following way:

a) The analogue part of the hybrid computer is scaled in terms of height above a datum level with computer time representing length along the coal face when the cutter is moving.

b) Historical data in terms of height above datum is stored in the digital computer against length along the coal face.

c) This historical data is combined on the analogue computer to give simulation of coal cutter tilt in two dimensions and hence the amount of coal cut.

d) Local control of the simulation model is achieved by an Intel MCS4 microcomputer with provision for remote control by digital computer although at this stage this is considered unnecessary.

e) The nucleonic sensors are simulated in real time, including the necessary random nature and distance lag, by the digital computer and then passed to the controller.

A block diagram of the simulation system design is shown in figure 3.1.

## 3.2 Pacer 100 Simulation Routines

### 3.2.1 Interrupt Executive Routine

The executive routine has to organise the following tasks.

a) Run the sensor simulation routine using a pseudo-random generator entered on a real time basis.

b) Run the machine simulation routine based upon distance along the coal face.

c) Produce an along face distance pulse for control purposes.

d) On command from the Pacer 100 console jump to the initialisation section of the executive or the run part of the executive.

The executive flow chart is shown in figure 3.2.

On normal start of the simulation run, the initialisation executive requests, via the Pacer 100 console, the dimensions of the coal cutter machine and the initial position of the conveyor above the datum and assumes that the position of the cutter along the coal face is at the extreme left hand position.

When this initialisation process is complete, the executive requests which routine the operator then requires. Normally the request would be to move to the run executive.

In this mode the simulation software is under control of a timer on the analogue computer and the micro-computer via four sense lines. Every 10 msec. the interrupt routine is entered and a very short pseudo-random number generator routine executed then used by the sensor simulation routine. If the cutter controller has requested forward travel of the machine, the recorded position of the cutter is increased by one, or if reverse travel is requested the cutter position is reduced by one. If the cutter is stationary the interrupt servicing routine returns to the main program.

In the process geometry routine, the distance between data storage of the process is specified. When the recorded cutter position is a multiple of this distance the interrupt servicing routine hands control to the simulation routine. A typical distance between storage of data is 2cm which at an average cutter speed of 5m/min is covered in 240msec. Therefore when the cutter is moving in one direction the simulation routine will be entered every 24th entry of the interrupt executive. It is essential therefore that this simulation routine is completed in less than this time.

Also in the process geometry routine, it is possible to specify the number of entries required of the simulation routine before generating an along face pulse for control purposes. If for example control action is required every 10cm along the coal face, the simulation routine part of the executive would generate an along face pulse every fifth entry.

Once the simulation routine has been completely executed in less than its re-entry time, the executive interrogates the space bar of the console, which when depressed will inhibit the master interrupt and pass control back to the initialisation executive.

At the end of a pass, jacking over to the next pass position is achieved by pressing the console space bar and then running the conveyor fitting routine. This initialises the left hand and right hand cut data blocks to simulate manual preparation of the next pass.

### 3.2.2 Process Geometry Routine

The process geometry routine allows for variations in the dimensions of the coal cutter and also for the distance between data storage and generation of control pulse. The routine flow chart is shown in figure 3.3.

It is important to note that the amount of data storage available is fixed and that as the distance between data storage is reduced so is the overall simulated distance of cutter travel reduced. This limitation is 2000 storage locations for each variable based upon storage every 2cm over an along face distance of 40m.

In addition, provision is also made for specifying disturbances in both the coal seam floor parting height above the datum and the coal seam thickness. Essentially these are specified in terms of a mean value plus the amplitude and frequency variation in rad/m about this mean. If the frequency variation is specified as zero, the disturbance is assumed a step disturbance of the specified amplitude from the specified mean.

Using the machine dimensions input to this routine, the potentiometers on the analogue simulation described in section 3.3 are automatically set.

### 3.2.3 Initial Conditions Routine

Before commencing a simulation run it is necessary to insert the initial state of the conveyor into the software system. This initial state must be linked with the coal seam floor parting height above the datum specified in the process geometry routine.

Initial conditions are therefore specified as a floor coal cut thickness at the front of the conveyor in the face advance direction and a tilt value enabling the determination of the floor coal cut thickness at the rear of the conveyor.

Using these values together with the algorithm for the coal seam floor parting height above the datum, the conveyor fitting routine is then executed in order to determine the initial condition of the front and rear conveyor position.

The initial conditions routine flow chart is shown in figure 3.4.

The routine is written to accept data from the high speed paper tape reader. The format of the tape is also shown in figure 3.4.

### 3.2.4 Conveyor Fitting Routine

The conveyor fitting routine is an attempt to simulate the act of pushing the conveyor pans over on to the freshly cut floor at the end of a cutting operation along the coal face.

The conveyor is not a rubber conveyor but of a semi-flexible nature and therefore the conveyor position at any point along the coal face is affected by the coal floor to either side of the point being considered. In order to simulate the conveyor behaviour when settling upon the new floor, a double exponential relationship is assumed.

In other words the height of the conveyor at any point is due to the floor height at that point plus the sum of floor heights to either side of the point multiplied by an exponential function of the distance from that point.

The mathematics of this relationship is shown clearly in the flow chart in figure 3.5 where Y(L) is the height of the floor above the datum at the along face distance L.

The exponential constant XC is determined in the process geometry routine and is a function of the number of storage points per unit distance along the coal face.

As a final action the conveyor fitting routine inserts in the left hand and right hand cut data tables the value of 100mm in order to simulate the manual action of cutting stable holes prior to the next along face machine cutting run.

3.2.5 Machine Simulation Routine

The flow chart of the machine simulation routine is shown in figure 3.6.

Upon entry to this routine, the position of the cutter, as determined by the executive routine, is read from the computer core. Using this value of position, the correct values of the front and rear conveyor heights above the datum are obtained and the values of the face advance tilt and along face tilt are calculated.

The face advance tilt is taken as the tilt at the left hand skids when the machine is moving to the right and vice-versa. The direction of movement is determined by sense line 2.

The along face tilt is taken as the height of the right hand skid relative to the left hand skid and is positive when the right hand skid is below the left hand skid. When the cutter is moving to the right, the along face tilt is calculated as being the smallest of the front conveyor edge tilt and the rear conveyor edge tilt. When moving to the left, it is taken as the largest of these two tilt values.

Once the face advance and along face tilts are determined these together with the height above the datum of the front left hand skid are passed to the analogue computer.

In addition, for recording purposes, the coal seam boundaries are passed via the data interface to the analogue computer. These are passed in terms of the seam boundary associated with the left hand cutter and the boundary associated with the right hand cutter.

When both cutting heads are operating and the cutter moving right, the left hand cutter is cutting the floor and the associated seam boundary will be showing the floor boundary at the along face position $\ell$. The seam boundary associated with the right hand cutter will show the roof boundary at the along face position $(\ell+F+2R)$.

With both cutting heads operating and the cutter moving left, the left hand seam boundary will show the roof boundary at position $\ell$ and the right hand seam boundary will show the floor boundary at position $(\ell+F+2R)$.

When a cutting head is not turning, the seam boundary associated with that cutter shows the boundary that was being recorded the last time the cutting head rotated until such time as it turns again, when the seam boundary recorded will be determined by the direction of cutter travel.

After passing data to the analogue computer the machine simulation routine reads the position of the bottom of the two cutting heads from the analogue simulation.

This data is adjusted by the use of the seam thickness and seam above datum subroutines in order to calculate the coal boundary thickness remaining and to store these in the left hand cut data block and right hand cut data block. The amount of data storage is sufficient to allow for the distance between sensor and the cutting head.

With both cutting heads rotating, the decision whether to insert roof or floor boundary data into the data blocks is determined by the direction of cutter travel.

When one cutting head only is rotating, the data from this head position is used to determine the floor cut data in the following way. If the right hand cutting head only is rotating, it is because the cutter has been retracted from the right hand end of the seam and the right hand cutting head under manual control is cutting the seam from floor to roof to the end of the seam. Since the roof coal will already have been cut and recorded the floor coal cut boundary only is required. Since it is possible that the cutting head will scan the seam while cutting, the data recorded will be either when the cutting head has moved lower than its previous position or less than 2% higher otherwise its previous position will be recorded.

In addition to storing for a short distance the left and right hand cut data, the floor cut data above the datum is recorded for the whole of the along face distance. The four sense lines between the analogue and digital computers are used to determine cutting heads running and traverse directions.

3.2.6 Generate Along Face Pulse Routine

This routine when called by the executive routine outputs a pulse via a control line on the hybrid interface. This pulse sets a bistable device on the logic part of the analogue computer. When detected by the controller, the bistable device is reset by the controller and awaits another pulse from the Generate Along Face Pulse Routine.

The flow chart for this routine is shown in figure 3.7.

3.2.7 Pseudo-Random Generator and Sensor Simulation Routines

The nuclear sensors possess two characteristics that require simulation, one is the effect of the sensor time constant and the other is the random nature of the radiation detection process.

Since the gamma radiation source used is weak for safety purposes the sensor time constant is usually of the order of 5 seconds.

Neglecting the randomness of the process at first, the time constant is simulated by every second (or each 100th entry of the interrupt service routine), the present value of the coal boundary thickness at the sensor position is stored in a small table of six values. The coal boundary thicknesses are obtained from right hand and left hand cut data blocks, and the small table of six values will contain the last five seconds of sensor readings. If the cutter is traversing these values will differ but after being stationary for five seconds they will be equal.

The sensor outputs to the analogue computer are then obtained by summing these values and dividing by six to keep within range. These sensor readings can then be calibrated in terms of coal thickness.

The flow diagram of this routine is shown in figure 3.8.

Further work is required to incorporate the correct form of randomness in the simulation.

## 3.3 Analogue Computer Simulation

### 3.3.1 Coal Cutter Simulation

The mathematical model of the coal cutter is represented by the equations in section 2.

For graphical recording purposes either the height of the top or the bottom of the cutting head above the datum level is required. Therefore for analogue simulation purposes equations (2.1), (2.2), (2.5) and (2.6) are utilised resulting in the analogue flow chart in figure 3.9.

The machine simulation routine in the Pacer 100 is used to determine the values of face advance and along face tilts and these are passed via the data interface to the analogue computer.

If the jack signal becomes positive the top of the cutting head of that particular cutter is recorded, while if the jack signal becomes negative, the bottom of the cutting head is recorded. This is achieved by switching in or out the value of $D_m$ in the simulation.

The heights of the datum of the bottom of both cutting heads is passed back to the Pacer 100 via the data interface. The machine simulation routine determines how to use this information as explained in section 3.2.5.

Also made available to the analogue computer for recording purposes is the coal seam limits above the datum. These limits are output at the same along face position as the associated cutting head. If the left hand cutter is cutting the floor, the floor coal seam limit will be recorded at position $\ell$.

3.3.2 Jack Dynamics Simulation

The two cutter jacks are identical and operated by a raise-off-lower signal from the controller.

In practise the actual jack mechanism and motor possesses a time constant of 2.75 seconds due to the inertia of the system. The jacks can therefore be simulated by a simple lag and integrator as shown in figure 3.10.

3.3.3 Along Face Position Simulation

For recording purposes, it is necessary to determine the conveyor position and the coal seam characteristics along the coal face.

The Pacer 100 executive routine records the position of the left hand cutter i.e. $\ell$ at all times. This position, set to zero when the initial conditions routine is run is passed to the analogue computer via DAC5. This signal is then used to drive the X-axis of two graph plotters.

One plotter is used to record the left hand seam and cut data while the other is used to record the right hand data.

The flow chart of the elements used for this is shown in figure 3.11.

3.3.4 Nucleonic Sensor Output Inhibits

The sensor simulation routine in the Pacer 100 considers the direction of travel of the cutter and adjusts for the position of the sensor. If the cutter is moving left, the sensor position is assumed to the right of the cutting head and vice-versa.

The sensor data is passed to the analogue computer via the data interface. If the appropriate sensor is in position, the sensor output is made available for the controller otherwise it is inhibited by the use of à comparator as shown in figure 3.12.

3.3.5 Hybrid/Controller Interface

The necessary interface between the control unit and the hybrid computer is also shown in figure 3.12.

# 4. CONTROL BY INTEL 4004 MICROCOMPUTER

## 4.1 Controller Hardware

### 4.1.1 Controller Panel

The layout of the controller front panel is shown in figure 4.1.

The panel allows for manual control by positioning the jack controls immediately below the analogue indication from the nucleonic sensors of the coal seam boundary thickness.

Also available for quick reference by the operator is the face advance tilt of the cutter body and the positions of the two nucleonic sensor arms. Derived from the jack position signals there is also simple indication whether the cutters are cutting roof or floor.

On the right of the panel are the stop/start controls of the coal cutter. The reset control will stop all actions and will await operation of the manual control button to again commence cutter operation.

A remote control button is provided for the possibility of future applications of a remote control computer.

The remainder of the controls are self-explanatory, the safety interlocks between them being provided by software explained later.

The machine position indication is provided by seven segment displays, resetting of these displays being possible when the cutter is stationary.

An alarm indication at the top of the panel is provided to give flashing indication before cutter operation commences and a steady light when in operation. In practise the flashing light would normally be enhanced by an audible alarm.

4.1.2 Controller Block Diagram

The connections between the controller and the cutter simulation is shown in figure 3.12.

The number of input and output connections to the microprocessor module is limited and hence signals must be multiplexed. The input and output multiplexors are shown in figure 4.2.

Each of the eight output ports and the four input ports are of four bits or digital signals.

Again, provision is made for the addition of remote signals to be multiplexed and available for a time division multiplex system to a remote computer. However the interface modules required for this are not specified or constructed.

For operator communication lights in the control panel pushbuttons are also driven through output multiplexors.

For isolation purposes, relays are provided on control signal outputs. This allows for the possibility of the controller being used for control of a physical scale model of a twin drum coal cutter if this should be built in the future.

#### 4.1.3 Multiplexor Details

Figures 4.3 to 4.7 are details of the five multiplexors (excluding the remote signal multiplexor).

For ease of reference figures 4.8 and 4.9 list the multiplexor and signal codes designated for the microcomputer module.

## 4.2 Controller Software

### 4.2.1 Controller Executive Routine

The controller executive flow chart is shown in figure 4.10.

This routine controls the running of the controller function routines and also makes some logical operation decisions on the sequence of events that the controller will allow.

For safety purposes, the cutting machine main supply relay must be energised before the executive will allow any operation. In addition, each cycle of the executive routine checks the master supply relay and if the relay is not energised all operation is suspended and the executive requires a complete run through of normal starting procedure before cutter operation can proceed.

When the master supply is available, the next operation required by the operator is to press the manual pushbutton. This will allow the software to proceed to run the panel scan routine.

After the panel scan routine, the output routine is run in order to acknowledge operator action by lights on the controller panel, to alter the position displays or to output new control actions.

Then the executive routine inspects data in the microcomputer memory to decide whether the first cutting head has been requested to run after a shutdown. If either cutting head has been requested the executive initiates the running of a flasher routine which causes the alarm to flash for a few seconds before allowing the cutting head to start.

If a cutting head is not rotating, a request for cutter traverse will only be allowed when the stationary cutting head drum is in mid-position.

When the cutter is not traversing, the machine position routine is run allowing manual setting of the seven-segment displays.

When the cutter is traversing, the executive looks for an along face pulse from the cutter simulation and when one occurs, the cutter position is updated and the analogue scan and control routines are run.

Upon completion of a particular activity the executive returns to the start of the main part of the routine.

The input and output port allocations and memory allocations for routines and data storage are shown in figures 4.11 to 4.15.

### 4.2.2 Panel Scan Routine

The panel scan routine is arranged to scan the pushbuttons on the controller front panel and to store state bits in the random access memory. Logic decisions associated with the order of operation of the pushbuttons are also included in this routine.

The panel scan routine flow chart is shown in figure 4.16.

Initially the routine scans the cutter head pushbuttons. If none are pressed, the routine progresses to inspect the traverse pushbuttons.

If the cutter head stop pushbuttons are pressed, the appropriate state bits are immediately altered to suit the operator demand. As with any other change to the cutter heads mode of operation the cutter will automatically stop traversing and will not inspect the traverse pushbuttons on this run through of the routine.

If a cutter head start is requested, the associated start bit is set ready for action by the executive routine. Only one cutter head start routine can be set in motion at once.

If both cutters are being stopped, the flasher light is extinguished.

Before inspecting the traverse buttons, the routine checks whether the controller is on auto. If it is, both cutters must be running and the probes positioned in order that the cutter can traverse.

Inspection of the traverse push buttons will cause setting of the appropriate state bits ready for action by the output routine.

No matter the operation action on the cutter head and traverse pushbuttons, the routine next inspects the manual pushbuttons. Pressing the manual pushbutton will cause immediate inspection of the jack raise and lower pushbuttons. A request for auto will prevent manual jack operation and set bits ready for action by the control routine.

A remote facility is available, auto having been previously selected before remote can be selected.

After inspecting the manual jack pushbuttons the panel scan routine inspects the probe position and retract pushbuttons. This part of the routine ensures that the probe arms are in the correct position when the cutter boom is raised and lowered through the mid-position.

The allocation of state bits in the random access memory as referred to in the executive and panel scan routines is shown in figure 4.17.

#### 4.2.3 Output Routine

The output routine is arranged to control the panel lights, the cutter position indication, the control actions to the cutter and the resetting of the along face pulse.

The flow chart is shown in figure 4.18. In general the multiplex control and the RAM character holding the relevant state bits have the same value enabling the output routine to be a simple repetitive loop of bit transfers.

4.2.4 Initialising Routine

The initialising routine inserts the values of state bits in RAM that represent to shutdown or non-operative state. Running of the output routine will then cause the shut-down state to be initiated.

The flow chart is shown in figure 4.19.

Initialising of the machine position indication is not included - this may be set by the appropriate set pushbuttons on the controller panel.

4.2.5 Flasher Routine

The flasher routine sets and unsets the flasher output bit dependent upon the number of times the routine is run. Once a count is exhausted the relevant cutter stop bit is unset allowing the executive routine to complete the cutter starting sequence.

The flasher routine flow chart is shown in figure 4.20.

The counts used by this routine are initialised to zero in the initialising routine and also in the executive routine to cover the situation when a cutter head is stopped in the middle of a starting sequence.

4.2.6 Jack Position Routine

This routine flow chart is shown in figure 4.21.

Run immediately after the analogue scan routine when either in manual or auto control, the routine examines the positions of the two jacks and sets the appropriate position bits stored in RAM. A mid-position between 45% and 55% of the jack travel results in both the up and down position bits, and hence the associated LEDs, being set.

4.2.7 Analogue Scan Routine

The analogue scan routine controls the multiplexing of five analogue signals through an analogue to digital convertor and then through a further multiplexor to give 3 characters i.e. 12 bits accuracy of the stored signals.

The routine flow chart is shown in figure 4.22.

The settling time required for the ADC operation is provided by demanding the next signal while storing the previous one during the settling period.

4.2.8 Machine Position Routine

The machine position routine is arranged so that the units, tens and hundreds digits of the position indication can be individually set to any decimal value when the cutter is not traversing.

Each operation of the set pushbutton will add one to the associated BCD display.

The flowchart of this routine is shown in figure 4.23.

4.2.9 Auto Control Routine

The purpose of the simulation study outlined in this report is to provide a facility for the study of the behaviour of a coal cutter and ultimately the production of a suitable control strategy.

Details of an auto control routine are therefore not included in this report.

# Bibliography


1. Bogdadi, W.A.: 'Digital Computer Control of the Vertical Steering of a Longwall Coal Cutting Machine', Ph.D. thesis, University of Sheffield.

2. Edwards, J.B. and Bogdadi, W.A.: 'Progress in the design and development of automatic control systems for the vertical steering of coal cutting machines', I.E.E., Vol.121, No.6, June 1974, pp.533 to 536.

3. Bogdadi, W.A. and Edwards, J.B.: 'The Automatic Vertical Steering of a Longwall Coal-Cutting Machine - An Experimental Investigation', Proc. I.Mech.E., Vol.189 32/75, pp.187-195.

4. Edwards, J.B.: 'Stability Problems in the Control of Multipass Processes', Proc. I.E.E., Vol.121, No.11, Nov. 1974, pp.1425-1432.

5. Edwards, J.B. and Greenberg, J.M.: 'Longitudinal Interactions in Multipass Processes', Submitted for publication.

6. Greenberg, J.M. and Edwards, J.B.: 'Stability of Systems with Multiple Transportation Lags', Submitted for publication.

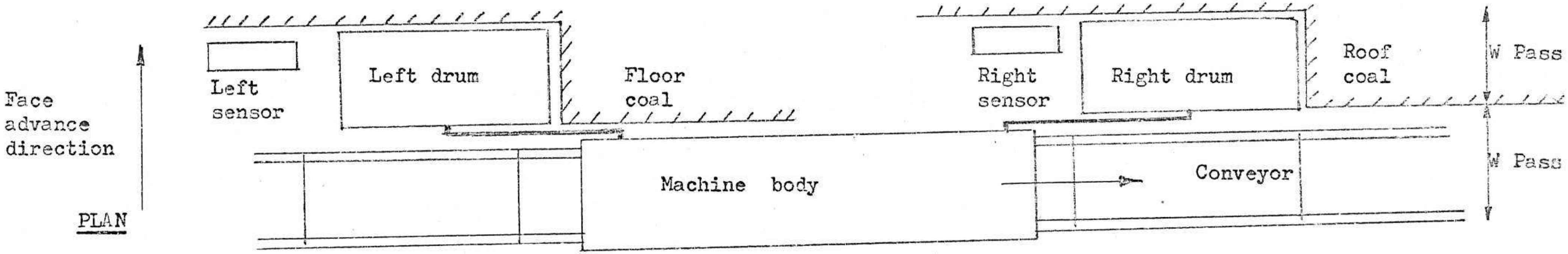



Figure 2.1 SCHEMATIC OF COAL CUTTER

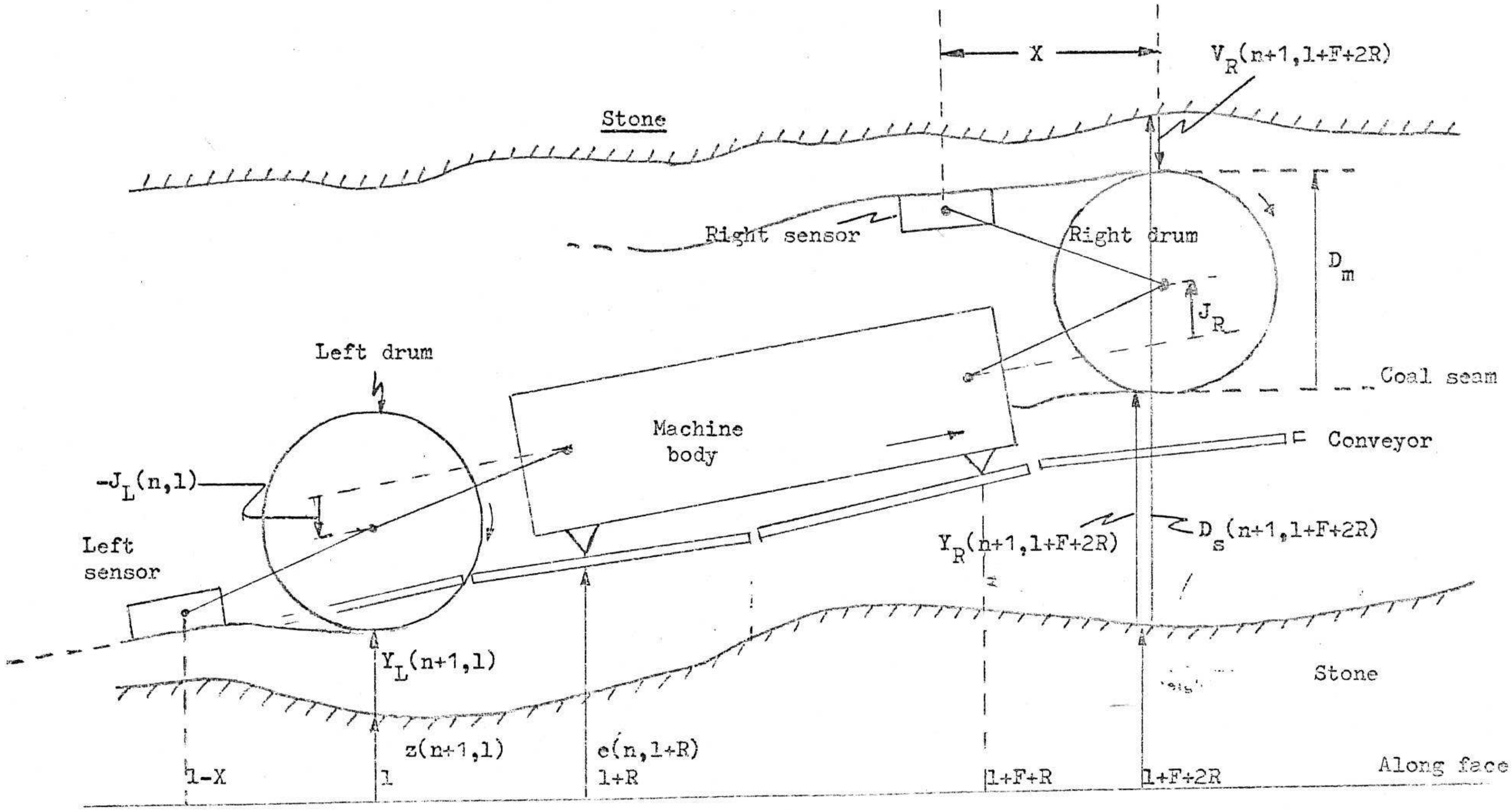


Figure 2.2

Sketch design of Coal Cutter and Probe Mechanism

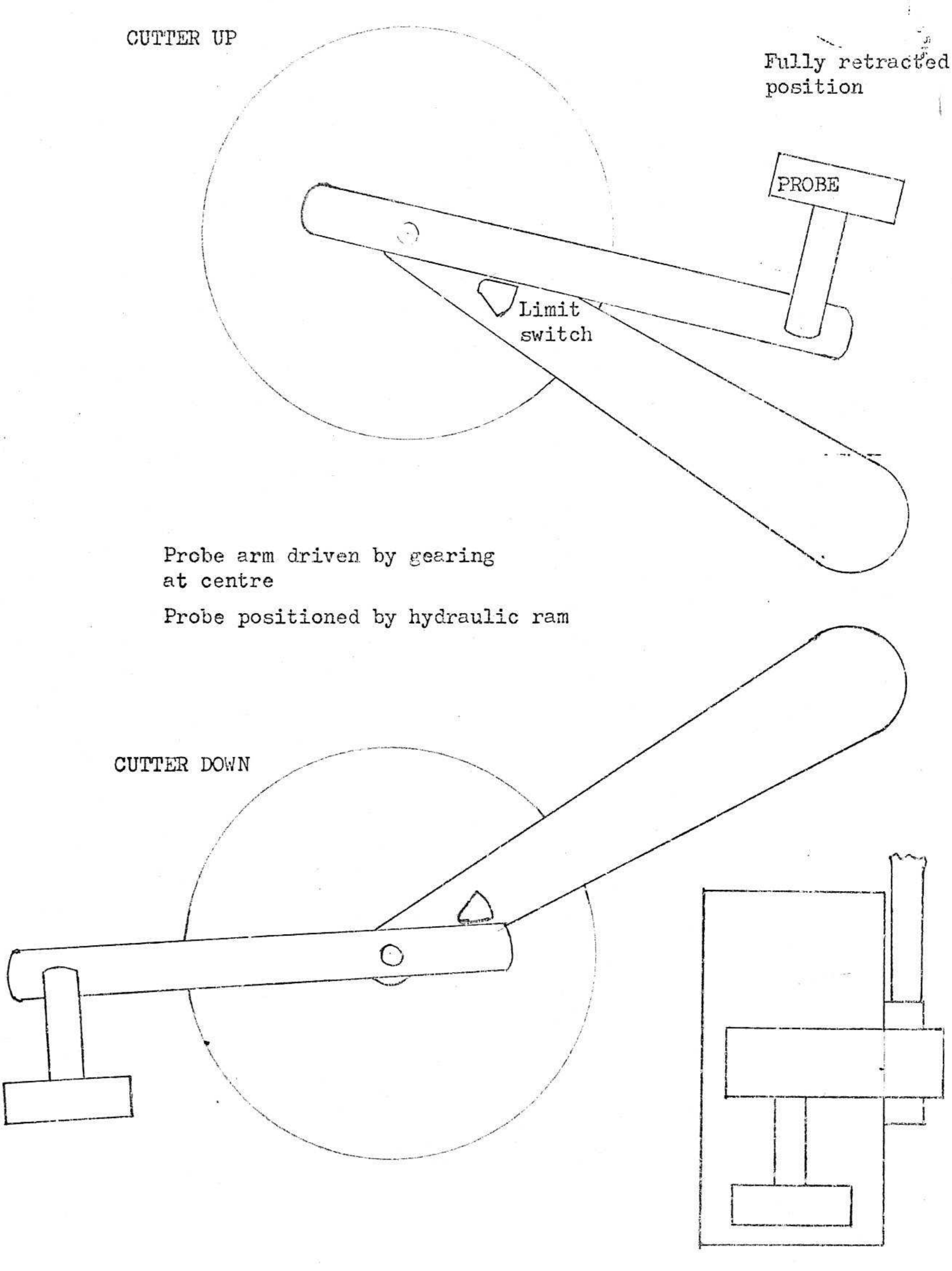


Figure 3.1
Simulation System Design

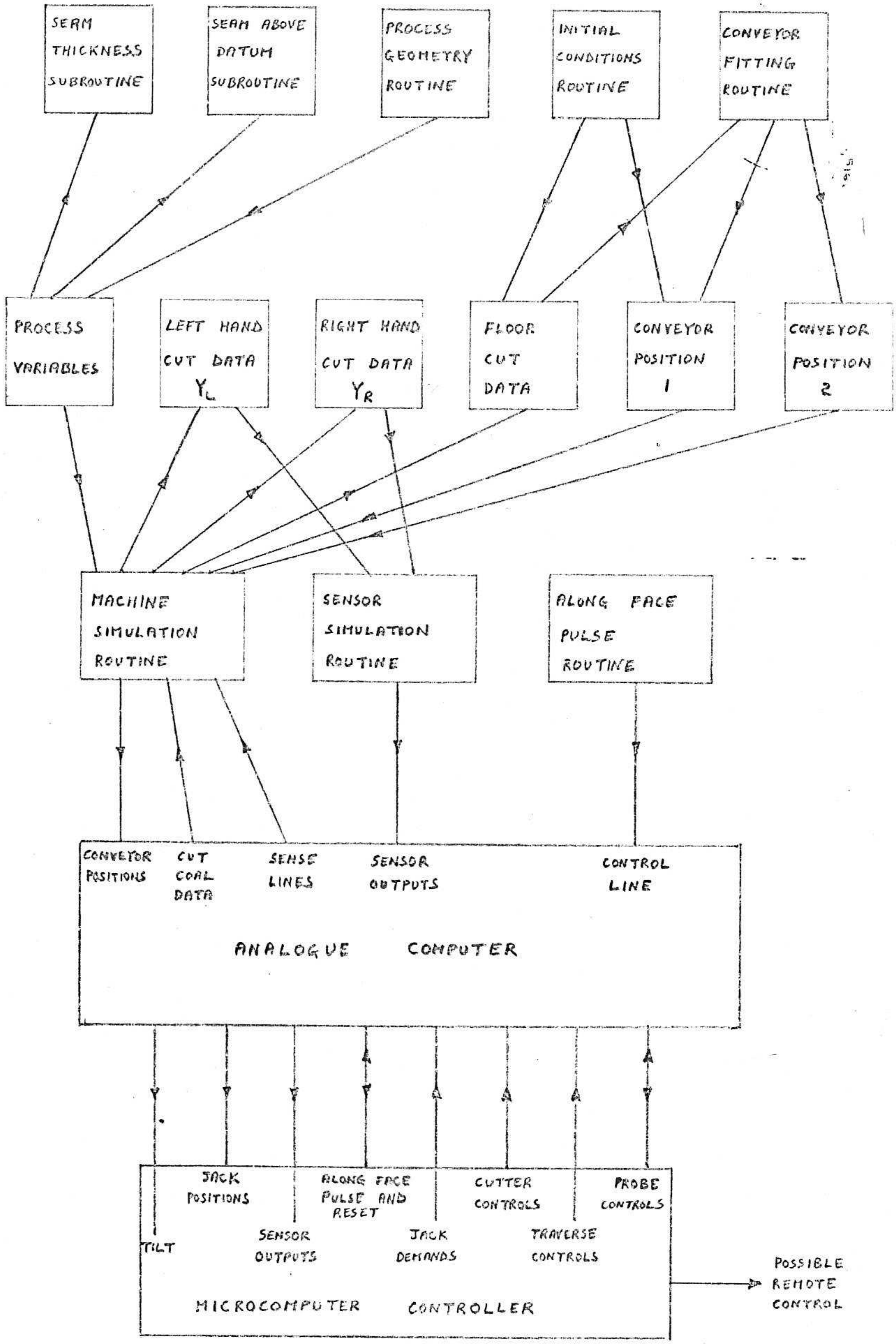


Figure 3.2

Executive Flow Chart

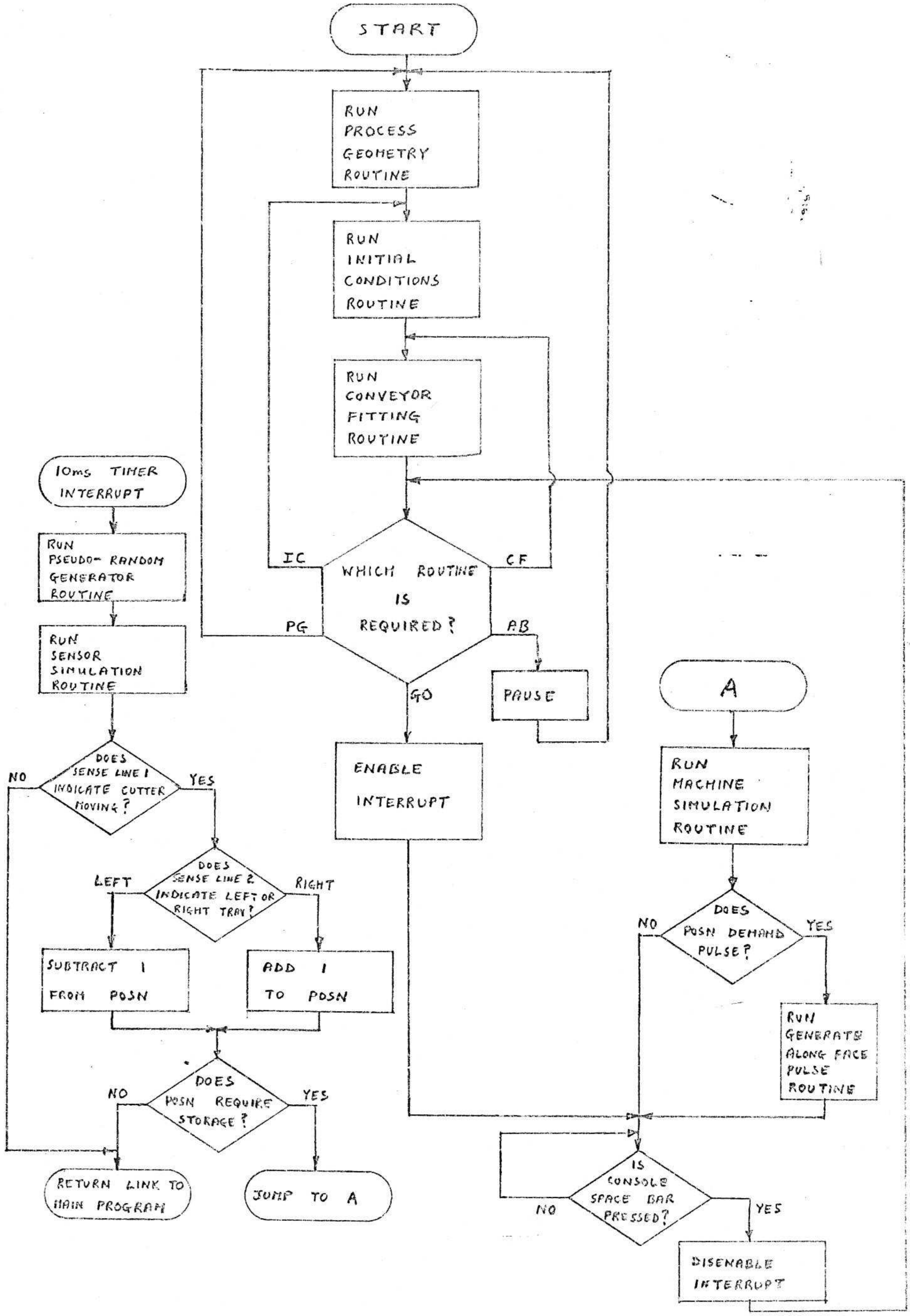


Figure 3.3

Process Geometry Routine

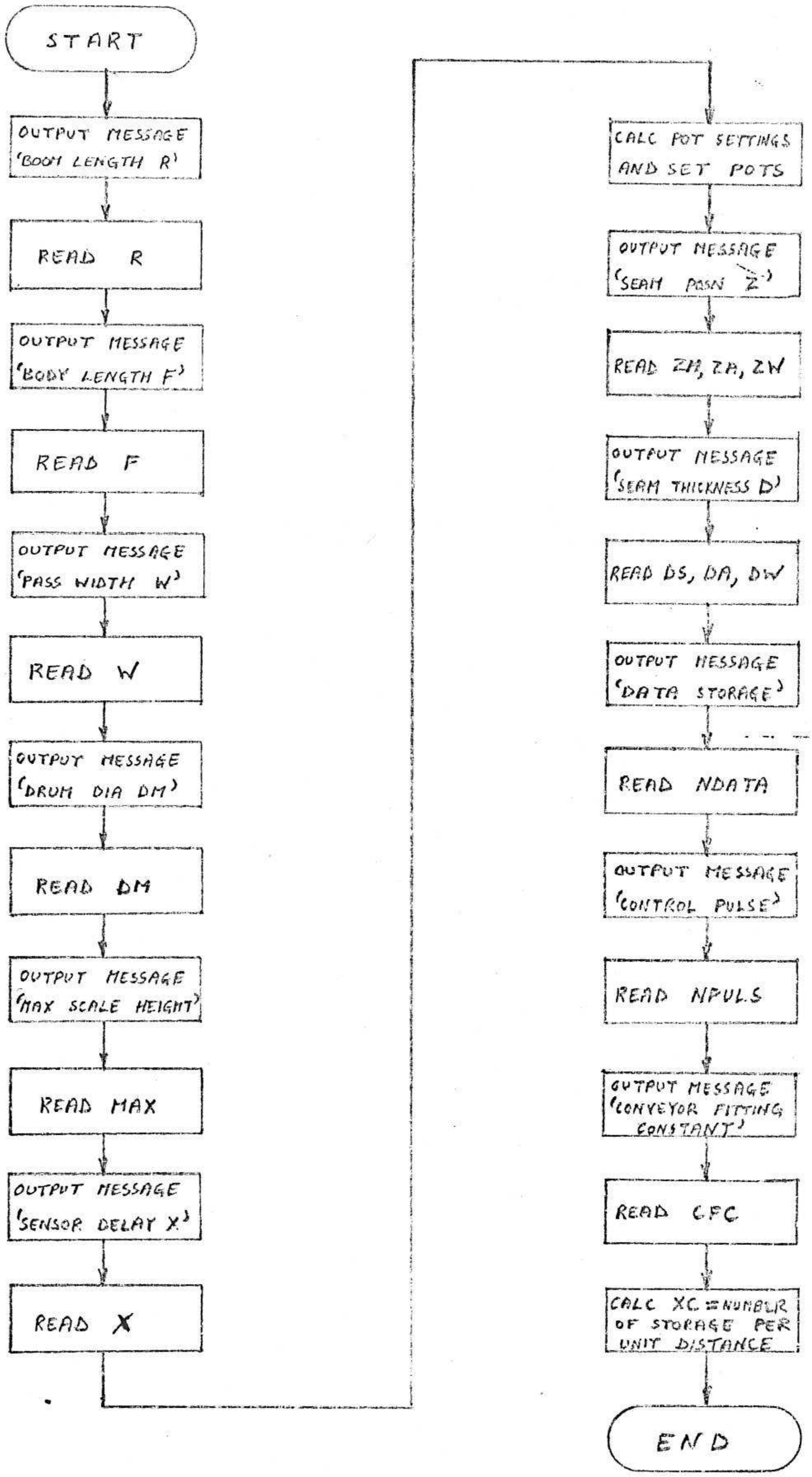
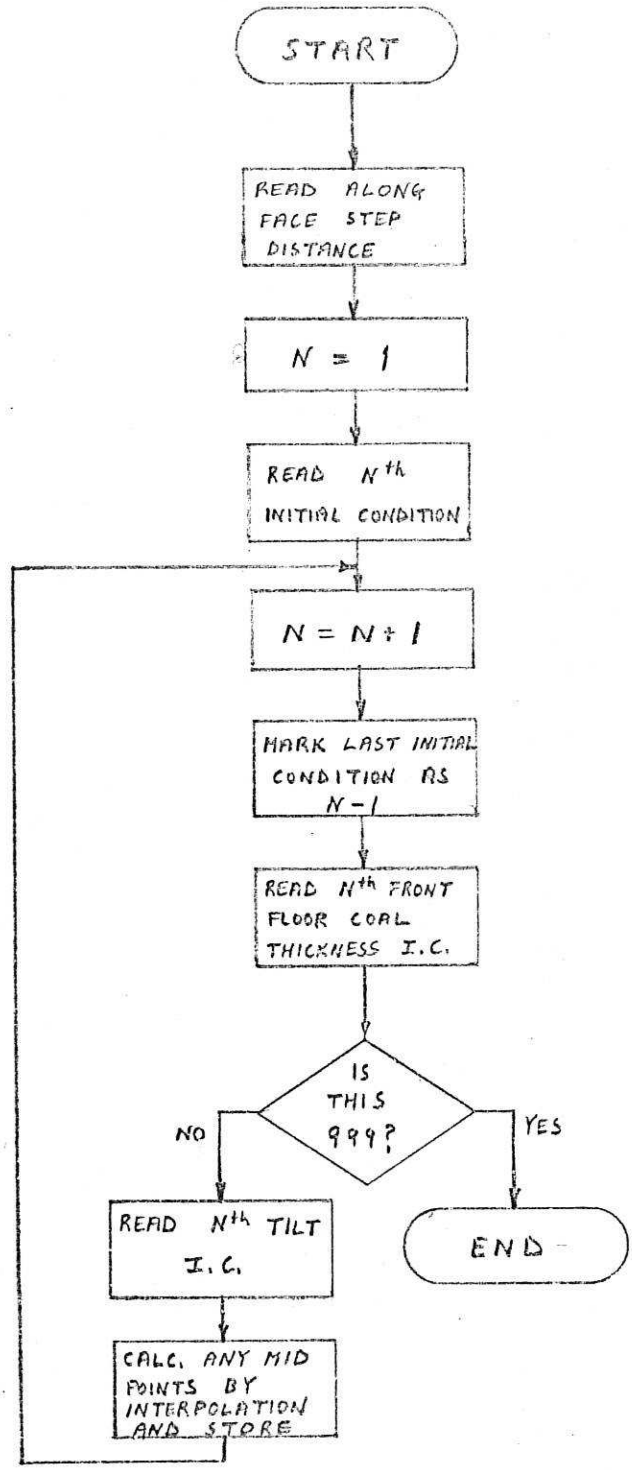


Figure 3.4

Initial Conditions Routine




PAPER TAPE DATA FORMAT (Example)

| | |
|---|---|
| 10 | / DISTANCE BETWEEN DATA IN CENTIMETRES - INTEGER FORMAT |
| 40 | / FLOOR COAL BOUNDARY THICKNESS IN MM - INTEGER FORMAT |
| -5 | / TILT IN DEGREES - INTEGER FORMAT |
| 42 | etc. |
| -2 | |
| . | |
| . | |
| . | |
| 999 | / INDICATES END OF DATA |

Figure 3.5

Conveyor Fitting Routine Flow Chart

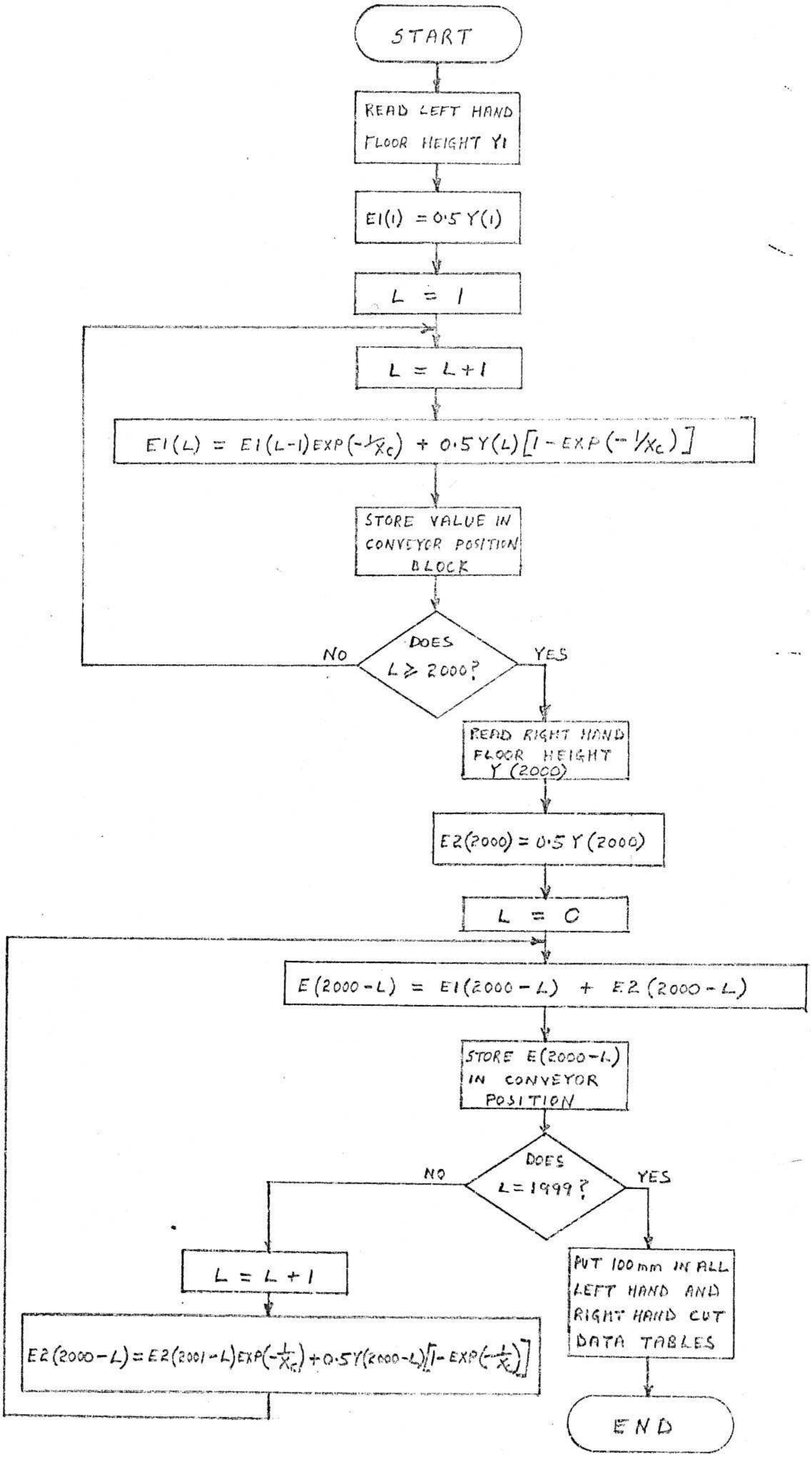


Figure 3.6

Machine Simulation Routine

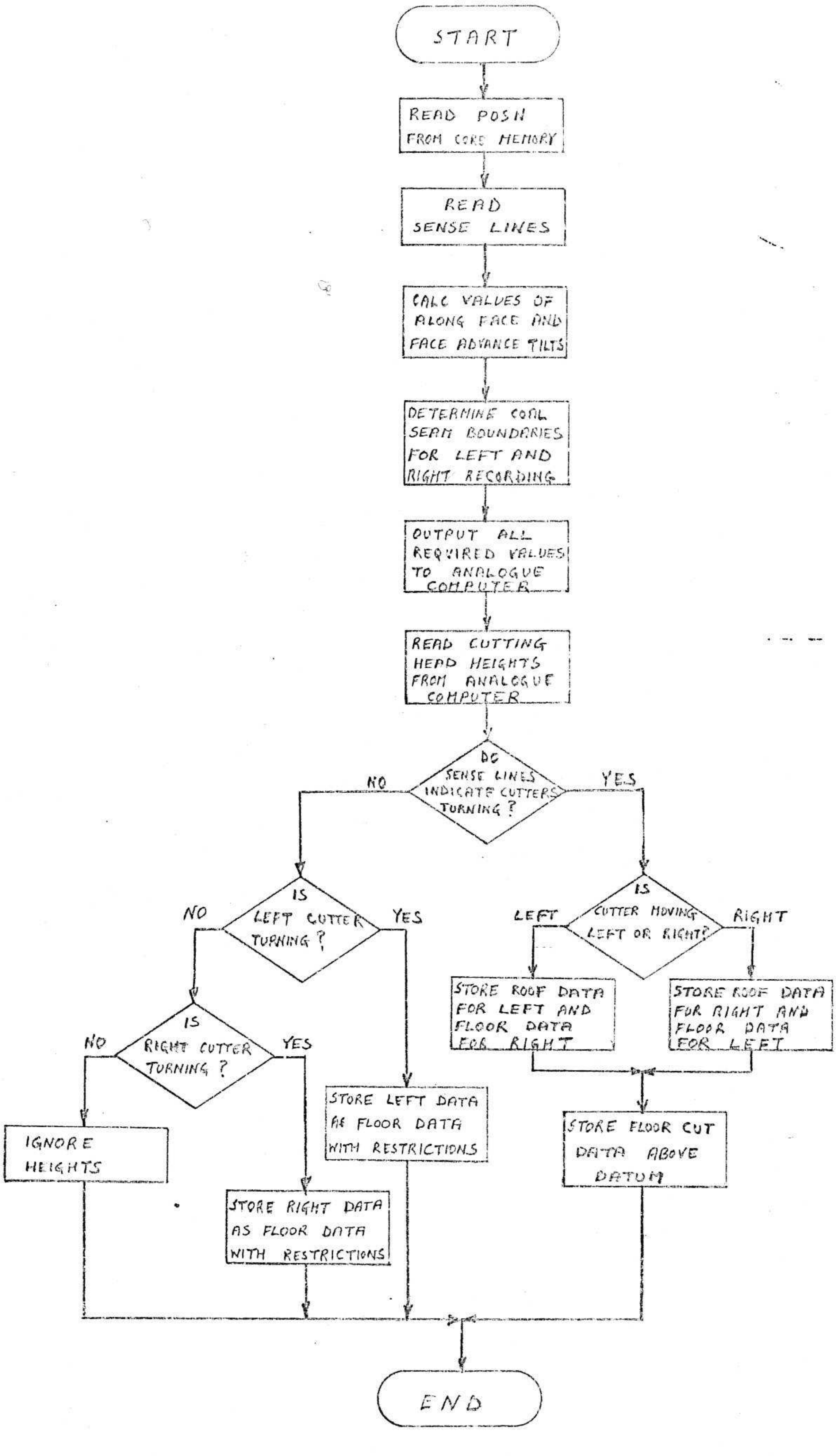


Figure 3.7

Generate Along Face Pulse Routine

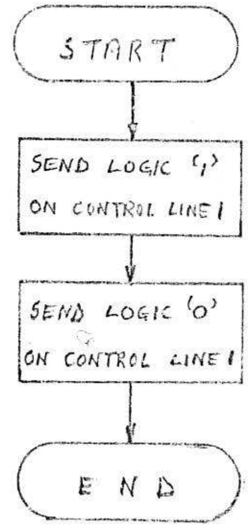



Figure 3.8

Pseudo-random Generator and Sensor Simulation Routines

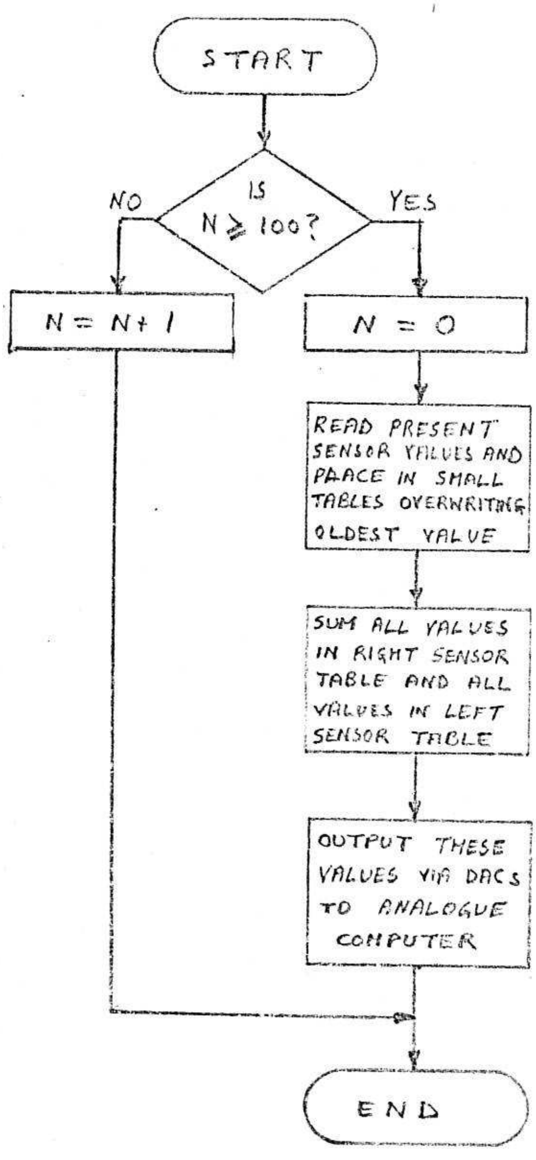


Figure 3.9 Analogue Simulation of Coal Cutter

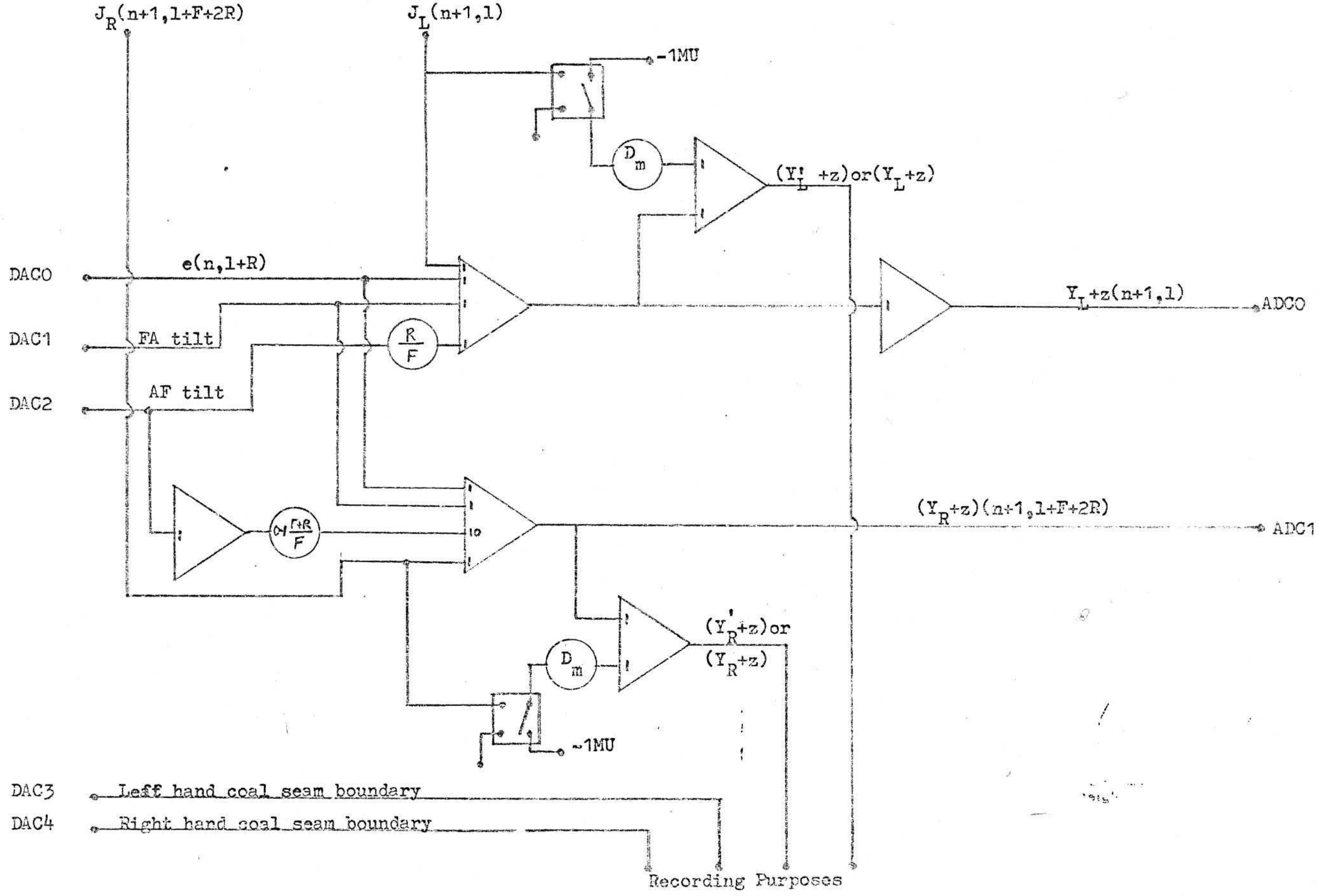
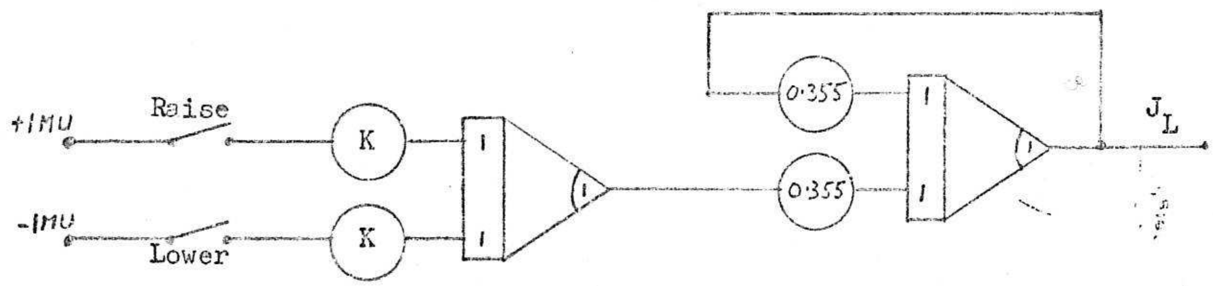


Figure 3.10

Jack Dynamics




Similarly for $J_R$

Figure 3.11

Recording Drive Elements

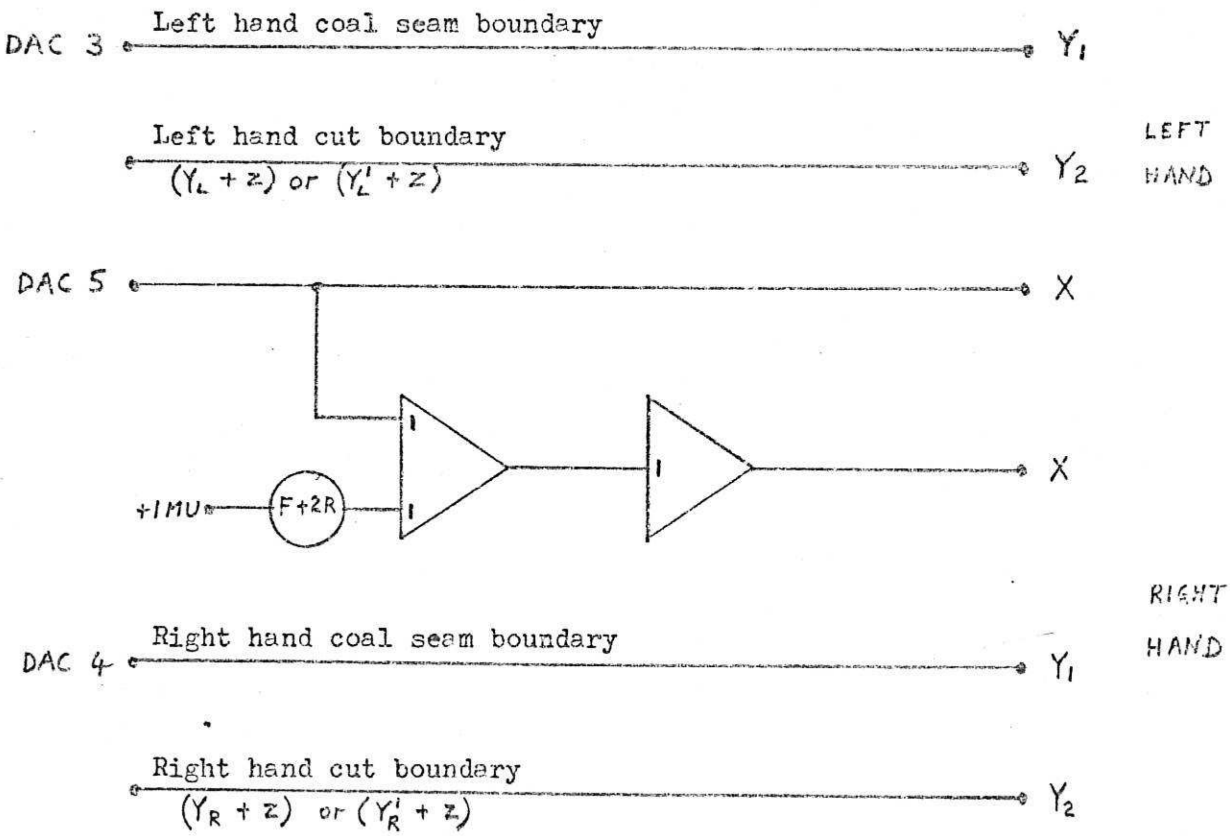


Figure 3.12

Hybrid Computer/Controller Interface

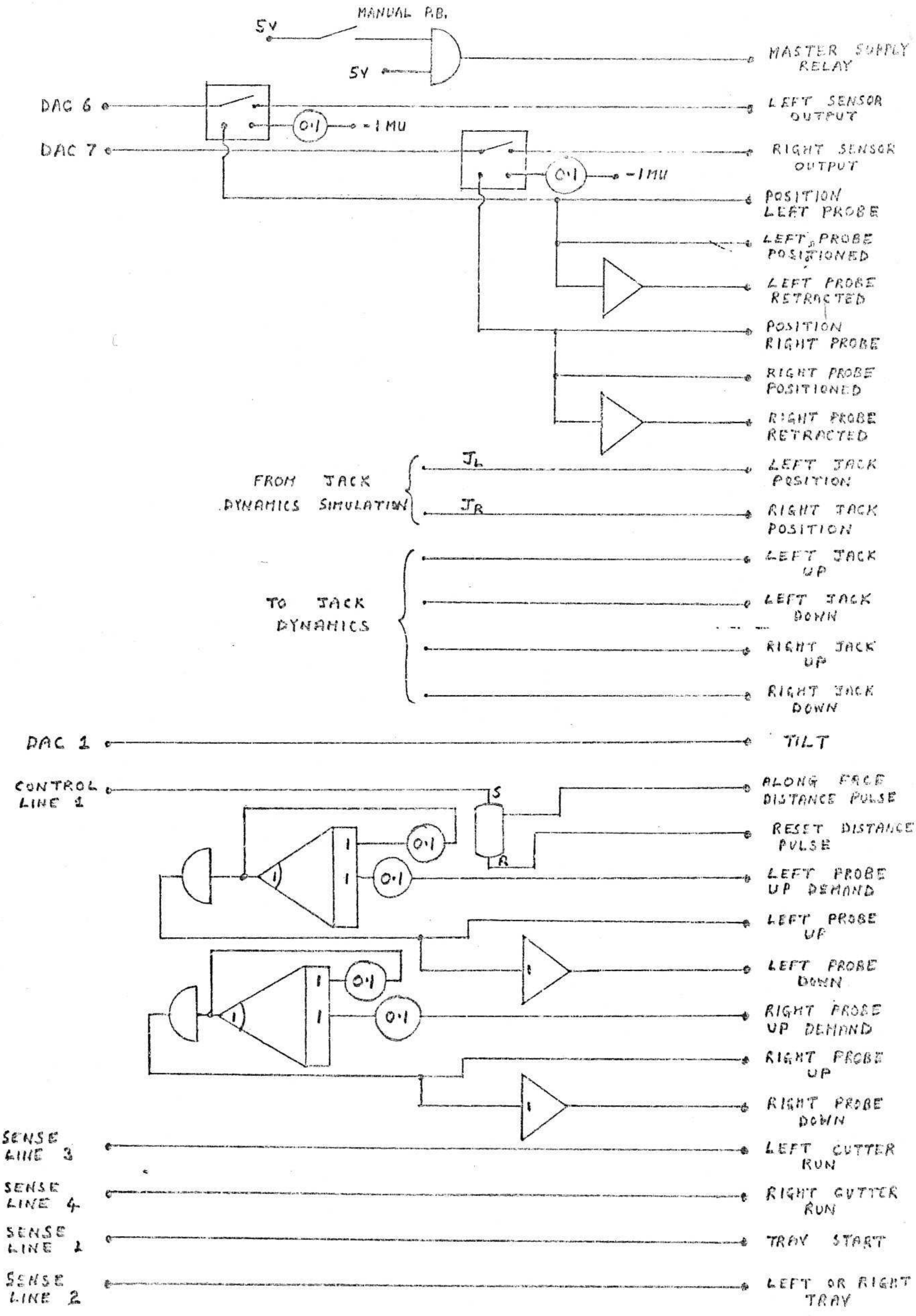
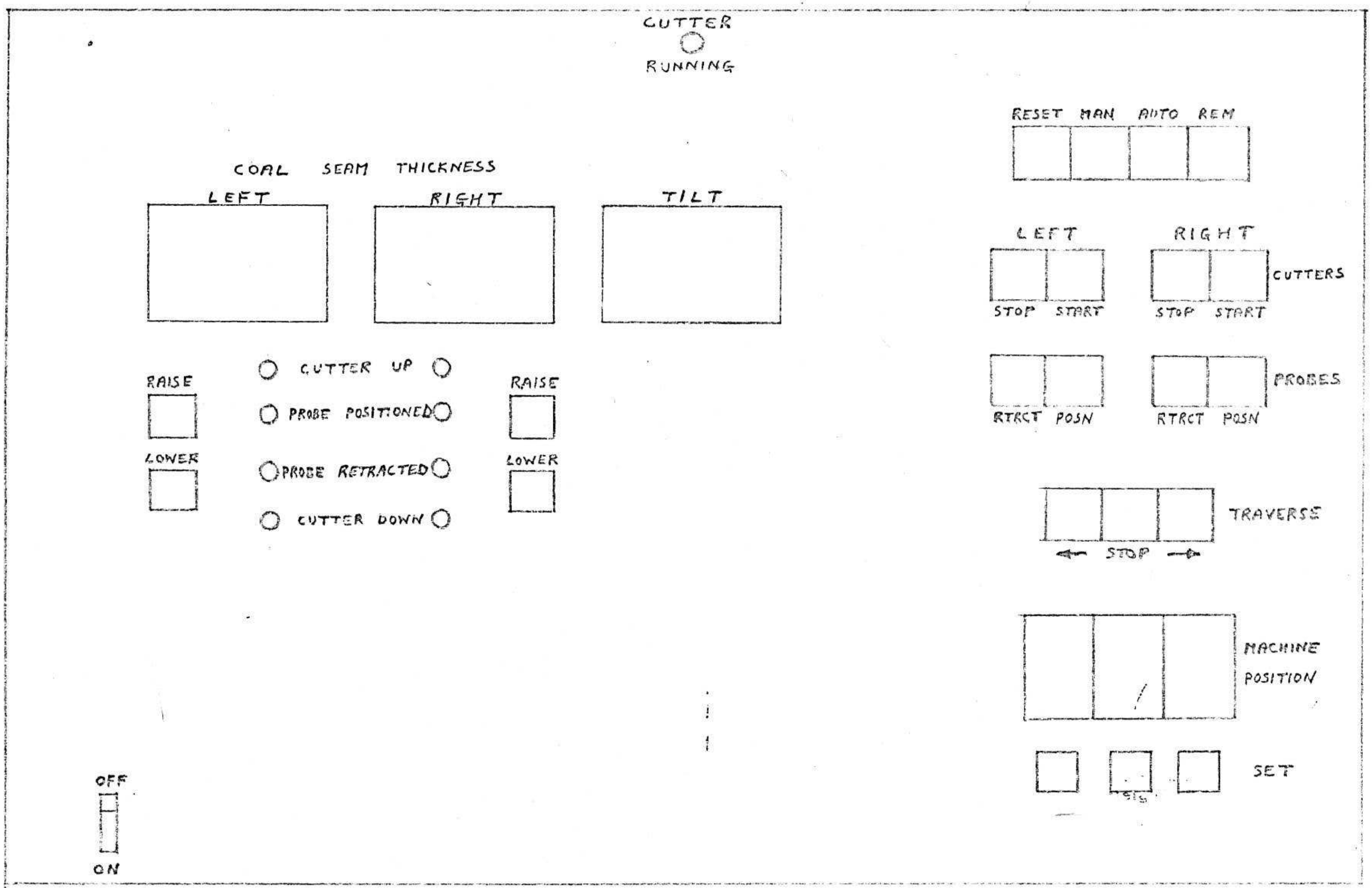


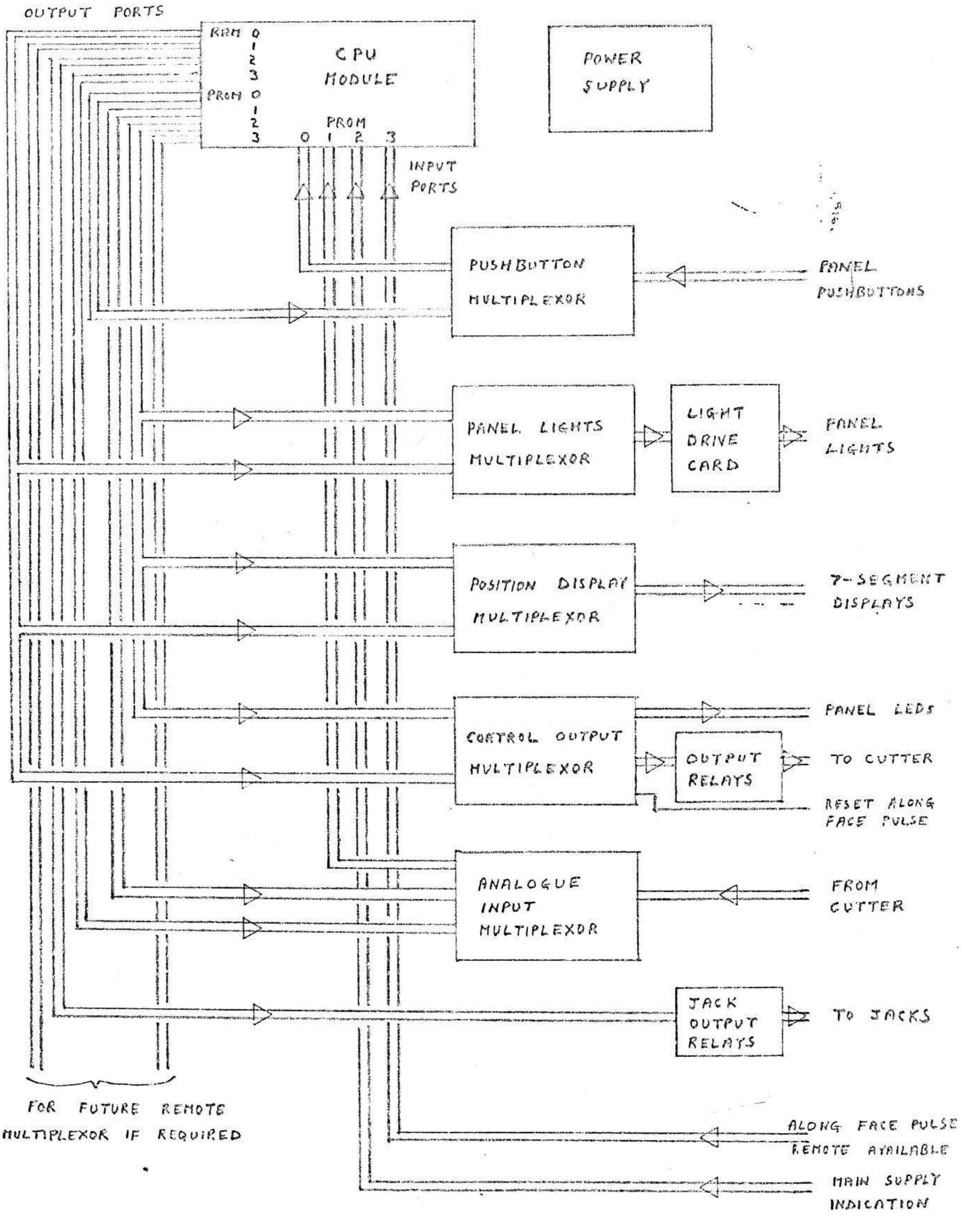
Figure 4.1

Microcomputer Front Panel



<u>Figure 4.2</u>

<u>Controller Modules</u>



## Figure 4.3

## Pushbutton Multiplexor

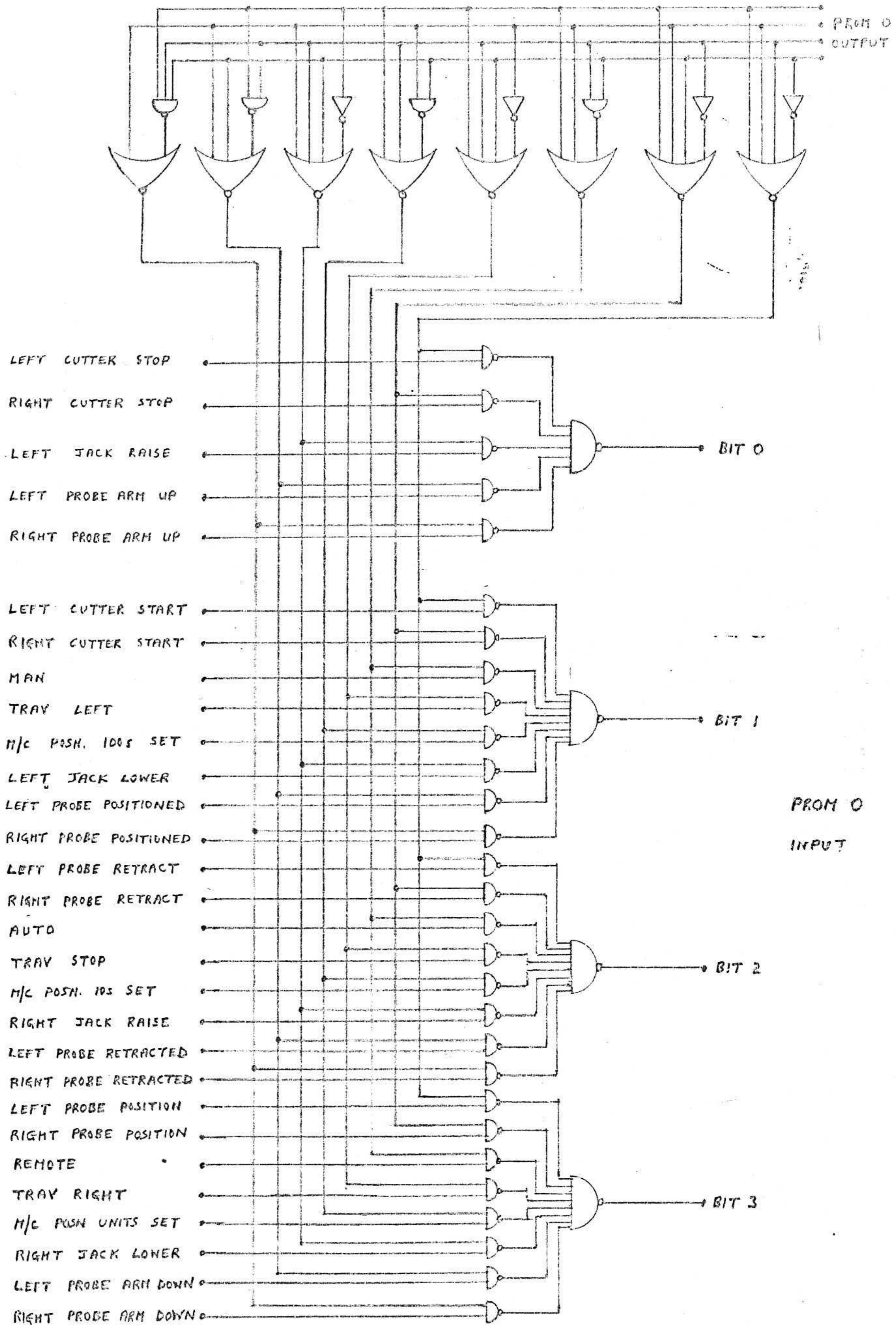


Figure 4.4

Panel Lights Multiplexor

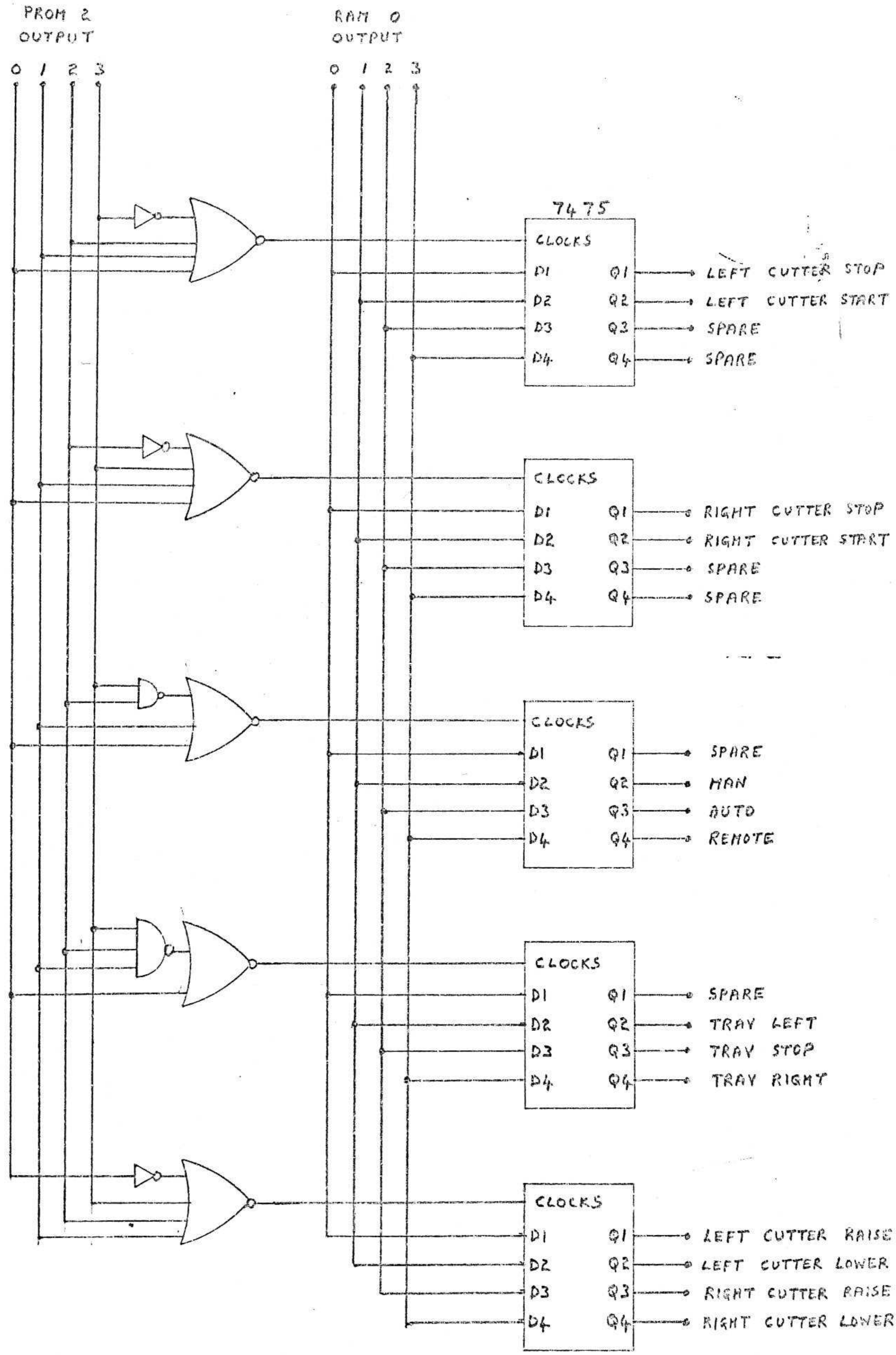


Figure 4.5

Position Display Multiplexor

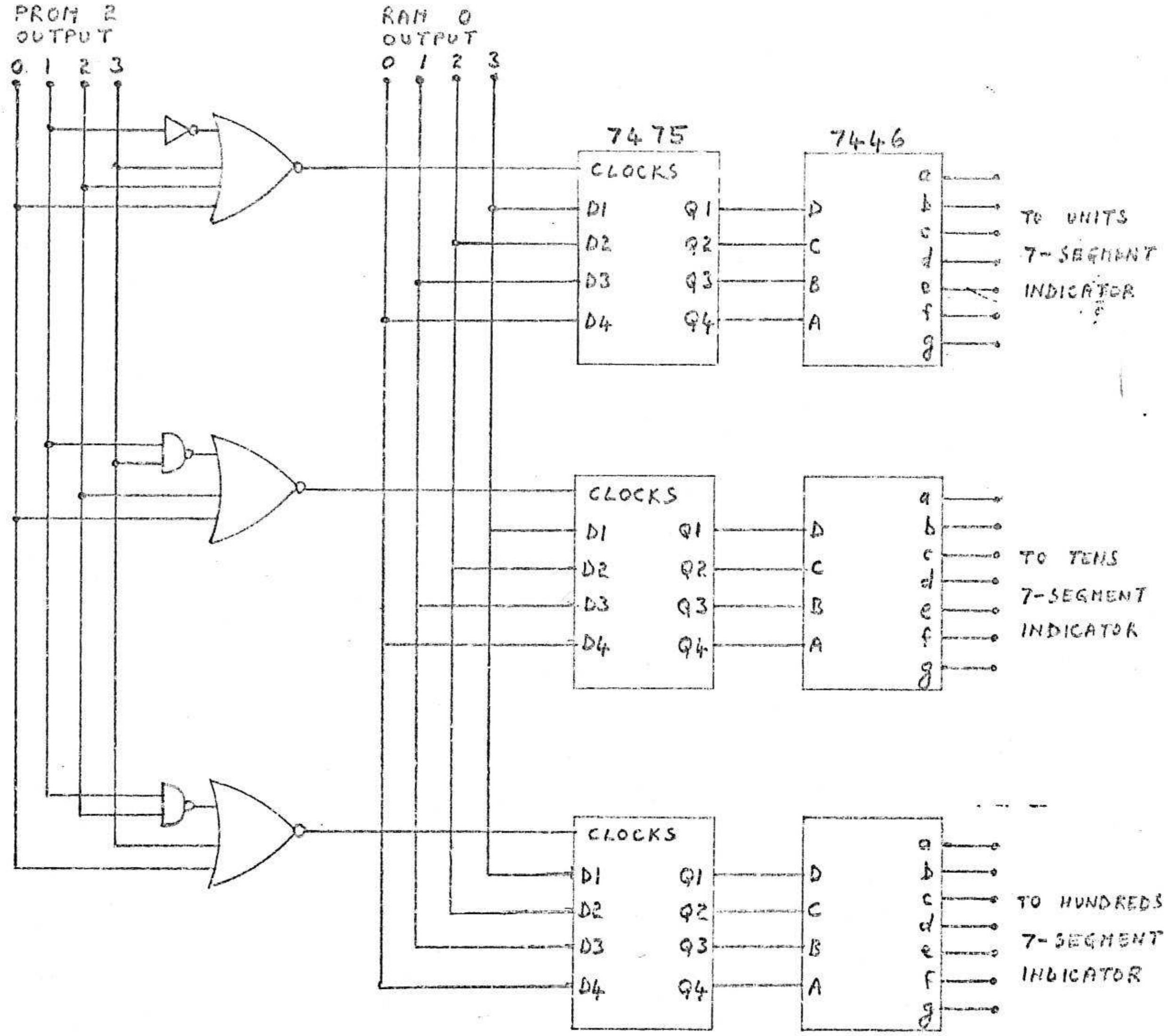


Figure 4.6

Control Output Multiplexor

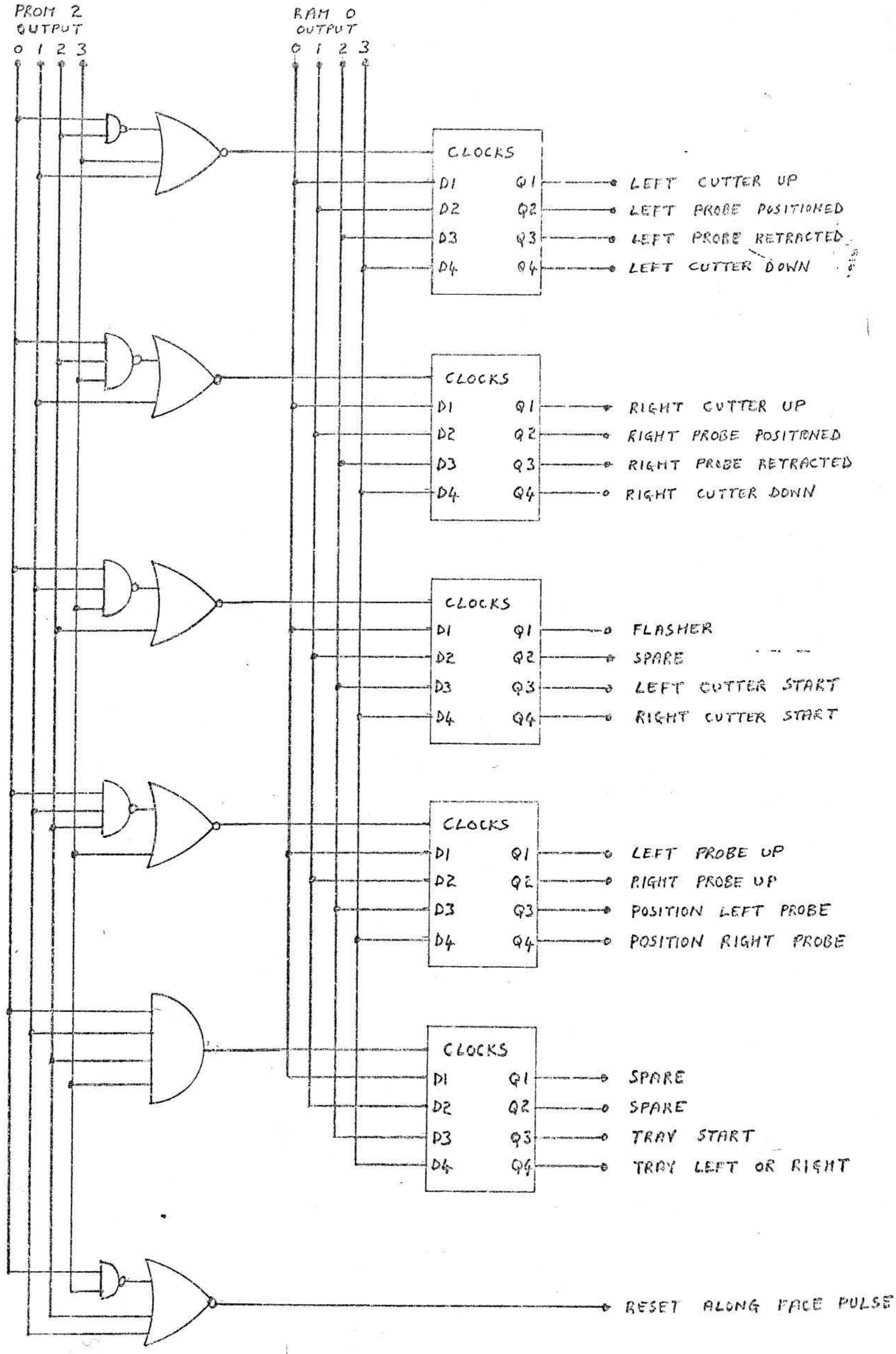


Figure 4.7 Analogue Multiplexor

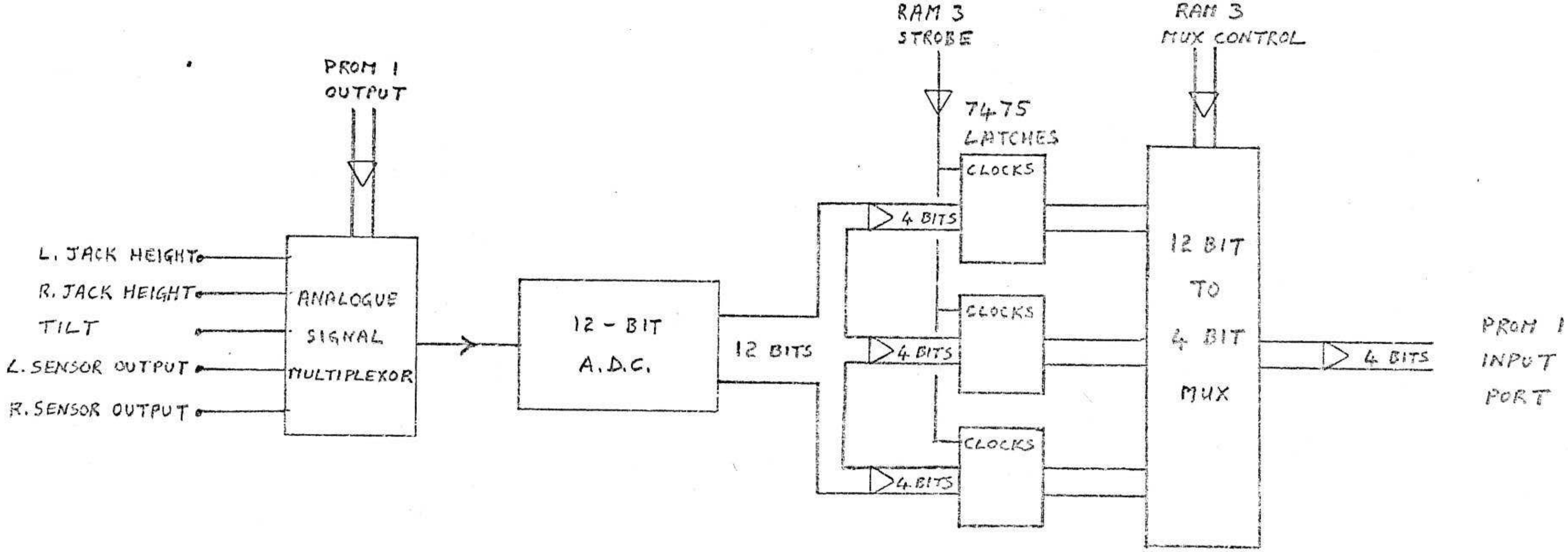


Figure 4.8

Input Multiplexor Bit Allocations

Multiplexor Control Signals via PROM 0 output port:

Input Signals via PROM 0 input port.

| PROM 0 OUTPUT BITS 0 1 2 3 | USE | PROM 0 INPUT SIGNALS BITS 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|
| 0 0 0 1 | Left cutter buttons | STOP | START | PROBE RETRACT | PROBE POSITIONED |
| 0 0 1 0 | Right cutter buttons | STOP | START | PROBE RETRACT | PROBE POSITIONED |
| 0 0 1 1 | Man/auto buttons | – | MANUAL | AUTO | REMOTE |
| 0 1 0 0 | Traverse buttons | – | ← | STOP | → |
| 0 1 0 1 | Machine position buttons | – | 100's SET | 10's SET | 1's SET |
| 1 0 0 0 | Manual control buttons | Left raise | Left lower | Right raise | Right lower |
| 1 0 1 0 | Left hand probe positions | Left probe arm up | Left probe positioned | Left probe retracted | Left probe arm down |
| 1 0 1 1 | Right hand probe positions | Right probe arm up | Right probe positioned | Right probe retracted | Right probe arm down |

Figure 4.9

Output Multiplexor Bit Allocations

| MULTIPLEX CONTROL PROM 2 OUTPUT PORT BITS 0 1 2 3 | USE | OUTPUT SIGNALS RAM 0 OUTPUT PORTS BITS 0 | 1 | 2 | 3 |
|---|---|---|---|---|---|
| 0 0 0 1 | Left cutter button lights | STOP | START | - | - |
| 0 0 1 0 | Right cutter button lights | STOP | START | - | - |
| 0 0 1 1 | Man/auto button lights | - | MANUAL | AUTO | REMOTE |
| 0 1 0 0 | Machine position units indication | B.C.D. OUTPUT | | | |
| 0 1 0 1 | Machine position tens indication | B.C.D. OUTPUT | | | |
| 0 1 1 0 | Machine position hundreds indication | B.C.D. OUTPUT | | | |
| 0 1 1 1 | Traverse button lights | - | ← | STOP | → |
| 1 0 0 0 | Manual control button lights | Left raise | Left lower | Right raise | Right lower |
| 1 0 0 1 | Reset along face pulse | Not applicable | | | |
| 1 0 1 0 | Left indicator LEDs | Left cutter up | Left probe positioned | Left probe retracted | Left cutter down |
| 1 0 1 1 | Right indicator LEDs | Right cutter up | Right probe positioned | Right probe retracted | Right cutter down |
| 1 1 0 1 | Cutter/Flasher control bits | Flasher on | - | Left cutter start | Right cutter start |
| 1 1 1 0 | Probe control bits | Ledt probe up | Right probe up | Position left probe | Position right probe |
| 1 1 1 1 | Traverse control bits | - | - | Traverse start | ← = 0; → = 1 |

Figure 4.10 Controller Executive Routine

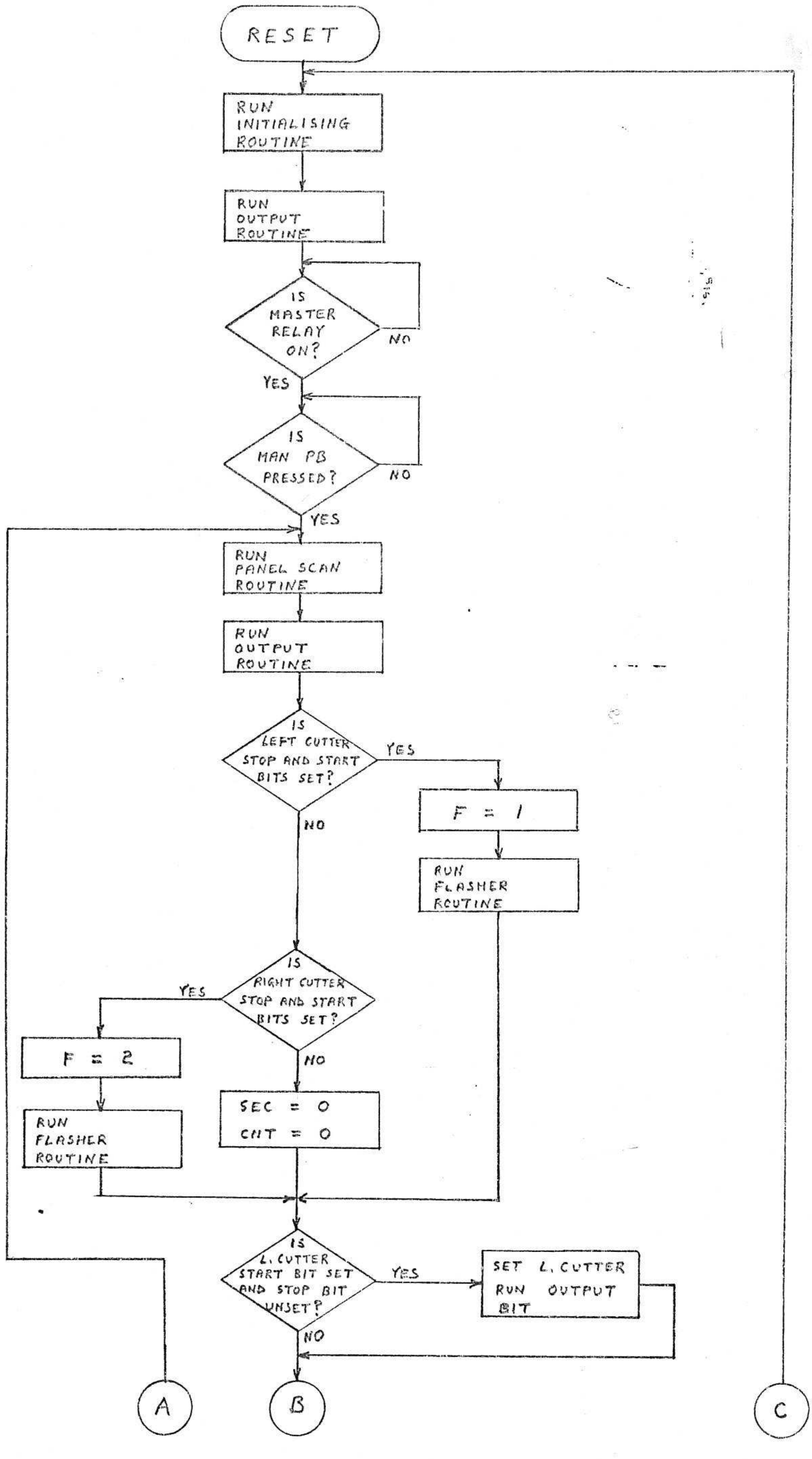


Figure 4.10 Controller Executive Routine (cont)

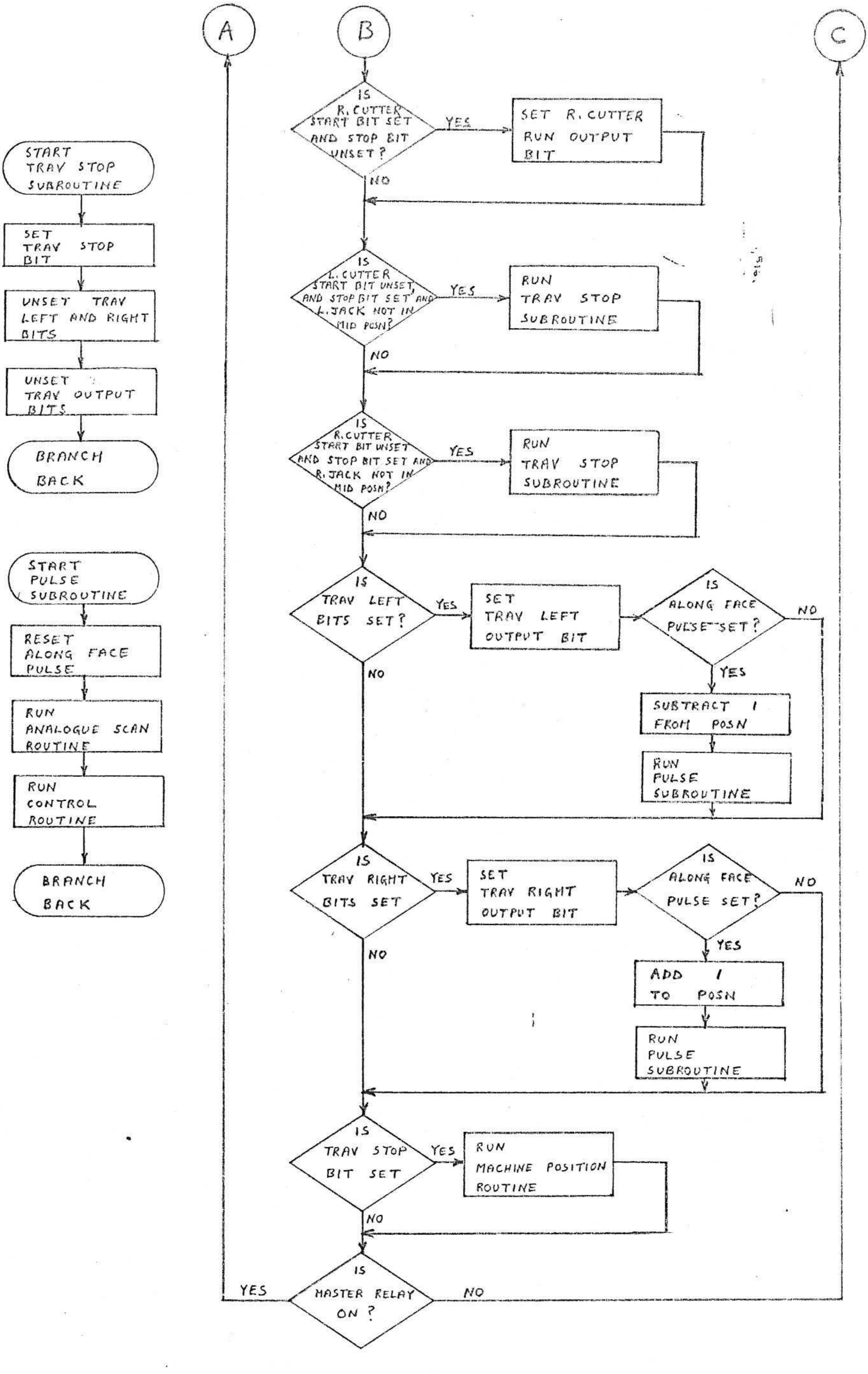


Figure 4.11

PROM PAGE 0

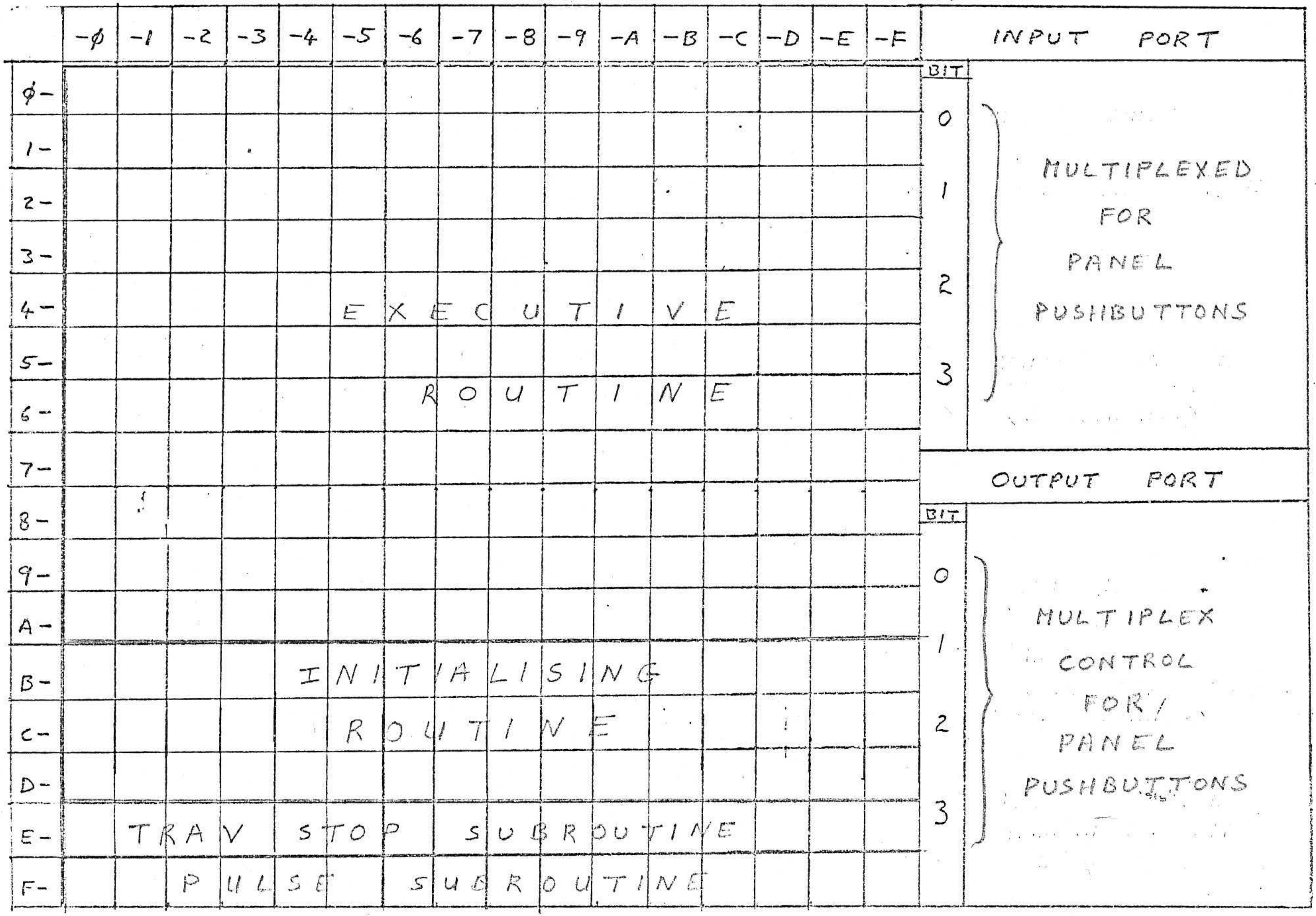


Figure 4.12

PROM PAGE 1

| | -ϕ | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -A | -B | -C | -D | -E | -F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ϕ- | | | | | | | | | | | | | | | | |
| 1- | | | | | | | | | | | | | | | | |
| 2- | | | | | | | | | | | | | | | | |
| 3- | | | | | | | | | | | | | | | | |
| 4- | | | | | | | P | A | N | E | L | | | | | |
| 5- | | | | | | | | S | C | A | N | | | | | |
| 6- | | | | | | | R | O | U T | I | N | E | | | | |
| 7- | | | | | | | | | | | | | | | | |
| 8- | | | | | | | | | | | | | | | | |
| 9- | | | | | | | | | | | | | | | | |
| A- | | | | | | | | | | | | | | | | |
| B- | | | | | | | | | | | | | | | | |
| C- | | | | | | | | | | | | | | | | |
| D- | | | | | | | | | | | | | | | | |
| E- | | | | | | | | | | | | | | | | |
| F- | | | | | | | | | | | | | | | | |

| INPUT PORT | |
|---|---|
| BIT | |
| 0 | 5 ANALOGUE INPUTS MULTIPLEXED EACH 3 X 4 BITS |
| 1 | |
| 2 | |
| 3 | |

| OUTPUT PORT | |
|---|---|
| BIT | |
| 0 | ANALOGUE MULTIPLEX CONTROL FOR 5 INPUTS |
| 1 | |
| 2 | |
| 3 | |

Figure 4.13

PROM PAGE 2

| | -ϕ | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -A | -B | -C | -D | -E | -F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ϕ- | | | | | | | FLASHER | | | | | | | | | |
| 1- | | | | | | | ROUTINE | | | | | | | | | |
| 2- | | | | | | | ANALOGUE | | | | | | | | | |
| 3- | | | | | | | SCAN | | | | | | | | | |
| 4- | | | | | | | ROUTINE | | | | | | | | | |
| 5- | | | | | | | | | | | | | | | | |
| 6- | | | | | | | OUTPUT | | | | | | | | | |
| 7- | | | | | | | ROUTINE | | | | | | | | | |
| 8- | | | | | | | JACK | | | | | | | | | |
| 9- | | | | | | | POSITION | | | | | | | | | |
| A- | | | | | | | ROUTINE | | | | | | | | | |
| B- | | | | | | | | | | | | | | | | |
| C- | | | | | | | MACHINE | | | | | | | | | |
| D- | | | | | | | POSITION | | | | | | | | | |
| E- | | | | | | | ROUTINE | | | | | | | | | |
| F- | | | | | | | | | | | | | | | | |

| INPUT PORT BIT | |
|---|---|
| 0 | MASTER SUPPLY RELAY |
| 1 | |
| 2 | |
| 3 | |

| OUTPUT PORT BIT | |
|---|---|
| 0–3 | MULTIPLEX CONTROL FOR PANEL LIGHTS AND MACHINE POSITION INDICATION |

Figure 4.14

PROM PAGE 3

| | -ϕ | -1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -A | -B | -C | -D | -E | -F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ϕ- | | | | | | | | | | | | | | | | |
| 1- | | | | | | | | | | | | | | | | |
| 2- | | | | | | | | | | | | | | | | |
| 3- | | | | | | | | | | | | | | | | |
| 4- | | | | | | | | | | | | | | | | |
| 5- | | | | | | | CONTROL | | | | | | | | | |
| 6- | | | | | | | | ROUTINE | | | | | | | | |
| 7- | | | | | | | | | | | | | | | | |
| 8- | | | | | | | | | | | | | | | | |
| 9- | | | | | | | | | | | | | | | | |
| A- | | | | | | | | | | | | | | | | |
| B- | | | | | | | | | | | | | | | | |
| C- | | | | | | | | | | | | | | | | |
| D- | | | | | | | | | | | | | | | | |
| E- | | | | | | | | | | | | | | | | |
| F- | | | | | | | | | | | | | | | | |

| INPUT PORT | |
|---|---|
| BIT | |
| 0 | ALONG FACE PULSE |
| 1 | REMOTE COMPUTER AVAILABLE BIT (IF REQUIRED) |
| 2 | |
| 3 | |
| **OUTPUT PORT** | |
| BIT | |
| 0 | MULTIPLEX CONTROL TO REMOTE COMPUTER (IF REQUIRED) |
| 1 | |
| 2 | |
| 3 | DATA READY FOR TRANSMISSION BIT (IF REQUIRED) |

Figure 4.15

## RAM RANK 0

| Registers \ Chars. | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | OUTPUT PORTS | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | | | STATUS | | | | | |
| RAM 0 | 0 | ← STATE BITS (SEE FIG 4.17) → | | | | | | | | | | | | | | | | | | | | 0 | MULTIPLEXED |
| | 1 | ← PUSHBUTTON STATES (AS MUX CONTROL) → | | | | | | | | | | | | | | | | | | | | 1 | FOR PANEL LIGHTS AND |
| | 2 | | | | | | | | | | | | | | | | | | | | | 2 | MACHINE POSITION |
| | 3 | CNT | SEC | F | N | M | | | | | | CUTTER HEIGHT BITS | | | | | | | | | | 3 | INDICATION |
| RAM 1 | 0 | TILT | L. JACK HEIGHT | R. JACK HEIGHT | L. SENSOR | R. SENSOR | L. JACK DEMAND | R. JACK DEMAND | | | | | | | | | | | | | | 0 | MULTIPLEXED |
| | 1 | | | | | | | | | | | | | | | | | | | | | 1 | FOR ANALOGUE DATA TO |
| | 2 | | | | | | | | | | | | | | | | | | | | | 2 | REMOTE COMPUTER |
| | 3 | | | | | | | | | | | | | | | | | | | | | 3 | (IF REQUIRED) |
| RAM 2 | 0 | | | | | | | | | | | | | | | | | | | | | 0 | LEFT JACK DOWN |
| | 1 | | | | | | | | | | | | | | | | | | | | | 1 | LEFT JACK UP |
| | 2 | | | | | | | | | | | | | | | | | | | | | 2 | RIGHT JACK DOWN |
| | 3 | | | | | | | | | | | | | | | | | | | | | 3 | RIGHT JACK UP |
| RAM 3 | 0 | | | | | | | | | | | | | | | | | | | | | 0 | MULTIPLEX CONTROL FOR |
| | 1 | | | | | | | | | | | | | | | | | | | | | 1 | 3 CHARACTERS FOR ANALOGUE |
| | 2 | | | | | | | | | | | | | | | | | | | | | 2 | INPUTS. |
| | 3 | | | | | | | | | | | | | | | | | | | | | 3 | STROBE CONTROL FOR ANALOGUE MULTIPLEXOR |

Figure 4.16 Panel Scan Routine

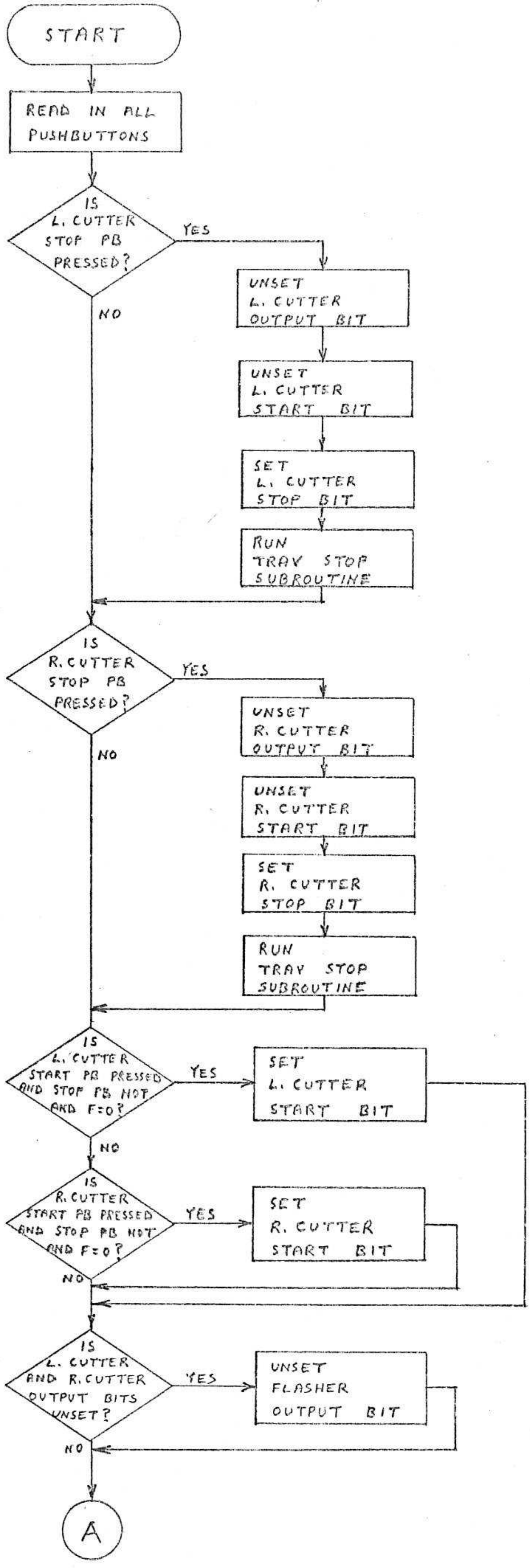


Figure 4.16 Panel Scan Routine (cont)

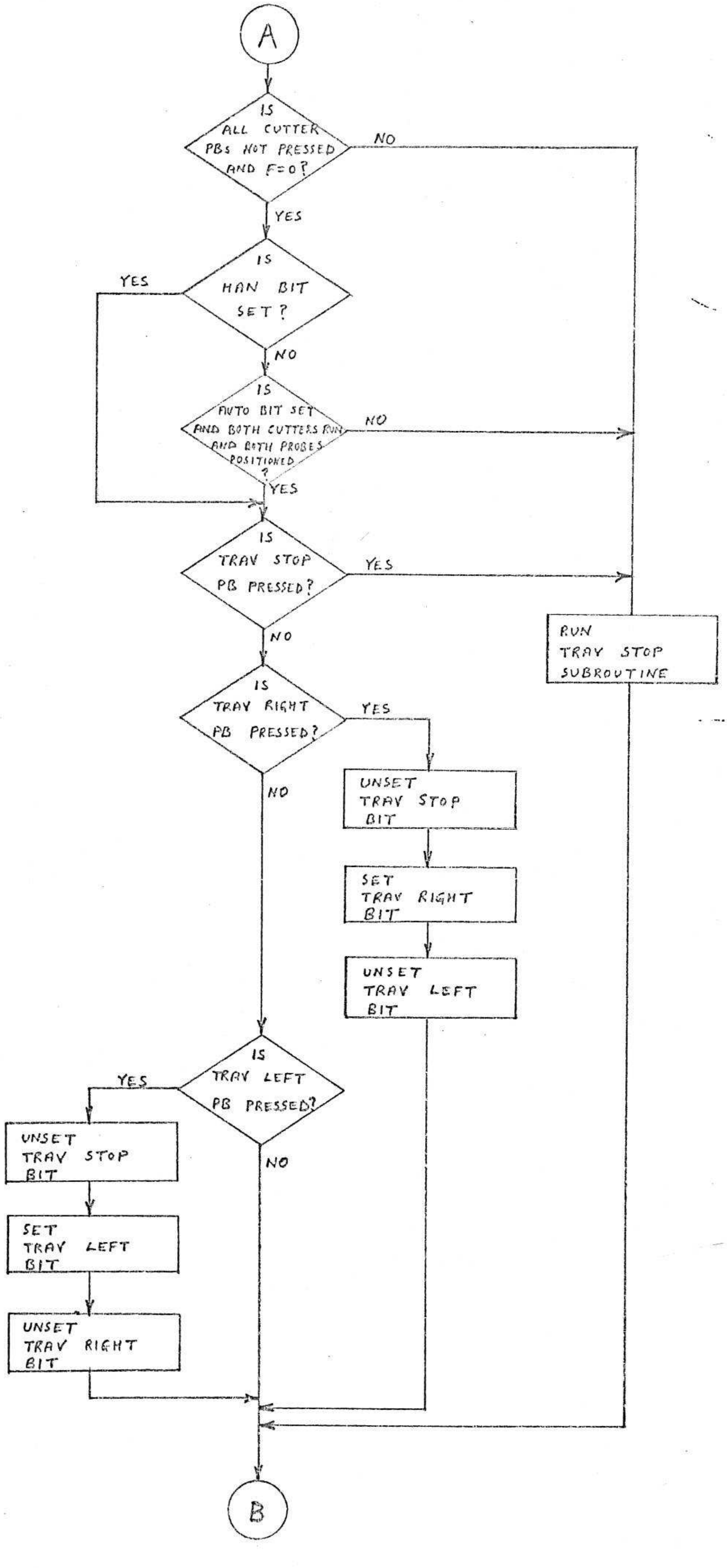


Figure 4.16 Panel Scan Routine (cont)

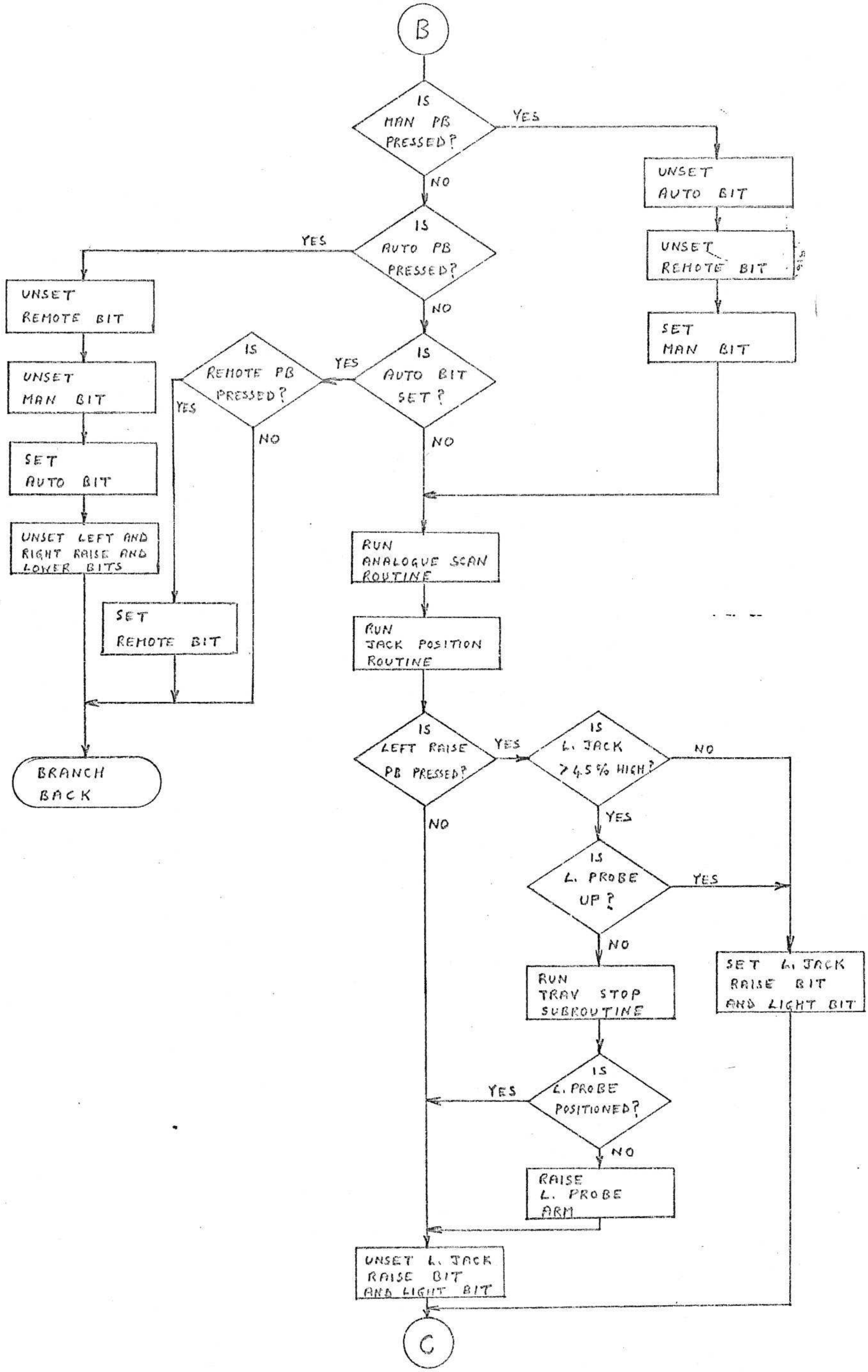


Figure 4.16 Panel Scan Routine (cont)

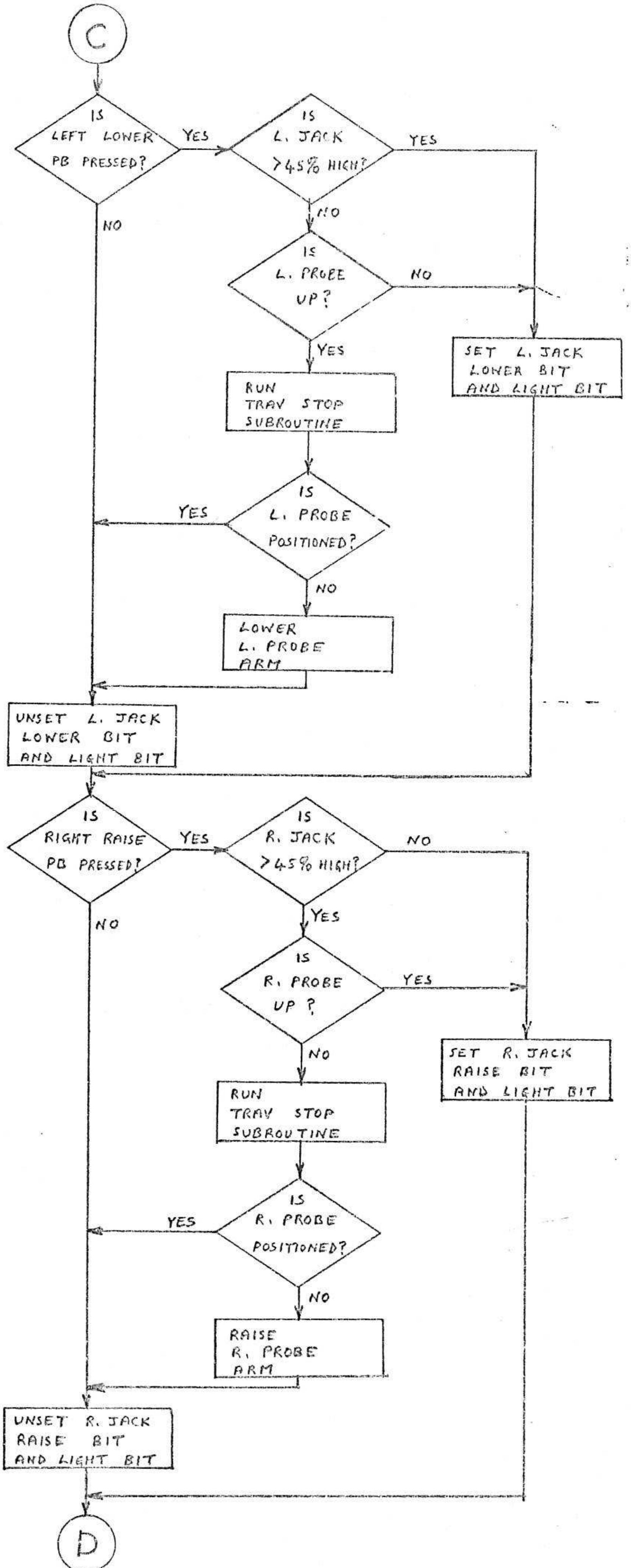


Figure 4.16 Panel Scan Routine (cont)

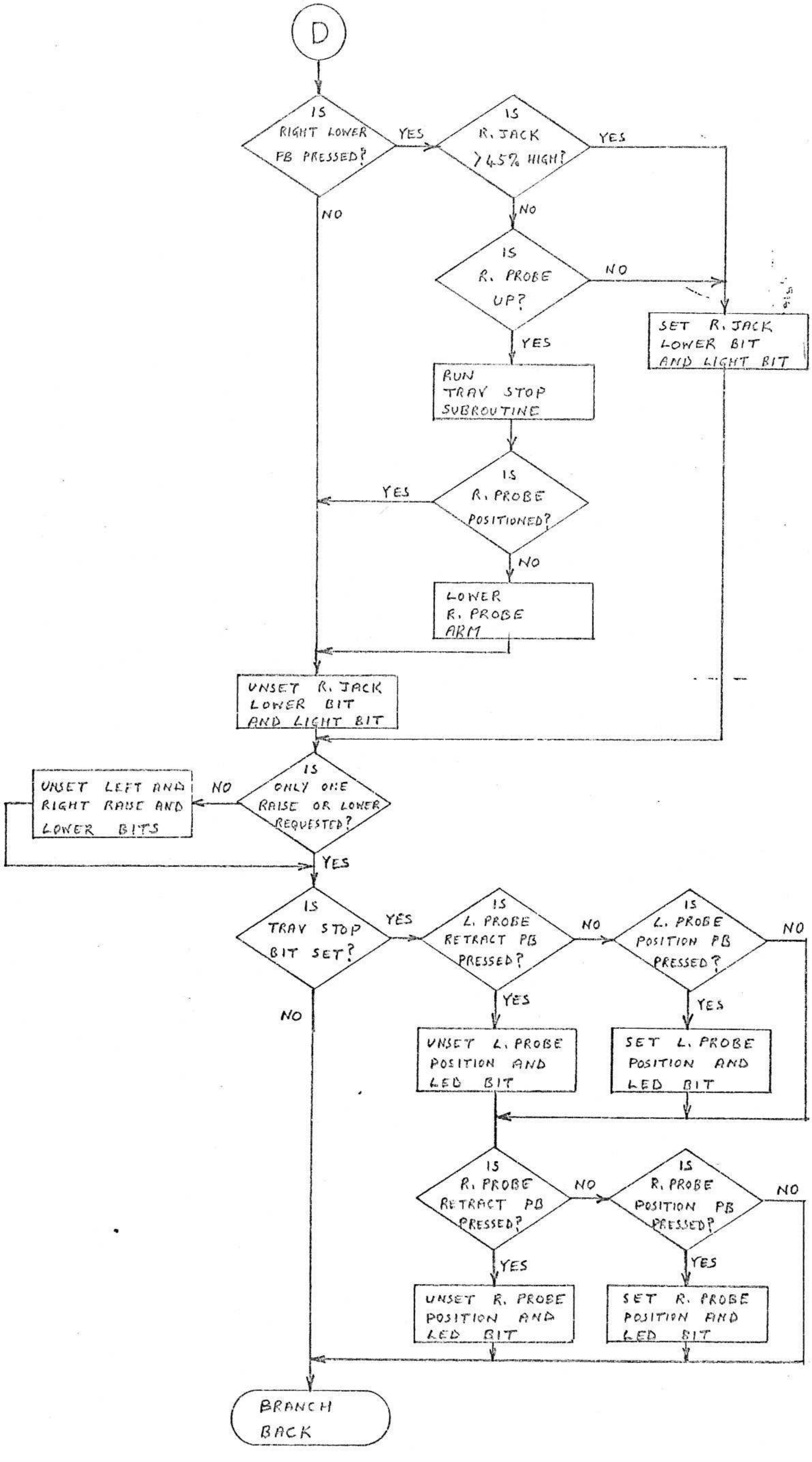


Figure 4.17

Storage of State Bits in RAM 0 Register 0

| Character | Bits | Description |
|---|---|---|
| 1 | 0 | Left cutter stop bit |
| | 1 | Left cutter start bit |
| 2 | 0 | Right cutter stop bit |
| | 1 | Right cutter start bit |
| 3 | 0 | - |
| | 1 | Manual bit |
| | 2 | Auto bit |
| | 3 | Remote bit |
| 4 | 0-3 | Machine position units in BCD |
| 5 | 0-3 | Machine position tens in BCD |
| 6 | 0-3 | Machine position hundreds in BCD |
| 7 | 0 | - |
| | 1 | Traverse ← bit |
| | 2 | Traverse stop bit |
| | 3 | Traverse → bit |
| 8 | 0 | Left jack raise bit |
| | 1 | Left jack lower bit |
| | 2 | Right jack raise bit |
| | 3 | Right jack lower bit |
| 10 | 0 | Left cutter up bit |
| | 1 | Left probe positioned bit |
| | 2 | Left probe retracted bit |
| | 3 | Left cutter down bit |
| 11 | 0 | Right cutter up bit |
| | 1 | Right probe positioned bit |
| | 2 | Right probe retracted bit |
| | 3 | Right cutter down bit |
| 13 | 0 | Flasher light bit |
| | 1 | - |
| | 2 | Left cutter run bit |
| | 3 | Right cutter run bit |
| 14 | 0 | Left probe up bit |
| | 1 | Right probe up bit |
| | 2 | Position left probe bit |
| | 3 | Position right probe bit |
| 15 | 0 | - |
| | 1 | - |
| | 2 | Traverse start |
| | 3 | Traverse ← (=0) or →(=1) |

Figure 4.18

Output Routine

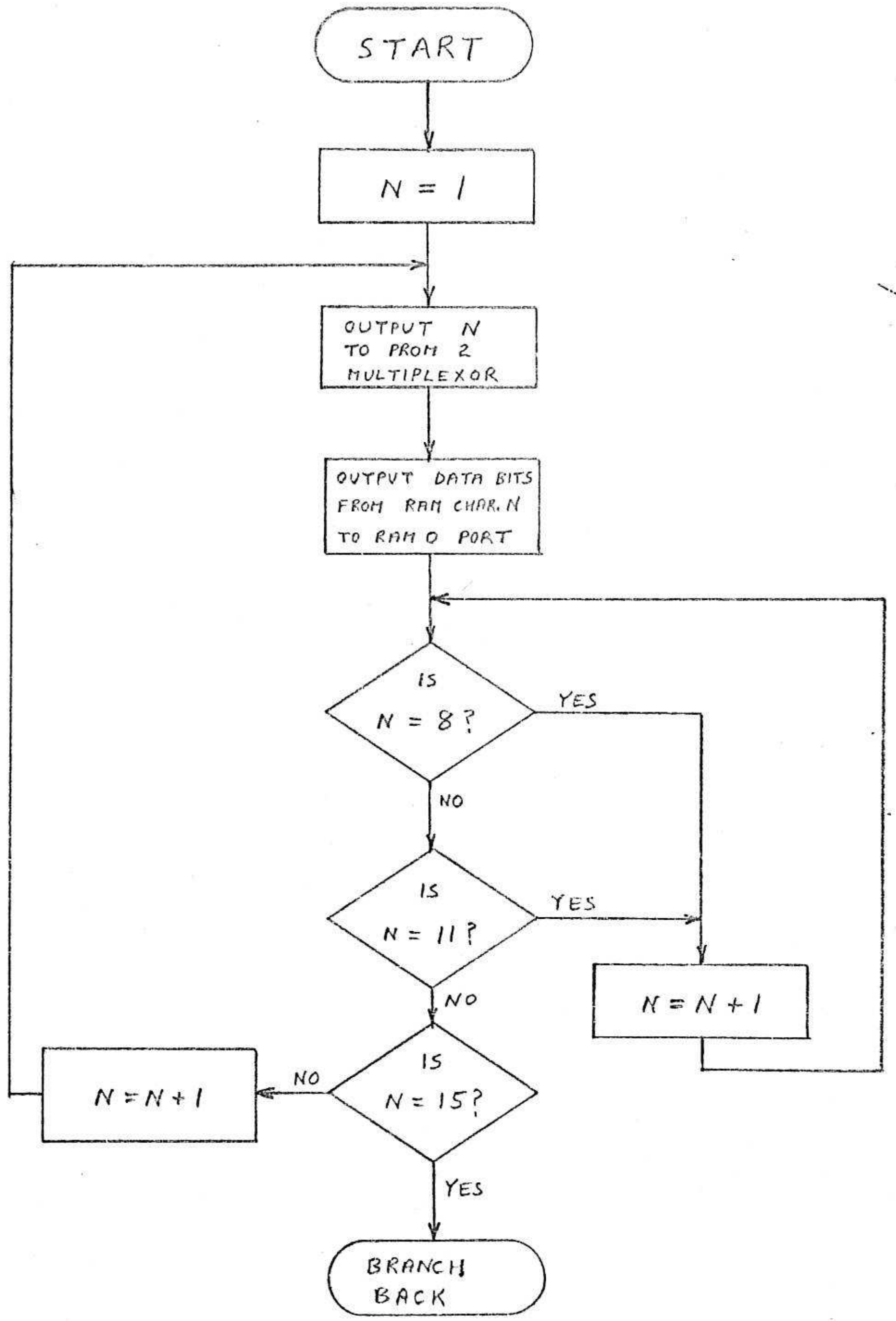


Figure 4.19 Initialising Routine

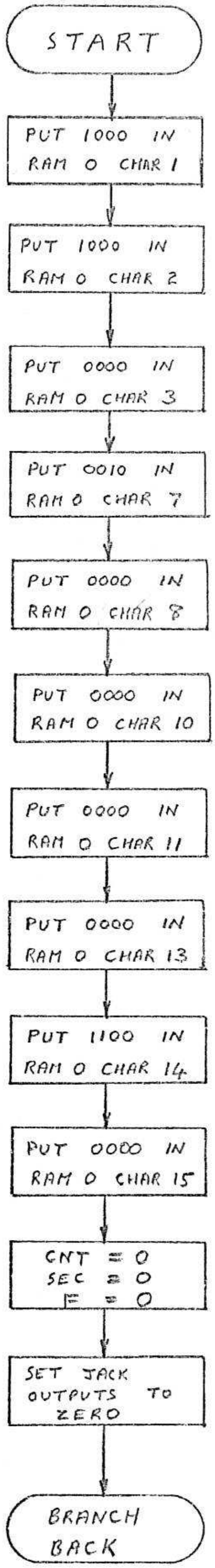


Figure 4.20 Flasher Routine

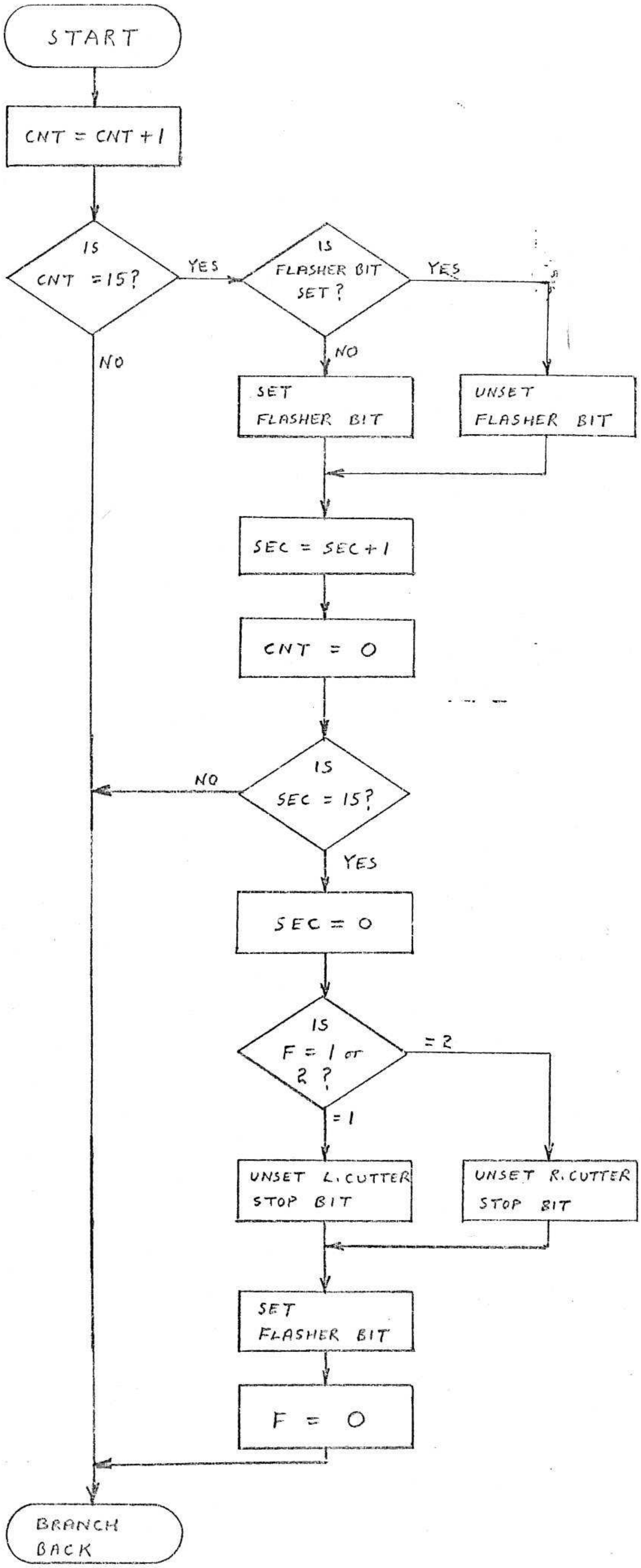


Figure 4.21 Jack Position Routine

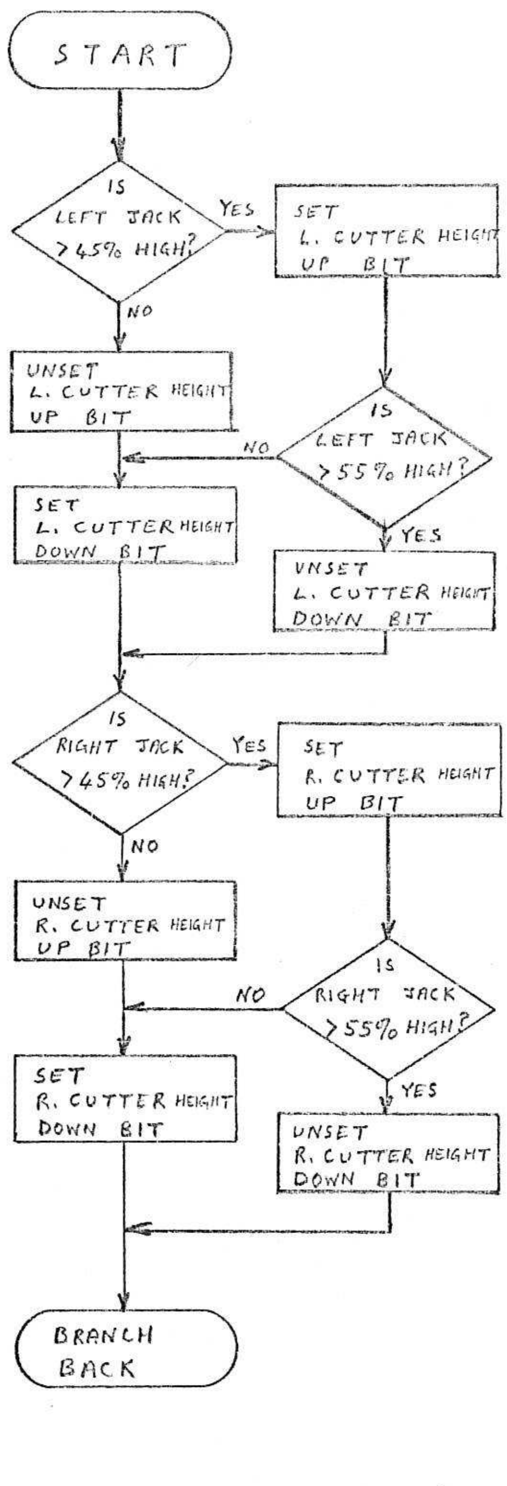


Figure 4.22 Analogue Scan Routine

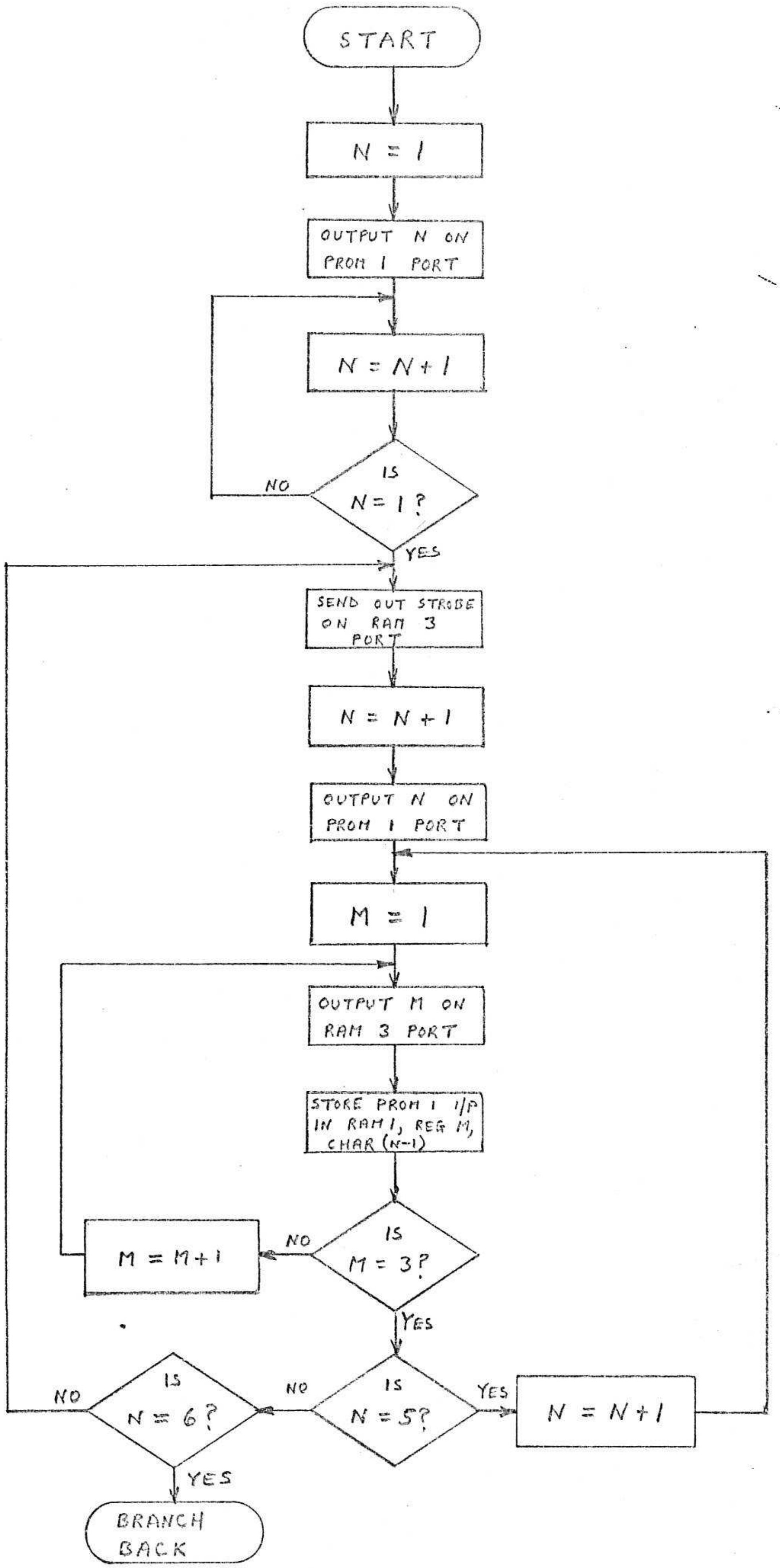


Figure 4.23 Machine Position Routine