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THE COLLEGE OF AERONAUTICS

(Proposed Cranfield Institute of Technology)

DEPARTMENT OF PRODUCTION ENGINEERING

DESIGN PROJECT 1968/69

REPORT OF THE CONTROL AND MOTIVATION COMMITTEE

DESIGN OF THE CONTROL SYSTEM FOR A VERSATILE AUTOMATIC ASSEMBLY MACHINE

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SUMMARY

Methods of control for automatic assembly machines are surveyed. The control requirements of the versatile automatic assembly machine are analysed, and the most practical system is specified and designed in detail.

CONTENTS

1.0 INTRODUCTION

This report is one of a series which give full details of the design project 1968/69. A Management Report is available which summarises the work done and the conclusions reached during the course of the project.

The report describes the detailed design of the complete control system for a versatile automatic assembly machine. The machine design is described in reports from the Assembly Analysis and Assembly Process Committees, (Ref 2 and 3).

The machine operates on a free transfer system where assemblies are built up on independent platens on a free moving track. For an assembly operation a platen is stopped, lifted off the track, operated on, and then released back on to the track. The operations are carried out by independent assembly heads.

It was the responsibility of the Control and Motivation Committee to devise a system for complete control of the machine and its functions, with the emphasis on modular construction for the purpose of versatility.

2.0 INVESTIGATION INTO CONTROL SYSTEMS

In order that the best method of control for the machine could be determined, it was decided to investigate all available practical systems. It was found that the control requirements for an automatic assembly machine could be conveniently divided into three main functions: "sensing", "decision", and "actuation".

Sensors must be provided to keep track of components and assemblies on the machine, and to sense the state of operation; they must also provide appropriate signals.

The decision function must contain the logic needed to analyse the signals from the sensors, and to make the decisions so that actuation may be initiated where necessary. Outgoing signals from this logic are needed for the initiation.

Actuation devices operating on the signals received from the decision logic must carry out the required movements.

Elements for carrying out the above three functions are available in the fields of electrics, hydraulics, pneumatics and mechanics, and are summarised in figure CM/01.

These elements are described and considered in detail in relation to the present application in Appendix 1.

3.0 PROBABLE CONTROL AND MOTIVATION SYSTEMS

Combinations of the varieties of sensors, logic for decision, and actuation devices can produce a large variety of integrated systems. In practice, they are limited by availability of practical interfaces to those shown in figure CM/02.

This figure shows the probable interface combinations. It can be seen that any assembly operation will require mechanical movement, and so all forms of actuation device lead to the mechanical motion.

There are no interface connections from mechanical sensors or logic because pure mechanical sensing can only operate levers, and pure mechanical logic, e.g. cams, can only cause mechanical movement. The exception to this is the use of mechanical sensing with hydraulic logic, e.g. copying heads, which would only be used to control hydraulic actuating mechanisms when the required forces demand them.

From the systems shown in figure CM/02 the first consideration is the control, based on pure mechanical operation. As stated in the section on mechanical elements, in Appendix 1, a system for control of a machine, based on a free flow transfer principle, would require a separate mechanical power supply for each module, which would be expensive. Because of the additional problems of building decision logic into such a control system it was decided that a mechanical system would be impractical for this application.

Secondly, hydraulic operation has its advantages in the power that can be applied. The proposed machine has no requirement for such power, so the added cost of hydraulics over the practical alternative of pneumatics would not be justified.

The other systems for consideration are based on the use of air and electricity.

It is possible to control and activate an assembly machine using almost any combination of these two quantities. Linear motion can be supplied by electric or pneumatic means but electrically it is difficult to obtain the desired control of the linear motions. Therefore, because it is more practical, and cheaper, it was decided to use pneumatic cylinders for all linear motion required on the machine.

Rotary motion can be provided electrically or pneumatically so both were considered.

The remaining systems on figure CM/02 are made up of combinations of electric and pneumatic elements. The problems of providing satisfactory interfaces are such that combinations of these two types of sensing and decision elements should be avoided unless such a combination becomes highly beneficial. For this reason the following systems were considered in detail:

1 Electric sensors, electric decision logic, pneumatic actuation.

2 Pneumatic sensors, pneumatic decision logic, pneumatic actuation.

From the survey of elements, in Appendix 1, it is apparent that, within these two systems, the most practical combinations of elements for the present application are as follows:

1 micro-switch and photocell electric sensors, electric relay decision logic, pneumatic cylinder actuation;

2 micro-switch and photocell electric sensors, integrated circuit decision logic, pneumatic cylinder actuation;

3 fluidic sensors, turbulence amplifier decision logic, pneumatic cylinder actuation.

The final decision on the selection of the most suitable control system is based on comparison of these three in terms of cost and the requirements of the particular application.

4.0 CONTROL REQUIREMENTS

The control requirements for the versatile automatic assembly machine were divided into two sections:

1 Requirements to provide safe effective control.

(a) Central Control
In order that an overall picture of the state of the machine could be obtained at any time it was thought necessary to provide a central display to give this information. This would take the form of a central console, and, as well as providing remote control of machine functions, would also house all standard logic units to simplify maintenance and fault rectification.

(b) Switch Selection
For a versatile machine which may be required to assemble different combinations of components it was decided that, as far as possible, the change over from one combination to another should be made automatic through a selection switch.

(c) Machine Malfunction

Additional control should also include some means of detecting malfunctions of the machine caused by improper sequencing, feeder jams, and faulty components, to safeguard the machine and operator, and to reduce machine shut down time.

2 Requirements as specified by the Design Committee

(a) Conveyor Drive
It was necessary to provide a power unit to drive the platen transfer system (Ref. 3)

(b) Platen Control

For each assembly operation a platen has to be stopped, lifted from the track, for location, and replaced on the track after completion of the operation (Ref. 3)

(c) Assembly Head Control

For the majority of assembly operations, control was required for a standard pick and place unit. This involved the control of sequential movements in two planes. (Ref. 2) Special control requirements were also specified for some fixing heads, (Ref.3.) and manufacturing heads (Ref.4.).

(d) Feeders and Escapements

For the supply of components to the assembly heads control was required of various feeders and escapements as specified, (Ref.4.).

In addition, with a free flow transfer machine, assembly operations may be at any phase of their cycle. To facilitate machine start up and shut down it is, therefore, necessary to provide some form of automatic control, both of power supplies at start up and at run down, to guarantee that the machine stops at a predetermined position.

The following sections of this report describe the design of each of the above areas of control in detail. Because the two main areas of control are those for the platen and for the standard pick and place head, circuits for these functions were fully designed using the three practical systems outlined in section 3.0 for the selection of the final system used.

5.0 CENTRAL CONTROL CONSOLE

The control panel carries a column of indicators for each assembly station, and switches to control various machine functions which are discussed in the following three sections.

The indicators show the following states of an assembly head:

S Station has been selected for operation.

A Assembly cycle has started.

C Assembly operation is completed.

F Feeder track is empty.

R Rejects from this station are excessive.

These indicators have been chosen to give a visual indication of the state of operation of the complete machine and, in addition, to enable areas of machine breakdown to be pinpointed.

The S indicators show which stations are in operation. These would normally be selected by the select switch described in section 6. However, the S indicator is also a push-button switch to enable manual selection of different station combinations. This selection can only be initiated when the select switch is turned to the program position. In all other positions the push button selection will be inhibited. The manual selection facility is provided to enable any head to be run independently, and any combination of stations to be utilised, without the necessity for reprogramming the automatic selection facility.

The A and C indicators show the start and finish of each assembly cycle. A is initiated by the assembly start signal from the platen control, and remains on during the assembly cycle. When the assembly is completed, a signal is received from the pick and place unit, or other head, which switches on indicator C. Indicator A will be switched off when the platen is returned to the track, while indicator C remains on until the platen is clear of the station. In the event of a head malfunction during its assembly cycle, this system of indicators gives a quick and clear indication to the operator as to which station is at fault.

The F indicator shows when the supply of components to this station reaches a low level. The sensor for this indicator is placed in the supply track from the feeder at such a position that ample warning may be given of impending component shortage. Component shortage on any station will activate a beacon on the console for additional warning.

The R indicator shows that rejects from a station are more than expected from considerations of component quality as outlined in section 7. Excessive rejects signalled from any head will stop that station and activate the beacon.

The column of indicators for each station is carried on a plug-in frame, which will also house modular controls for that station. The console will also carry main power supplies and start and stop control logic.

The control panel is shown in drawing CM/03.

6.0 SWITCH SELECTION

There are several varieties of switch to be assembled. Each type requires a different combination of assembly heads to be in operation.

To set up the machine to produce a particular switch type can be done in several ways. Each stage of the assembly process can be considered individually, and can be switched on or off according to the requirements of the switch to be produced. This method involves considerable effort, and gives plenty of chance for mistakes to be made which may jam the machine. It does, however, keep the versatility of the machine at a maximum as any combination of assembly heads is possible.

This versatility is desirable, but a simpler system is required to reduce the chance of error. It would be ideal to have a switch on the control panel with which each variety of assembly could be selected, while still retaining the ability for selecting any required sequence.

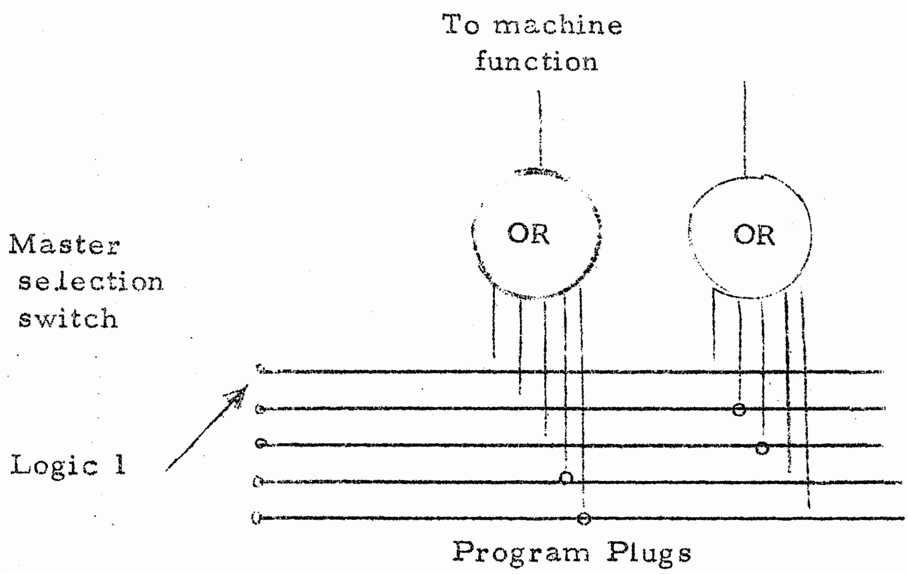
There are eight operations on the eleven stations of the proposed machine which vary according to which of the five varieties of switch is being assembled. Therefore, an automatic selection signal is required to be sent to all stations which are required to operate. Signals for station selection and for different station functions are needed so that the operation can be varied according to the assembly.

The selection combination for the heavy duty switch assemblies is shown on drawing CM/05. This shows that, as an example, for the five varieties of switch a total of eighteen programmed signals is required for the eight varying stations in addition to eleven station select signals. Stations which are not selected in any combination will allow platens to pass straight through without any operations being performed.

As stated in section 5.0, on the central control console, the override programming facility is provided by button switches. A sixth position of the master selection switch will provide supply to the selection buttons. In any of the five preprogrammed switch positions the programming facility will, therefore, be inhibited. In order that the control of the switch selection, and the programming facility, may be out of the hands of the machine operator, the selection switch will be key operated, the key being under the control of supervisory or skilled maintenance personnel.

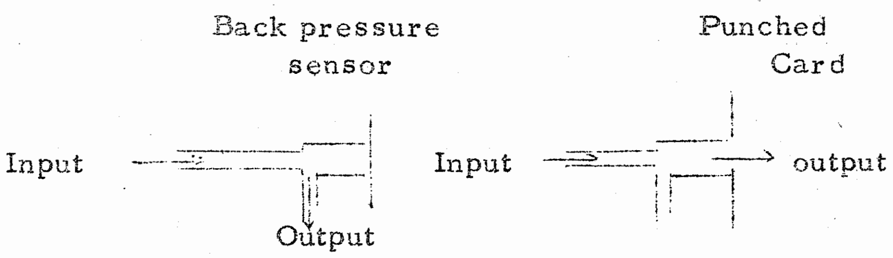
a) Electrical

A circuit, designed for easy selection of these five combinations, is shown below. This takes the form of a plug board which can be programmed to give the correct combination of assembly operations for each variety of switch. Each selection position of the master selection switch puts a logic "1" signal on to a line of the plug board; each plug in the line will send a control signal to a machine function through an OR gate - the OR gate is included to prevent feedback to other lines on the plug board.



b) Pneumatic

To obtain a similar result with a pneumatic system the station select switch for each operation will be positioned on the control panel. The switches will be in line and fixed such that the output connection from the switches can be interrupted with a card. A punched card will be inserted with holes in it such that only when the back pressure sensor is blocked will the operation be in action. A punched card will be available for each type of switch, and all station select switches can be left "on" when a blank card is inserted. In this state, for manual selection of stations, individual stations can be switched off by the operator.



7.0 MACHINE MALFUNCTION

The proposed machine is designed to assemble up to thirty separate components into switch assemblies. Evidence from the report of the Economic Planning Committee (Ref. 5, shows that the quality of supplied components will probably be in the region of 1% defective, which means that bad components will be fed into the machine at regular intervals. These bad components may have different effects, depending on the degree of their defectiveness, but they may jam the feeders, prevent satisfactory assembly, or even cause damage to the machine. It is, therefore, necessary to provide some form of detection to prevent such malfunctions to safeguard both the machine and the operators.

The control, resulting from the detection of this type of malfunction, can take two forms. It can be the type known as "instantaneous control" where the machine, or in this case the assembly module, is stopped as soon as malfunction is detected. This results in lost production time for every malfunction, and with thirty components 1% defective the lost time could be considerable.

The second type of control is known as a "memory system control" which, in the ideal case enables the machine to take corrective action to rectify a malfunction, but, more practically, detects a misassembly at a particular stage and differentiates between acceptable and rejected assemblies.

It was necessary to evaluate the requirements of the proposed machine to lay down some general requirements for a memory system control which would apply to a wide range of components. It was decided that the switch assemblies were a reasonable example of the type of assembly that would, in general, be assembled on the machine. A detailed investigation was carried out into these particular components and some general rules were extracted on which the provision of a memory system type of control was based. The report of this investigation is included as Appendix 11.

From the conclusions of this report several of the recommendations were adopted:

Control was built into the system so that detectors could sense whether or not the downward stroke of the placing mechanism had been completed. The pick and place head is sprung loaded in this direction, and not under pneumatic actuation. Thus any obstruction to the downward motion, such as a misaligned component, would halt the head. Two detectors are sited in the head, one to sense when the components are about to be placed into the assembly, and one to sense when the placing motion is completed. In the control these detectors are connected by a time delay and, if the second detector is not actuated within a certain time after the first, the placing cycle is continued by opening the jaws and raising the head, and the assembly is marked as a reject.

The marking system used is that recommended by the investigation report, Appendix 11, where a lever on the platen is moved by a piston into a "reject" position.

The position of this lever is sensed at subsequent stations and no work is done on the assembly carried by this platen. At the station which removes assemblies from the platen, those marked as rejects are rejected without a functional check.

The report suggests that, for certain components, it is necessary to provide some form of detection to guarantee that they have been placed into the assembly as their presence cannot be confirmed through the functional check.

This type of detection is practically very difficult to do and, at the same time, it was thought advisable not to distinguish between particular components but to provide some form of check which applied to all components so that versatility of operation could be maintained. This was done by putting detectors in the pick position so that no assembly operation can be carried out unless components are available. This does not guarantee that they are present in the completed assembly, but once the pick and place mechanism is fully adjusted then, if components are available and the assembly operation is successful, there is a high probability that the components have been placed in position in the assembly.

The final recommendation of the report was to include on each head a counter which should give warning if three successive misassemblies are detected. It was decided that this was applicable only to those stations where the complete control system had been designed by this Committee. In particular, the counter could not be included on the cover assembly station because of the reasons outlined in the report.

These counters take the form of a simple combination of two flip-flops which count misassemblies, but are reset to zero every time a successful assembly operation is carried out. If the count reaches three the station is stopped, the rejects high indicator for that station is activated on the central control panel, and the control console beacon is lit to give warning to the operator. This sequence is also activated every time a misassembly on the cover station is dected.

8.0 CONVEYOR DRIVE

The conveyor is required to run within a speed range of 10 ft/min (0.05 m/s) - 30 ft/min (0.15 m/s) as stated by the Assembly Process Committee. The conveyor, when set at a certain speed, will maintain the speed throughout the assembly of one type of product. The horse power of the conveyor motor is 0.5 (0.375 kw) at 30 ft/min (0.1 m/s), which was calculated, see Appendix 111, by considering full buffer stock before each work station, the lengths of buffer stock being 6 ft (1830 mm). The motor can either drive the conveyor directly through the sprocket, or can be coupled to the conveyor through gearboxes and pulleys to obtain the required speeds.

Determination of Type of Motor

There are three types of motor available:

(1) Electric
(2) Hydraulic
(3) Pneumatic

From the survey of elements, in Appendix 1, it can be seen that:

(a) As the machine does not require any hydraulic actuation, the extra cost incurred in obtaining auxiliary equipment, such as pump, filters, etc., makes an hydraulic motor unsuitable.

(b) Pneumatic motors are generally more expensive than electric motors, and environmental conditions do not require the use of such a motor. Also, they are very noisey and require an exhaust system to reduce the noise.

It was, therefore, decided to use a squirrel cage motor, running at a synchronous speed, driving the conveyor through a worm reduction gearbox and pulleys, as shown in Fig. CM/05. The reasons for choosing such a method are given below:-

(a) Conveyor speed is constant and alteration in speed is only required initially when setting for greatest assembly efficiency. Therefore, by using pulleys, a constant speed motor can be used, with limited speed control.

(b) The squirrel cage motor is the cheapest, and most robust, of all electric motors.

Design of Modular System

Specification of Motor

Type:	Totally enclosed fan - cooled - cage motor, manufactured by Brook Motors Limited
Horse Power:	0.5 (0.375 kw)
Syn. & Speed:	1000 rev/min
Frame Size:	D80a
Cost:	£13.12.0

Speeds required from conveyor:

15, 20, 25, and 30 ft/min (0.075, 0.100, 0.125, 0.015 m/sec).

When using a 10.5 in (26.6 mm) pitch circle diameter sprocket, the speed of sprockets are 5.49, 7.32, 0.15, 11 rev/min. The speed of motor is constant at 1000 rev/min, therefore giving total overall ratios of 182.1 to 1, 136.6 to 1, 109.3 to 1, and 90.91 to 1.

A worm reduction gearbox is used with a gear ratio of 50 to 1, and the ratios required from the pulleys are, therefore, 3.64, 2.73, 2.18 and 1.82.

It was decided to use V belt pulleys because of the high velocity ratio between the two shafts. The V belt used is produced by J H Fenner Co Ltd., and the calculations for size of pulleys are arrived at from data given in the Fenner catalogue. These calculations are shown in Appendices 1 and 11.

Specification of Belt:

Type: Spacesaver wedge belt Alpha section 425

Supplier: Fenner Power Transmission

Belt Pitch Length: 42.5 in (108 mm)

Cost: 8/6d

Pulleys:

The layout of pulleys is shown in Fig. CM/05

Motor Pulleys OD = 2.5 (53.5 mm), 3.15 (80 mm)
3.7 (94 mm), 4.25 (108 mm)
Gearbox Pulleys OD = 9.1 (231 mm), 8.60 (218 mm)
8.06 (205 mm), 7.24 (196 mm)
V angle for Motor Pulleys = 38^{0}) As given
V angle for Gearbox Pulleys = 40^{0}) in the Fenner
Depth of V groove = 0.350 in (8.9 mm)) Catalogue.

The reduction gearbox was required to have a ratio of 50 to 1 to obtain correct sprocket speeds, and to be of worm and pinion type in order to obtain a right angle drive. The worm is required to be right handed for correct direction of rotation of the sprocket.

Specification of gearbox used in Fig. CM/05

Type:	Worm gearbox (Dapta-gear D G O 3, Mounting 6)
Supplier:	Opperman Gears Ltd
Ratio:	50 to 1
Worm:	Right handed
Cost:	£16.5.0.

9.0 PLATEN CONTROL

From the requirements outlined in sections 4.0 to 7.0, the platen control must be designed to provide the following sequence of operations.

Platens on the conveyor are either normal, or are marked as carrying a reject assembly. When a reject platen enters a selected assembly station it must be allowed through without being operated. on. If there is no room in the succeeding buffer store the platen should be stopped in the station until room is available.

When a normal platen enters a selected assembly station it must be stopped, and following platens must be halted in the preceeding buffer store. The platen must then be lifted from the conveyor and the assembly operation carried out. When the assembly operation is completed the platen is returned to the conveyor, and released from the station when there is room in the succeeding buffer store.

To carry out the above sequence of operations the following detailed control was adopted, and is shown in flow chart CM/06. At an empty assembly station, the buffer-stop is withdrawn, and the station stop is extended. As a platen enters the station a sensor will register whether or not the platen is marked as carrying a rejected assembly. If a reject is sensed, the signal will cause the station-stop to withdraw when there is room in the succeeding buffer and the assembly passes through. The reject signal also inhibits all assembly operations.

If the platen is normal, no reject is sensed and the platen continues to the station stop. Its arrival is detected by a sensor which sends a signal to extend the buffer stop, and to a jacking mechanism which raises the platen. When the platen is sensed to be in position, a signal is sent to the assembly head to start its operating cycle.

Upon completion of the assembly operation a signal is sent from the assembly head logic to the platen control, the jack is lowered, and when there is room in the succeeding buffer both buffer and station-stops are withdrawn. When the outgoing platen is sensed clear of the station, the station-stop is extended. The cycle is now completed, and the station is ready for the next platen.

Also required in the platen control are logic circuits for the special conditions of machine start up, run down, and when a station is not selected.

At machine run down all the buffer stops are biased in the extended position so that on completion of each assembly operation no further platen will be worked on, causing the machine to run down and stop. When all stations are halted the machine is automatically switched off, as described in section 14.0

On machine start up, buffer-stops are retracted only when stations are clear, allowing normal cycling to start.

When a station is not selected, buffer-stops and station-stops are biased in the withdrawn position so that all platens are let through without being worked on.

Platen control circuits for the three practical systems selected in section 3.0 were designed in full detail and are shown in drawings CM/07 to CM/09

10.0 STANDARD PICK AND PLACE HEAD CONTROL

From the requirements specified by the Design Committee (Ref. 1.) control is required for the following sequence of operations.

The pick and place head picks up a component, or components, from a position on the outside of the track, and on a signal from the platen control places them into the assembly.

The control for these operations is purely sequential; the sensing of the completion of one action giving the signal for starting the next. The detailed control sequence for these actions is shown in the flow chart CM/10

When in use, the idle position of the pick and place head is with the jaw closed, holding components above the assembly. On the signal that the jack is up, the head moves down to the assembly. When the components are in position the jaws open, and the head moves up clear of the assembly. In this position a signal is sent to the platen control that the assembly operation is complete. The head then moves sequentially to pick up more components and returns to its idle position. If components are not available the head stops.

If the head does not reach its final place position, it is assumed that the assembly operation has been unsuccessful. A signal is sent to the reject counter, and also to identify the platen as carrying a reject assembly.

Also required in the pick and place head control are logic circuits for the special condition of machine run down. When the machine is stopped the pick and place head operation is inhibited from further sequencing so that the head remains in the pick position with the jaws open after movement 4 on drawing CM/10.

Pick and place control circuits for the three practical systems selected in section 3.0 were designed in full detail and are shown in drawings CM/11 to CM13.

11.0 SELECTION OF CONTROL SYSTEM

Circuits have now been designed for control of the platen and the pick and place head using the three practical systems outlined in section 3.0

For each system the component costs have been summated to give an approximate comparison. These are summarised below.

	Pneumatic	Electronic	Relay
Platen Control	£62	£44	£41
Pick and place head control	£68	£94	£75

These costs illustrate the fundamental difference between the two sections. The platen control involves considerable decision logic to separate the various states that can be met, while the pick and place head control is a matter of controlling sequential operations.

Because of the pneumatic actuation of the head, fluidic control is more practical because of the elimination of interfaces.

It was also found that by using fluidic sensors, the size of the pick and place clamp unit could be made much smaller than by using any other type of sensor.

It is, therefore, cheaper and simpler to use fluidics, controlling the sequential pneumatic operations. The decision logic, on the other hand, is very much cheaper, and less bulky, when built up out of electronic units, than when built from fluidic units. Relays are cheaper still, but are bulky.

If the costing is taken as the main criterion, and it has been shown that in this case the cheapest systems are also the simplest, then the final suggested system would seem to be platen control with electric sensing and electric relay logic, and pick and place control with fluidic sensing and sequencing of pneumatic movements.

This system would make the most of the advantages of both types of control used, but there are two main objections. The first is the argument that mixed systems produce interface problems. This is true, but as some of the special purpose heads are electric, and as the conveyor drive is electric, some combination of systems cannot be avoided. Because the operation of the pick and place head is so contained, there are in fact only four air/electric interfaces, and one of these can be eliminated cheaply by providing duplicate sensors. The second objection is to the use of relays. Although the life of a relay can be measured in millions of operations, there is always a finite life to such a device. For a machine which is designed with versatility in mind we would hope that the useful life of the machine would outlive that of a relay. This would mean that in the future a time would come when the relay logic would need replacing, preceded by a period of reduced reliability. Relays also compare unfavourably with electronics when their relative merits in circuit building, debugging and maintenance are considered.

As the additional cost of providing electronic platen control is relatively low, and taking into account the advantages stated, electronic logic is the best for this application.

The machine control system is, therefore, made up of the following:

1 Pick and place head, fluidic sensors, turbulence amplifier logic, pneumatic cylinders. The circuit is that shown in drawing CM/13, and its operation is fully described in Appendix IV.

2 Platen, micro-switch sensors, electronic logic, pneumatic cylinders. The circuit is that shown in drawing CM/09, and its operation is fully described in Appendix V.

3 Control Console, Preliminary costing was also carried out for comparison of control panels using electric and pneumatic methods. It was evident that, for the required panel, pneumatic switching and indicating would be very expensive, and would also be bulky and impractical when compared with the electrical equivalents. In addition, the majority of indicators on the control panel are activated by signals that come from circuits that have now been specified as being electric.

For the above reasons the control console is completely electrical, and switch selection is by the electrical method described in Appendix VI.

All the elements selected for the above sections have a suitable response time for the requirements of the machine.

12.0 CONTROL OF SPECIAL HEADS

Additional control is also needed for five special heads, which are specified by the Assembly Process, Assembly Analysis, and the Component Supply and Separation committees (Ref. 2, 3 & 4) Stations 2, 7, 8, 9 and 11 contain assembly heads that are manufactured items, and as such require only signals to synchronise their operation with the rest of the machine.

Stations 5 and 10 are designed by the committees concerned, and control for these stations has been specified in detail.

12.1 Cover & Rivets (Station 7)

This assembly is carried out using a standard pick and place head and a riveting machine. The assembly is sequenced such that when the pick and place head, holding the cover, is in position over the assembly a low power air signal is sent to the riveting head. The riveter then carries out its operation and gives a low power air signal when the operation is completed. The pick and place head then opens its jaws and completes the cycle. The riveting head is shown in drawing AP/24.

12.2 Terminal Screws (Stations 8 and 9)

When the jack is raised holding the assembly an electrical signal is sent to start the screwing operation. Upon completion of the operation a signal is sent to the platen control system and also to index the next screws.

12.3 Fixing Screws (Station 11)

When an assembly is in position under the fixing screw head, a signal is sent for the head to start its operation. On completion of the operation the head sends a signal which operates the eject cylinder, pushing the completed assembly from the head.

12.4 Printing (Station 2)

The printing head is built with its required control. When the jack is raised holding an assembly an electrical signal is sent to control the solenoid operated valve, thus activating the cylinders. The cylinders are extended for approximately 2 seconds and then released. An electrical signal is then sent to the platen control system. The printing head is shown in ref 3., drawing AP/26.

12.5 Insulator Manufacturing Head (Station 5)

The control of the insulator manufacturing head is carried out using pneumatics. The logic uses the Maxalog system (Turbulence Amplifiers) details of which are in Appendices 1, and 1V and figure CM/A2. The outline of the control for the head is shown in flowchart CM/14 and the detailed control system is shown in figure CM/15.

Referring to reference 4, figure CS/23, and the above figures the control of the head is as follows.

When the machine is first used the head is operated manually by simulating an assembly in position by actuating the limit sensor. This is done six times until the first set of insulators is ejected from the in process store to the assembly.

The idle position of the system is with the index cylinder and the roll feeder cylinder retracted and the cutter cylinder extended. The following sequence is carried out upon an assembly start signal from the jack rising.

1 As the cutter cylinder is extended and a start signal has come from the jack the index cylinder is extended.

Assuming four insulators are being assembled, as the four insulators have been indexed into the assembly position they are blown through the four passages to the assembly. As they pass through the passages they are sensed by back pressure sensors. If all four pass through the passages a signal is sent to reset the reject counter. If any of the insulators do not pass through to the assembly their respective memory systems are not signalled and a reject signal is sent to the reject cylinder and to the reject counter. If three rejects occur in succession the station stop is held "on" and a warning light is activated on the main control panel.

If the assembly needs only two insulators, say 3 and 4, a permanent signal is set as shown on figure CM/15

2 The parts having been indexed and the assembly complete the cutter cylinder is retracted. This being retracted the indexing cylinder is retracted, which sends a signal to reset the memory systems in the sensing logic. At this stage the assembly complete signal is also sent to the platen control logic.

3 When the cutter is retracted the rolls of insulator are fed into the cutting position.

4 When the roll has been fed the cutter cylinder is extended and the insulators are blown into the in process storage.

The above sequence is then repeated when the next assembly is in position.

12.6 Inspection (Station 10)

The inspection station comprises a modified pick and place head and a specially designed checking unit of which a detailed description is given in the report of the Assembly Analysis Committee, ref 2. The station's function is to remove the assembly from the platen, inspect it for continuity, and despatch the inspected assembly to the next station. If, however, a reject is detected during inspection the assembly is inhibited from continuing to the next station and is ejected into a reject shoot. A detected reject before inspection inhibits the inspection cycle and ejects the assembly down the reject shoot.

The control involves two distinct requirements: firstly, to provide a system to check all types of switch for continuity with the plungers in the normal and operated positions and, secondly, to control the sequencing of the pneumatic cylinders on the inspection unit. A flow diagram of the system is shown on figure CM/16.

1 Continuity Check

Because the functional check is electrical the circuit elements used are integrated circuits, manufactured by Texas Instruments, with a supply voltage of 5 volts, logic 1 voltage of 3.5 - 4.5 volts, and logic 0 voltage of 0 - 0.5 volts. All integrated circuit elements are mounted on a printed circuit board, which is housed in the central control console.

The switch can be considered as two distinct halves, which are denoted by "A" and "B". The truth table below shows the expected output from one terminal, if logic 1 voltage is applied to the other, for the plunger in the normal and operated conditions for all types of switch.

LOGIC TABLE 1

Type of switch	A Plunger N	A Plunger O	B Plunger N	B Plunger O
1	1	0	1	0
2	1	0	0	0
3	1	0	0	1
4	0	0	0	1
5	0	1	0	1

The switch selection facility is programmed to act as the master side of a comparator against which the switch continuity check is compared. Truth table 2, below, shows the switch accept and reject conditions:

TRUTH TABLE 2

X	0	0	1	1
Y	0	1	1	0
Accept	$\bar{X}.\bar{Y}$		$X.Y$	
Reject		$X.\bar{Y}$		$\bar{X}.Y$

if X = master side of comparator
Y = signal from switch

$$\text{Accept} = \bar{X}.\bar{Y} + X.Y$$
$$\text{Reject} = \bar{X}.Y + X\bar{Y}$$

The continuity check circuit is shown on figure CM/17 and consists of a switch selection program, comparator, and counter and reject logic.

(a) Switch Selection Program

Four switch selection channels are utilised and programmed as shown on truth table 1. Two channels are required for each side of the switch to give the master condition for the switch in the normal and operated conditions.

b) Comparator

The signal sent by each switch selection channel is gated with the switch plunger condition. This changes the master condition presented to the comparator for the plunger in the normal and operated conditions.

The comparator circuit has two outputs: one of these gives a logic 1 signal if the master (Y) and the switch (X) conditions are the same, and the other gives a logic 1 signal if the conditions are different.

c) Counter and Reject Logic

The comparator accept and reject lines are gated with the plunger conditions and only allow a signal through when the plunger is in the normal or operated condition. This ensures that only the correct comparator signal sets the flip flops 1 and 2. Because there are two inspection conditions, i.e. with the plunger operated and normal, it is necessary to store the first condition until the second has taken place. Then, when both conditions have been effected, the results are transferred to the counter, thereby only counting 1 if one or both tests produce reject conditions. The flip flops are reset during the eject part of the inspection cycle. The counter circuit cumulates the number of consecutive rejects and after each acceptable assembly is inspected the counter is reset. The logic consists of two JK flip-flops with dc resets coupled together to count to binary 11, i.e. (3), the principle of which is given in Appendix V111.

2 Sequence Control for Inspection Unit

The sequence control for the inspection unit integrates the pick and place control and platen control systems and is shown in figure CM/18. Because of the pneumatic motion and sensing which are necessary the logic control is fluidic, using the Maxalog system, and therefore reducing the number of interfaces needed. The motivation is performed using Martonair mini cylinders, activated via a diaphragm operated spring return valve.

The sensing of the completion of motions is carried out using back pressure sensors described in Appendix 1. The electrical micro switch which detects the assembly reject condition on the platen is replaced by an interruptible jet to avoid using an interface for this station.

Operation Sequence

There are two cycles of operation of the inspection head:

1 When a good assembly is picked up from the platen.

Initial Conditions

Clamp cylinder extended
Plunger cylinder extended
Eject cylinder retracted
Reject cylinder extended
Platen reject reset cylinder retracted.

The assembly is picked up from the platen by the pick and place head and transported until it is over the top of the inspection unit. If the inspection unit is ready to accept the assembly the pick and place head moves down, placing the assembly on the inspection track. Because the plunger cylinder is extended it causes the plungers to be compressed when the assembly is placed in the inspection station.

The switch is sensed with a back pressure sensor which sets the clamp cylinder FF and activates the diaphragm activated valve, causing the clamp cylinder to retract. As the slides close the switch is trapped and contact is made between the inspection probes and the switch terminal clamps. The completion of the slide movement is sensed and this causes the pick and place jaws to release and start the first inspection cycle with the plunger in the operated position.

A pneumatic/electrical relay converts the pneumatic signal from the sensor into an electrical one for the continuity check circuit. After a short delay the sensor signal sets the plunger cylinder F/F causing the cylinder to retract and the switch plunger to move to the normal position. When the plunger cyclinder is retracted a sensor sends a signal which starts the second inspection cycle. After the same delay as the first inspection cycle the clamp cylinder F/F is reset, causing the slides to open.

When the slide has completed its motion a sensor is activated which, together with the switch being sensed and plunger retracted, causes the eject F/F to be set. The eject cylinder then extends, pushing the assembly to the next station. The extension of the eject cylinder activates a sensor which, after a small time delay, resets the eject F/F, and plunger F/F which retracts both cylinders. It also sends the assembly complete signal to the platen control and this completes the inspection cycle.

2 When a reject assembly is picked up from the platen.

The reject marker on the platen entering the inspection station sets the reject F/F by interrupting an interruptible jet. A signal from the reject F/F sets the plunger F/F, causing the plunger cylinder to retract.

When the platen has been jacked up, the pick and place head transports the assembly to the inspection unit. The normal inspection cycle is inhibited by the reject F/F being set.

On detection of the assembly on the inspection track the following operations are carried out:

1 The claws are released on the pick and place head.
2 The platen reject marker reset cylinder is extended.
3 The eject cycle, which follows the same sequence as described in 1 above, is started.

On completion of the eject cycle the assembly complete signal is sent, which returns the platen to the conveyor and releases it from the station. As it leaves a sensor is actuated which is used to reset the reject shoot F/F platen reject marker reset F/F and the reject F/F.

This then completes the cycle.

13.0 CONTROL OF FEEDERS & ESCAPEMENTS

The control of feeders and escapements is carried out using fluidics for two main reasons. Firstly, both the feeders and escapements are directly connected with the pick and place head, which is controlled using fluidics. Secondly, fluidic sensing is the most practical method for this application. The control logic of the escapement is carried out using the Maxalog system. The control of the feeders and escapements is outlined in detail.

13.1. Level of Parts in Feeder Lines

All the components that are being fed from a vibratory bowl feeder have a sensor approximately half way down the track between the bowl and the escapement.

Stations 1 and 7, the assembly of the housing and the cover assembly, have back pressure sensors in the track which give a signal when there are components present (ref Appendix 1). The output of the sensors is fed to the control of Turbulence Amplifiers in the pick and place control unit and an air to electric relay (ref Appendix V11) to a warning light on the main control panel. Therefore, if there are no components in the feeder track the warning light will be "on".

Stations 3, 4 and 6, the assembly of plungers and contact plates, have interruptible jet sensors (ref Appendix 1) in the track which give a signal when there is no component present. The output of the sensor is fed through an air to electric relay to a warning light on the main control panel.

The sensors are spaced such that when a warning light comes "on", the operator has time to refill the feeding mechanism before the head has completely run out of components.

13.2. Housing (Station 1)

Referring to figure CM/19, when the housing comes down the track to the pick position a back pressure sensor sends a signal to raise the jack. With the jack raised another housing cannot come into the pick position. From the same sensor a signal is sent to the pick and place head control showing that a part is ready for assembly. When the part is picked the sensor no longer sends a signal and the jack is lowered to allow the next part to come into the pick position.

13.3 Plungers (Stations 3 and 6)

Referring to figure CS/20 and figure CM/20 the idle position of the escapement system is with slides A and B (CM/20) retracted and cylinder X extended. In this state two plunger assemblies are in the pick position, each being sensed by an interruptible jet.

When the assemblies are picked and the head is raised, a signal is sent for slides A and B to be extended feeding the next two plunger assemblies to the pick position. When the slides extend, the drum indexing the plungers automatically brings the next two forward. When A and B are extended, cylinder X is retracted, thus leaving the plunger assemblies in the pick position. Slides A and B are then retracted and X is extended bringing the claws connected to A and B into position to feed the next two plunger assemblies.

If only one plunger assembly is required a permanent signal is on as shown in figure CM/21 and the above sequence is carried out, the head picking only one part.

13.4 Contacts (Station 4)

Referring to figure CM/22 and figure CS/19 the idle position is when the four contacts are in the pick position and the four cylinders, which fully feed the contacts, are fully retracted. In this state the four back pressure sensors give a signal to the pick and place head control that the contacts are ready for assembly.

When the contacts are all picked the sensors no longer send a signal and the cylinders are actuated feeding the next four contacts into the pick position. When they are sensed in the pick position the four cylinders are retracted.

If any of the parts are not picked the cylinders are not actuated and the next assembly cannot be carried out as all the required contacts are not available for assembly.

The control caters for the assembly of 4 N/C 4 N/C or 2 N/O and 2 N/C contacts.

13.5 Cover & Rivets (Station 7)

The feeding of the cover and spring assembly is carried out using a roller mechanism as shown in figure CS/21. Referring also to figure CM/23 when a cover assembly is in the pick position the back pressure sensor gives a signal to the pick and place head control. When the cover is picked and the jaws are closed a signal is sent to index the roller.

14.0 ELECTRICAL AND PNEUMATIC POWER DISTRIBUTION AND MACHINE RUN DOWN AND START CONTROL

14.1 Electrical Power Distribution

The input supply voltage is 440 V, 3 phase at 50 Hz, This is connected into a main isolate switch which contains a fuse for each of the three lines. The fuses provide the main protection circuit for the machine against overload. Closing the isolate switch applies the line voltage to the transformer and also to the motor starter, which is designed to carry high load currents and incorporates integral overload protection.

The transformer secondary circuit has two tappings and gives a voltage of 250 V, the other 18 V both being at 50 Hz. The 250 V supply is used to provide the power for the special purpose heads, stabilised power supply, solenoid valves, and the timer.

The 8V supply is applied to a bridge rectifier circuit which rectifies the ac voltage to a 12 volt dc level, whichh is used for the lights and relay circuits. A fuse is connected into both the output legs of the transformer and acts as a secondary protection. Because of the high load currents needed for the machine run down and start control equipment, relays were used. The control circuit is shown in drawing CM/24.

14.2 Pneumatic Power Distribution

The main air supply is fed through a filter, regulator and lubricator. This supply at 80 lbs/in^2 (55 N/mm^2) is fed to all the cylinders in the system. For this a secondary supply is fed off through a 5 micron filter and a regulator giving an 8 in (200 mm) supply to the fluidic logic and low pressure sensors. The circuit is shown on drawing CM/26.

14.3 Machine Run Down and Start

When switching the machine off for testing, maintenance or machine shut down at the end of a shift it is necessary for the machine to be stopped in some predetermined point of the cycle. This prevents the control system from getting out of sequence when it is restarted. The machine run down and start-up sequence are shown on drawing CM/24.

Machine Run Down

When the stop button is pressed the stop machine relay (E) will energise. This starts the timer and also de-energises the platen and pick and place run down relays (C & D). At the same time relay (E) will hold itself on. The time which elapsed before the timer relay (F) energises is such that all the assembly stations will be in the run down position as stated in section 9.0.

The timer will then energise relay (F) which de-energises the machine start relay (A), which stops the machine. The main isolator can then be manually switched off and this completely isolates the machine from the main electrical input. A flow diagram= is shown in drawing CM/25

Machine Start Cycle

When the start button is pressed the machine start relay (A), will energise, providing the pressure switch has closed, indicating that the air supply has reached its working pressure.

Relay (A) is kept energised by one of its own contacts when the start button is released. Relay (A) then controls the starting of the motor, platen control, pick and place head, and some special purpose head.

15.0 SUMMARY OF FINAL SYSTEM

The final system, resulting from the fundamental analysis of the requirements of the versatile assembly machine, is summarised on drawing CM/27.

This drawing takes the form of a block diagram, each distinct part of the control system that has been described in the above sections being represented by a block, and indentified as using either air or electric control. An overall picture of the control system is given by grouping these blocks to show the control of each station, together with the major control lines between all control sections and the central panel.

The control panel is shown in diagrammatic form, with all major controls illustrated.

Drawing CM/27 also shows that, when integrating the separate sections into one complete system, there is a need for interfaces to transmit signals between sections using different types of control. Interfaces used in the positions shown on the drawing are described in Appendix V11.

16.0 CONCLUSIONS

The above report describes in full detail the derivation and design of a complete control system for a particular design of versatile assembly machine. The system is based on a fundamental analysis of the requirements of the machine, with the most suitable types of control to satisfy these requirements being selected from a survey of all those available.

From initial considerations of the machine design it seemed probable that the control system could predictably be based on a single control medium, and that this type of system would simplify both design and operation, and would minimise cost because of the elimination of interfaces. However, the final system that evolved from logical consideration of the problems contradicted these first impressions and, in fact, is based on combinations of two different control media, electricity and pneumatics.

The basic reason for this combination was the fact that the requirements of the particular machine could be divided into two types, one of which was more suited to pneumatic control, and one to electric control.

This raises a general point that the control for an automatic assembly machine cannot be predicted with any certainty, or generalised for automatic assembly machines or even versatile automatic assembly machines. The form that a control system takes depends entirely on the degree of control required, and the mode of operation of the machine.

This point is illustrated by consideration of the present machine. The platen control logic controls the movement of platens through a station. The signals from sensors determine action to be taken on the platen, and this involves considerable decision logic. It was found that this could be done more compactly, more economically and with easier maintenance, using integrated circuit electronic logic, rather than the fluidic alternative. The construction of the machine, and the types of movement that were sensed, was such that there was no problem in using conventional micro-switch sensors.

On the other hand, it was decided that the most suitable form of actuation for the designed pick and place assembly mechanism was pneumatic cylinders, and the type of control required for this mechanism was pure sequencing, each operation being initiated by the completion of another.

This involved a considerable number of sensors, and the design of the pick and place head necessitated these sensors being compact and, in some cases, an integral part of the construction. The only sensor which completely satisfied this requirement, and also guaranteed satisfactory reliability, was the fluidic type.

At the same time the selection of pneumatic actuation was such that any use of electrical devices would involve the use of costly interfaces.

For these reasons the control of the pick and place head was completely based on pneumatics, with fluidic sensing, going through fluidic logic direct to high pressure air actuation.

As well as the type of control, the overall principle of operation of the machine also has considerable bearing on the chosen control system.

The present machine is based on a free transfer type of system, of modular construction, with each assembly head operating independently of the others, and the control system has been derived accordingly. It is a memory type system, with a major requirement that the shut down time of the machine be minimised, by sensing the progress of components through the machine and automatically dealing with the more common types of malfunction.

For a different machine, with different control requirements, the ideal system could be based completely on some other mode of control. For example, a machine based on the free transfer system, with independent assembly heads, which did not require a memory type control system, and which is not designed with the need for versatility as a prime consideration, it may be more practical to provide mechanical control and actuation for the assembly stations. This type of system, if acceptable, would probably result in a faster machine cycling time than any other, together with the high reliability usually associated with cam type systems.

To carry this suggestion further, for an indexing machine, specifically devised for special purpose assembly, the most suitable type of control would seem to be a complete mechanical system with all indexing and assembly operations being actuated from a single central cam shaft.

From the above examples it appears that some generalisation can be made. The systems with mechanical control give the fastest operation, but the scope for application of memory control within these systems is limited. For the memory type system it is therefore necessary to use some form of actuation such as pneumatic cylinders, and this results in a reduction in the maximum operating speed obtainable. It therefore appears that in general the provision of more sophisticated control techniques is done with a corresponding reduction in maximum operating speed.

The control system has been devised to allow for possible future developments in the field of production. It is hoped that the facility for automatic selection of different combinations of assembly operations will become particularly useful for application to the assembly of groups of products which are designed under the principles of modular interchangeability and group technology. Identical components will be assembled in varying combinations to produce different products. It may be that a further development could keep the same principles of control, but could utilise a small dedicated computer to provide simple selection of all possible combinations of assembly operations.

RECOMMENDATIONS FOR THE FUTURE

The field of automatic assembly, and the design of automatic assembly machines, is still in its very early stages and up to the present time versatility has not been a prime consideration. However, during the investigation into control systems it has become apparent that considerations of versatility add to the problems of control system development. It is, in fact, another of the many factors which have to be taken into account. One of the important results of our investigation has been the fact that the type of system used for control does depend so much on these factors, which include the machine operating principles, and the degree of control required. It would be of considerable help if an investigation could be carried out into the relationships between these factors and the various means of control that are available, to try and lay down some standards which relate various control requirements with their ideal solutions, taking into account variables such as cost, reliability, maintenance, response times, etc.

A further study which would aid the design of control systems for future versatile machines would be into the possibilities of the application of on-line computer control. It may be possible with this type of system to not only select assembly operations, but also program the form that the operation takes, controlling positioning and operating speeds, and perhaps enable automatic set up of the complete assembly process resulting in the creation of true "assembly centers".

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APPENDICES

APPENDIX 1

SURVEY OF AVAILABLE ELEMENTS FOR THE CONTROL OF AUTOMATIC ASSEMBLY MACHINES

1. ELECTRICAL

1.1. Sensors

Photocell

A photocell is an electronic device which changes its electrical characteristics in the presence of light. There are three common types, which are:

1) Photovoltaic Cell - in which incident light is converted to a direct current.

2) Photoconductive Cell - in which current flow is altered by incidence of light.

3) Photoemissive Cell - in which electron emission from a cathode is proportional to the intensity of light falling on it.

A sensing system consists of a light source, a photosensitive detector and an amplifier. The light is focussed through a lens, although this may not be necessary for all applications, and is beamed directly, or by reflection, at the detector. The amplifier then converts the small electrical signal to one that is capable of operating a relay or digital circuit.

Photocells have response times in the region of 50 - 100 ms and have the ability to detect the presence of any type of material. They do not exert any external force on the component being sensed, and they are, therefore, suitable for inspecting the most fragile of components.

When used in an industrial environment it is sometimes a problem to keep the lenses and detectors clear of dirt and obstructions. Also, care must be taken to ensure that no reflected light from the sun, or other light distribution source, is reflected on to the detector.

Micro-switches

A micro-switch is a switch which is operated by a light mechanical pressure and small movement. The switch can carry control currents without the use of relays, or amplifying devices. Micro-switches are available in a wide variety of forms. They can be used to detect the presence of parts, or the completion of assembly motions.

Magnetic Field Interference Devices

These detect the unbalance of a magnetic field caused by the presence of ferrous, or in some instances non-ferrous, metallic material. The device can be used as a limit switch or to check for presence, but because of its limited use for non-ferrous parts the versatility of the device is restricted.

Electronic Gauging

Small movements of an inspection probe cause electical unbalance in a bridge circuit. This unbalance signal is usually amplified so that it can operate industrial controls.

Electronic gauges can measure extremely small displacements, i.e. 1×10^{-5}in (0.3 mm) and have a fast response time.

1.2 Logic for Decision

Solid State

The most common solid state devices used for decision logic are transistors, thyristors and integrated circuits. All perform switching operations without any moving parts. Normal supply voltage lies between 5 and 15V dc which has to be stabilized.

Transistor Circuits

Logic function can be built up by using discrete components, i.e. transistors, but they can be bulky and expensive when compared with integrated circuits. However, where it is necessary to drive large loads, up to approximately 10 amps, the power transistor must be used because integrated circuits are only low power devices.

Thyristors

These can be used in both ac and dc circuits for switching high currents. They can be triggered with only a few milliamperes, thus enabling a low current switching device to control loads of several kilowatts.

Integrated Circuits

Integrated circuits are complex electronic circuits formed on a single piece of semi-conductor material, usually silicon. Impurities are etched, using photographic techniques, into the material, which is then treated in a diffusion furnace. The result of this process is a complete circuit including resistor, transistor, diodes and capacitors. Output wires are then joined to the circuit and the unit is then sealed in epoxy resin to give a completely airtight unit.

The range of integrated units includes gating circuits, e.g. (OR, NOR, AND, NAND,) flip-flops, e.g. (J.K. and R.S.) monostables, shift registers, memories, comparitors, counters, decoding networks, etc.

Each circuit block is a complex function and this enables the designer to construct complex circuits without the need to go into electronic circuit design. The control of the manufacturing process, and the encapsulation of the circuit block, gives the integrated circuit a very high degree of reliability.

The integration of units, to form a complex logic function, means a reduction in the number of electrical interconnections. This in turn leads to a reduction in manufacturing costs and lower maintenance times. Also, reliability is much higher as the main source of failure in electronic equipment is the system of interconnection.

The majority of all the circuits, whether discrete or integrated, are assembled on printed circuit boards, which are easily removed for maintenance or modification purposes. But when using integrated circuit units a much higher component density can be obtained, which results in a more compact unit.

Using integrated circuits, a printed circuit board could easily accommodate all the logic required for one station, which makes it especially suitable for modular construction.

Characteristics of these elements are very fast operating times, low power consumption, small size, and extremely high reliability.

Relays

A relay consists of an electo-mechanical coil and a network of electrical contacts. When a current is passed through the coil of the electro-magnet it produces a magnetic flux, which in turn produces a mechanical force. This opens or closes the relays electrical contacts. Relay contact networks can be used to build up complicated logic circuits.

But care must be taken to ensure that when the relay is de-energised the back e.m.f. does not cause high voltages to be generated. The voltage can be supressed by using it to charge a capacitor through a resistor, or by using a diode to by-pass the excess voltage.

Mechanical wear and electrical burning of the contacts limits the life of relays, even though this life can be measured in millions of operations. Relays are available in a wide range of coil voltages and operating currents.

Reed Switches

These consist of two blades of nickel-iron sealed in a glass tube in vacuole. The reeds overlap within the tube so that when a magnetic field is applied it causes the reeds to attract each other making electrical contact. When the field is removed the nickel-iron is demagnetised and the reeds separate.

Reed switches have a considerable advantage over relays because there is no contamination of the contacts, contact resistance is low, speed of operation is high, low power is required to operate the coil, making them highly suitable for transistor circuits, and their operational life is much longer.

1.3 Actuation

Solenoids

Solenoids use electrical energy to obtain a linear mechanical force. They are widely used for activating air valves, brakes, machine gates and escapements. Care must be taken when selecting solenoids because certain factors will affect the operating life and performance. These are:

1 They should only be used at the specified current because excessive loads will cause overheating and premature coil failure.

2 If the solenoid is operating continuously, it is necessary to use a continuously rated solenoid otherwise premature failure will result.

3 It is an advantage to keep the stroke as short as possible as the power falls off as the stroke increases.

Solenoids have a fast operating time (2 ms), are cheap, and are available in a wide range of operating voltages and forces.

They do, however, tend to be bulky when compared with an air cylinder of a similar force and it is difficult to obtain any control over its motion.

Motors

Types of Motors:

(a) D C electric motor

(b) Single phase motor

(c) Polyphase induction motor

(d) Commutator motor

(e) A C Servo motor

(f) Stepping Motor

(a) D C Electric Motor

The motors have a large speed range, and suitable torque speed characteristics. The supply of direct current is achieved by using either an a c motor driving a d c generator, or by vacuum tube or solid state rectifying devices. However, due to the necessity of a rectifier and control gear, this type of motor can be more expensive.

(b) Single Phase Motor (series)

The current required for single phase motors is twice that needed for three phase motors of the same power rating. They are also heavier, and more expensive, than polyphase machines due to the fact that a given frame can be wound for approximately double the horse power with polyphase compared with single phase. However, a single phase motor gives a full range of speed control, with a transformer.

(c) Polyphase Induction Motor

This type of electric motor is theone most extensively used for general industrial purposes, the main type of motors being the squirrel cage induction motor and the slip ring induction motor

The squirrel cage motor is the simplest and cheapest of all electric motors; it is highly efficient and has practically no maintenance costs. It is possible to have a speed control on this motor, by using a static invertor speed controller, but this is relatively expensive. Slip ring motors provide higher starting torque, but are more expensive than the squirrel cage motor.

(d) Commutator Motor

This type of motor offers high starting torque, high power factors, and a wide range of speed control, but the commutator and brush rectifying gear add to the cost and weight of commutator motors. This motor is used when high starting torques are required, or when it is necessary to maintain a constant speed regardless of variation of load.

(e) A C Servo Motors

These can be either two or three phase induction motors, one phase of which is controlled by a servo-amplifier. They are used for positioning and control of servo systems. Usually a tachogenerator is built into the motor to provide stabilisation to the control loop.

(f) Stepping Motors

A stepping motor comprises a magnetically polarized rotor, and a stator which has three or more separate field coils. By applying voltage pulses to the stator coils in a suitable order the resultant magnetic field causes the rotor to rotate incrementally. The number of pulses applied to the stator coils determines the motors angular position. The motor gives a very high starting and holding torque and no feedback loop is required in a position control system.

2 HYDRAULIC

2.1. Sensors

For the application of automatic assembly machines there is no practical method of hydraulic sensing.

2.2. Logic for Decision

The only common type of hydraulic logic equipment is the spool valve. This valve consists of a piston which can be actuated mechanically through a mechanical probe, the piston moving within a sleeve and opening and closing ports, therefore controlling the flow of oil through the valve. The spool probe can also be actuated electro-mechanically, a flapper valve controlled by a solenoid being used to restrict the flow of oil to either of the spool valve ports, which in turn controls the flow of oil to a motor or hydraulic ram. The spool valve is usually expensive due to the high precision required in manufacture.

2.3. Actuation

Hydraulic Motors

Most hydraulic motors use pistons connected to a crankshaft, or swashplate, actuated by hydraulic pressure to cause the rotary motion, the pistons moving axially or rotating. The torque speed characteristics can be controlled by varying the flow of oil, or by varying the displacement of the pistons. These types of motors are small compared with other forms of motors with equivalent power, but are usually more expensive. The main advantage of hydraulic motors is their high power to weight and size ratio, and the high torque possible at low speeds. Therefore, this type of motor is most useful for the form of control system such as is found in machine tools. The disadvantage of these motors is their low efficiency due to the excessive heat generated in the oil, which requires cooling and, also, a large hydraulic power pack is necessary to pressurise the oil. For the present application and the specified machine design the advantages of the hydraulic motor over electric motors do not apply as there is no demand for their particular characteristics, while the comparative high cost would make their use uneconomical.

Hydraulic Rams

The hydraulic ram consists of a piston which moves linearly in a cylinder under the actuation of hydraulic pressure. Due to the incompressibility of oil, the hydraulic ram is usually used when extremely high forces are required, such as in presses. The rams can be positioned very accurately by controlling the flow of oil into the cylinder by a spool valve, and, therefore, rams are used extensively to position slideways on machine tools when accurate position control is required. A high range of ram movement speeds can be obtained by varying the rate of flow of oil.

The main advantage of hydraulic rams is their ability to transmit high forces. In the present application there is no requirement for such forces, and the use of hydraulics would present no particular operating advantages over the alternative method of using pneumatic rams. On the other hand, the cost of the hydraulic type would be comparatively much higher than pneumatic, so in this case the use of hydraulics would be uneconomical, and unnecessary.

3 PNEUMATICS

3.1 Sensors

The most common type of high pressure pneumatic sensors are pilot and micro valves which work between 20 - 100 lb/in^2 (.55 - 2.75 N/mm^2). A ball in the head of the pilot valve operates a plunger which in turn operates a sealing ball to the ports. Movement required to operate the pilot is approximately 0.25 in (6.7 mm).

There are two types of valve: normally closed which, when actuated, allows air to pass from the inlet to outlet, and a normally open valve which, when actuated, prevents air from passing to outlet. These valves can be actuated by using any of the following operating attachments: roller, one-way-trip, or lever push button.

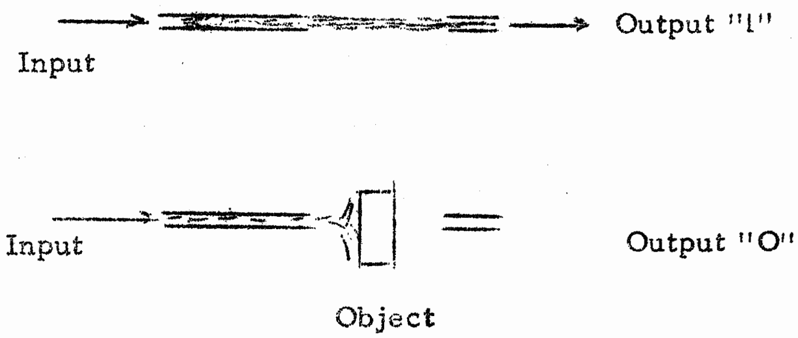
Micro-valves are similarly lever operated valves which can be roller lever or one-way-trip operated. The movement required to operate micro-valves is approximately 0.05 in. (1.3 mm). Such high pressure pneumatic sensors are bulkv.

Fluidic

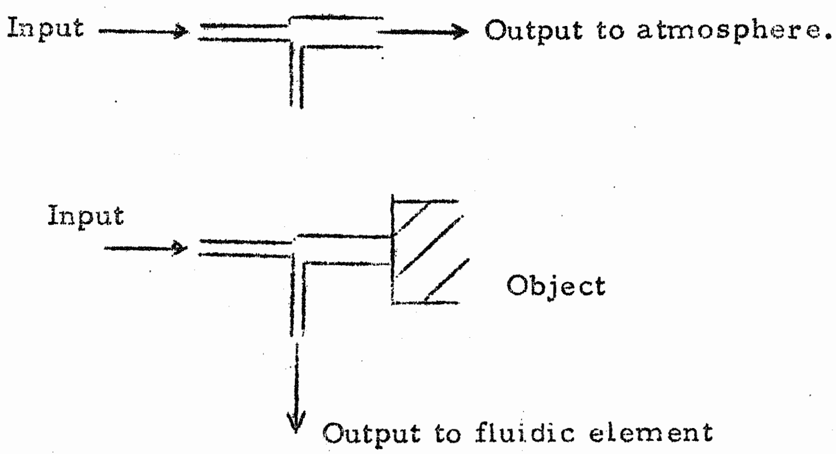
Sensing can be carried out using either of two techniques associated with fluidics, namely, back pressure and interruptible jet sensing. These methods use low pressure air and have no moving parts.

As the name suggests, back pressure sensing uses the build up of air, when a vent is blocked, to send the flow of air and thus a signal to output.

Principle of Interruptible Jet



Principle of Back Pressure Sensor



The button and touch sensor seals the vent of a system, thus making the flow of air from the inlet go through the outlet port, which is of smaller area than the vent. The limit sensor uses the same principle, but some movement causes a lever to close the vent. The proximity sensor works on the reflection of air from an adjacent object being directed to the output. When there is no adjacent object, there is no output signal. These sensors can be obtained for different ranges up to about 1.5 inches (28 mm).

Interruptible jet sensing is the breaking of a signal when an object interrupts a flow of air. When fed into a NOT logic gate the interruption is then a signal from the output of the gate. The interruptible jet works on the principle that a laminar flow of air from a small diameter tube (approx. 0.03 in (.8mm) is fed through a gap to a pick up tube. When there is no object in the gap there is an output, but when an object interrupts the flow there is no output. The maximum gap is approximately (0.75 in (19 mm). With a supply pressure of 8 in (200 mm) WG the output pressure is 2.3 in (58 mm) W G. The interruptible jet can be connected by tubing directly to the control port of a turbulence amplifier.

The air stream detector works on the same principle, having two in-line tubes with air passing through them. An air nozzle, through which air is passed, is placed perpendicular to the two in-line tubes, such that when no object is between the nozzle and the tubes the flow of air from the nozzle disturbs the flow from inlet to outlet, thus producing no output. When an object is in front of the nozzle the flow between the tubes is not disturbed and there is an output. The gap between the nozzle and pick-up can be up to 17 in (432 mm) with a supply pressure to the nozzle of 5 lb/in^2 (.034 N/mm^2)

Fluidic sensors are simple and very compact, with adequate response characteristics for the present type of application.

3.2. Logic for Decision

High pressure.

Logical decisions can be carried out using standard valves that operate between 20 - 100 lb/in^2 (.55 - 2.75N/mm^2) air pressure (usual workshop supply). The valves can be two, three, or four way and either two or three positioned. The valves have inlet, outlet, and exhaust ports, and when actuated a spool in the valve is moved to alter the direction of flow in the valve. All valves can be adapted to various mechanical movements and can be mounted in many ways. Logic circuits using high pressure valves tend to be very bulky.

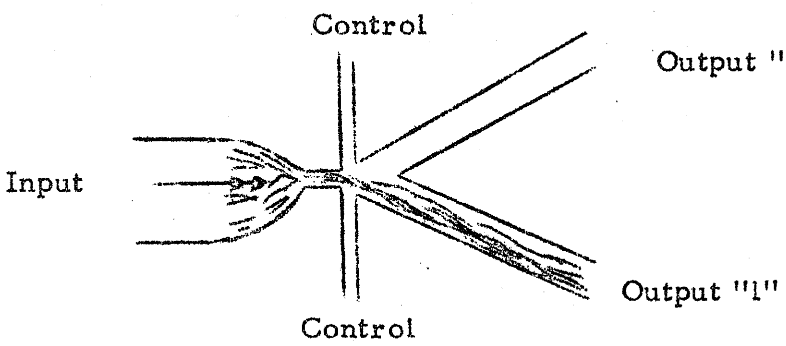
Moving-part fluidics.

Between high pressure pneumatic and no-moving part fluidics is a pneumatic logic system working on approximately 20 lb/in^2 (.14N/mm^2) supply pressure. Basic logic blocks are made using diaphragms, rubber discs or small ball bearings which, when moved by air, alter the flow sequence in the element to obtain logic functions. By varying the signal arrangement the basic logic functions can be made.

No-moving-part fluidics

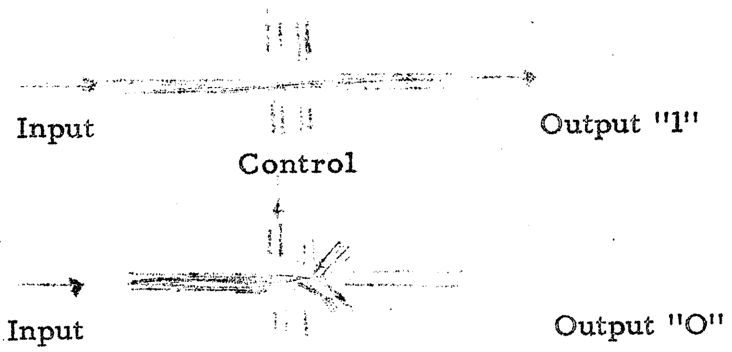
There are two main types of no-moving-part fluidic elements, which are wall-attachment elements, and turbulence amplifiers.

Wall-attachment elements work on the principle that the flow of air from a nozzle will attach to a wall when that wall is at a certain angle in relation to the nozzle.



This device uses built-in elements which work on a supply pressure of 1 - 5 lb/in^2 (.007 - .034 N/mm^2) By correct positioning of walls, control ports, and other characteristics, the basic logic functions can be made.

Turbulence amplifiers(T.A.'s) work on the principle of a NOT gate in that a control flow is used to break the laminar flow of air between two in-line tubes, therefore preventing an output.



These elements have four inputs, and can be connected together to form logic functions.

For the particular application to control logic for a modular assembly machine, turbulence amplifiers have the following advantages over other fluidic elements.

They are:

(a) Ideal for digital sequencing
(b) Of modular construction
(c) Comparatively low cost elements
(d) Low power consumers
(e) Independent of output load
(f) Ideal for simple construction of circuits.

3.3. Actuation

Air Motor

Most air motors work on the vane or radial cylinder principle. They can operate in a horizontal or vertical position. The operating pressure can be adjusted, depending on the output, speed and power required.

All motors are normally supplied reversible with equal power in either direction. Motors with a power bias in one direction are also available. Standard gearboxes are available for motors to obtain different speed ranges.

Cylinders

Pneumatic methods of motion, using pistons in cylinders is a common method of actuation. Cylinders are available in many diameters together with pistons of many stroke lengths. Applied to automatic assembly they can be used to:

Move: feed, position, transfer

Hold: for fastening, adjusting, fitting.

Form: stamp, crimp, rivet, test

Process: assemble, fasten, glue, weld, form etc.

The thrust and movement needed for the application determines the size of cylinder to be used. On the end of a piston, attachments can be fitted to hold, strike, etc., and various types of mountings are available for the cylinders.

4 MECHANICAL

4.1. Sensors

A mechanical sensor must make physical contact with what it is sensing. For mechanical function, the movement of the sensor would operate a lever system, but the movement could also be used to operate a valve in some logic system other than mechanical. Some sensors in other systems convert mechanical sensing direct to a digital output for logic processing, and these have been described in the preceeding sections.

4.2. Logic for Decision

A mechanical logic system could be devised using:

(a) levers and linkages
(b) a series of geared shafts
(c) a series of cams on a driven shaft
(d) a combination of the above.

A system of levers and linkages would be quite complex for the present application, while the problems of modularising such a system for the ease of addition and removal of modules would be so great as to be largely impractical.

For an assembly machine it can be assumed that the requirement for rotary motion will be small. A system consisting of (b) only can supply purely rotary control and motion and would, therefore, not be ideal for this application.

Motion of cam followers is limited to linear motion in only one plane but, for synchronising a series of these motions,a cam shaft is more versatile than either gears or levers.

The most feasible system of mechanical logic would, therefore, seem to be a cam shaft to synchronise assembly actions. There are two ways that this can be applied:

(a) With one power unit, each module would be driven from an extension of one main cam shaft.

(2) With a separate power unit and cam shaft for each module.

A system with one power supply would guarantee synchronisation between movements on a module, and between modules. The system would, however, have to be a fixed cycle system with indexing of the assemblies, also controlled by the cam shaft. It is impossible to operate assembly modules independently with this system. If one module jams, or breaks down, the whole machine must stop.

A system with individual power supplies to each assembly head would synchronise actions within the head, but each module would be independent. Each operation would need to be initiated either by some external control, or by detection of the arrival of an assembly.

For any cam system the movement of assemblies from the workhead must be controlled by the cam shaft, and each complete workhead cycle must take place in one revolution of the cam shaft.

To build in logical units to act on signals from sensors to change the function of the cam operated cycle would need some system of clutch mechanisms to select the required cam sequence. This would be very costly, and, probably, completely impractical. However, a system with separate power supplies may half individual modules, but this will, in turn, cause halting of the whole machine within a short space of time.

The possibility of including a mechanical logic system for monitoring progress of any one component through the machine is remote because of the problems involved, and the ease of doing the same job by other methods. The provision of mechanical logic to provide rejection motion, if required, is difficult because of the need to find a source of movement other than the cam shaft.

Mechanical logic systems seem ideal for assembly machines designed to index and mass produce one particular component, but when applied to a machine of modular construction with a requirement for a sophisticated degree of control to aid versatility, mechanical logic control is not ideal.

4.3. Actuation

Any actuation system for automatic assembly will probably need some form of mechanical linkage in its final stages. The initial movement to this linkage and lever system could be provided from any form of linear and rotary power.

A system of levers for an assembly head is liable to be very inflexible, and applicable to a very narrow range of operations. For versatility it would be ideal to reduce the mechanical part of the assembly motion control to a minimum.

APPENDIX 11

THE DETECTION AND REJECTION OF INCORRECTLY ASSEMBLED SWITCHES

This report investigates the need for the detection and rejection of incorrectly assembled switches, and discusses the various ways of doing both.

1 INTRODUCTION

It must be a requirement of the machine that assemblies emerging from the output end can be given an economic guarantee of perfection. This means that bad assemblies must be reduced to numbers of an order which is economical to replace in the event of return by a customer. Although the ideal situation would seem to be 100% good assemblies, this is not necessarily so, as the cost of providing the machine with equipment to give 100% may be so high that, firstly, it is not justified when compared with the cost of providing a customer guarantee, and, secondly, the overall cost of the machine may be increased in a proportion significant enough to affect its sales potential.

However, it has been decided to include on the present machine a station to carry out a functional check on all assembled switches. This will guarantee that all accepted switches will operate as required, but it does not necessarily mean that the assemblies are correct, or complete.

Apart from the final quality of the assembled switches it is also necessary to safeguard the machine. Although a large proportion of incorrect assemblies will be detected during the functional check, it must be made certain that these bad assemblies will not harm the operation of the machine during their progress to the checking station. Similarly, any bad assembly that could jam the machine at any stage must be detected.

In order to take these considerations into account the remainder of the report has been prepared in the following sections.

2 Investigation of the assembly at functional check stage.

To determine which components could be badly assembled and still not affect the functional operation.

3 Investigation of possible mis-assemblies, safeguarding the machine.

4 Investigation into mis-assemblies.

Consideration of the operations isolated in sections(2) and (3) to determine whether the probability of bad assembly warrants its detection.

5 Action to be taken on detection of a mis-assembly.

6 Methods of rejection.

7 Number of rejects.

8 Conclusions.

2 INVESTIGATION OF THE ASSEMBLY AT FUNCTIONAL CHECK STAGE.

Before considering the assembled switches at the checking station it is necessary to assume a particular state of each switch on its arrival at this stage, and, if necessary, provide control to make sure that this state is guaranteed.

It is assumed that on arrival at the functional check station the switch is completed, with the cover located and held in its correct position, either by the rivets, or by some temporary clamp.

This being assumed, then anything wrong with the switch at this stage can only be due to components misaligned, or to components missing.

Consideration of the switch in all of its forms shows that misalignment of components inside the housing with the cover in position and with satisfactory functional operation is impossible, except in the case of the main helical springs which can be assembled slightly skew and still function. It could be argued in this case that functional operation means satisfactory assembly.

At this stage of functional check, the following components could be missing from the assembly and remain undetected:

1. Insulation plates
2. Fibre spacers
3. Contact spring.
4. Terminal clamping screws.
5. Fixing screws.

All other components must be present and correctly assembled in a switch if the cover is in position, and if the functional check for that particular switch is satisfied.

As far as the provision of correct assemblies is concerned, therefore, additional checks to the final functional check are required, firstly, on the correct alignment and position of the switch cover, and then on the presence and position of those components listed above at their assembly stage.

3 INVESTIGATION OF POSSIBLE MIS-ASSEMBLIES, SAFE-GUARDING THE MACHINE.

It is necessary, for this investigation, to consider the placing of individual components, rather than the assembly station operations. For each of the components the effects of its absence, or misplacement on the placing of subsequent components, are analysed.

(1) Housing
This part is the basis of the whole assembly. It is essential that no parts are placed unless the housing is in position.

(2) Plungers
(a) N/C plunger sub-assembly.
This sub-assembly consists of a plunger, a moving contact, and a spacer. The absence of the space, the contact, or the whole sub-assembly at any future

assembly operation would not harm the machine.

During the sub-assembly, the contact and the spacer must not be placed unless a plunger is present.

Any misalignment of the contact on the plunger would result in probable loss of position of the contact during placing of the sub-assembly.

If the complete sub-assembly were to be mis-placed laterally a sufficient amount, it is possible that the plunger could fail to locate in the vertical slideways of the housing. Either of these last two mis-assemblies would affect location on the helical springs and the subsequent fitting of the cover. In either case also the switch would not function.

(b) N/O Plunger Sub-assembly

This sub-assembly consists of a plunger, a moving contact, and a conical helical spring. The absence of the contact, or the whole sub-assembly at any future assembly operation would not harm the machine. There is some possibility that in the absence of the spring, the contact, although laterally located by a plastic step, may vibrate loose. If so it would have an effect on the placing of the fixed contacts.

During the sub-assembly, the contact, and the spring, must not be placed unless a plunger is present. Any misplacement of the sub-assembly would have similar results to those in (a) with the additional result that the placing of the N/O fixed contacts may be forced out of position. Because of the limited stability of these contacts, even when assembled in the correct position, it is essential that the way be clear for their placing, or they may fall onto the conveyor.

(3) N/C Contacts

These contacts are placed into the machine before their associated plunger sub-assemblies. Any mis-positioning of the contacts could result in incorrect location of these sub-assemblies, with the results as described above.

(4) N/O Contacts

These contacts are placed into the assembly after their associated plunger sub-assemblies. Any misplacement of the contacts will result in either the contact falling out or obstruction of the cover assembly.

(5) Helical Springs

Absence of the springs at any subsequent assembly operation would not harm the machine. The springs could be badly assembled by misplacement at either end, or by damage to the springs during assembly. If a spring was badly damaged it could affect the final locating of the cover, but otherwise no damage to the machine at subsequent assembly operations would result.

(6) Cover

If the cover is missing the helical springs would not be contained. If the cover is not perfectly located, then the fitting of the rivets into the assembly would be impossible.

(7) Terminal Clamping Screws

Absence of the clamping screws would not affect subsequent operations but misalignment may hinder the functional check.

(8) Fixing Screws

Absence of fixing screws and their associated washers would not affect any subsequent operation, but any mispositioning of the screws would prevent their assembly.

SUMMARY

The following checks must be made to safeguard the machine:

1. The housing must be present for any assembly operation.
2. A plunger must be present for any sub-assembly operation.
3. N/C moving contact must be correctly aligned during assembly.

4. N/O sub-assembly must have spring present with contact.
5. Sub-assemblies must be positioned correctly.
6. Fixed contacts must be positioned correctly, especially the N/O variety.
7. The cover must locate correctly.
8. Terminal clamps must be present.

4 INVESTIGATION INTO MIS-ASSEMBLIES

Sections (2) and (3) have isolated those parts of the assembly process which need keeping account of from the point of view of machine safety and switch functional operation.

It is now necessary to look at these stages to decide why the errors may occur, how often they will occur, and finally whether the frequency of occurrence justifies detection.

The following is a combined summary from sections (2) and (3) of the operations that need to be monitored:

(1) Arrival of the housing at its station.
(2) N/O sub-assembly.
(3) Placing of plunger sub-assemblies.
(4) Placing of insulator plates.
(5) Placing of contacts
(6) Placing of the cover.
(7) Placing of the clamping screws.

The majority of these operations are placing of parts into the assembly. It is the policy of the Control Committee that the control system will ensure that no placing operation will start unless all the required parts are in position to be picked. This will mean that no part can be missing from an assembly unless it has been dropped between picking and placing. This raises two points: firstly, the machine must be designed to allow for odd parts to be dropped on to the conveyor without damage, and, secondly, those parts isolated in section (2) must be detected as far as possible in the assembly after they have been placed.

If a part is successfully transported to the assembly then the next possibility is that it will not be successfully placed in its correct position. This could be due either to an obstruction or to a misalignment of the placing mechanism.

Misalingment of the mechanism should only be due to wear or damage, both of which should be rare occurrences. However, the presence of an obstruction, due to bad components or to the presence of foreign bodies on the machine, is much more likely. The first will be a regular occurrence even with a high standard of components while the second is something that is random and unpredictable. Because of this both must be allowed for. The result of a misplacement, or an obstruction, would be the same; the placing head would be unable to complete its movement. It will be necessary, therefore, to check for the completion of the placing stroke on every placing operation.

A final possibility is that because of the unstable state of some of the parts after assembly (section 3.) allowance must be made for the parts falling out. None of these parts could fall out without being detected at the functional check.

All the above points are considered in the following summary of the problems of the listed operations.

(1) Arrival of the housing at its station.
The platens arriving at this station should be empty. Care must be taken to ensure this. The operation will commence when an empty platen and a housing are in position. The housing must be placed very accurately in position on the platen as the whole of the remaining operations depend on this. It will, therefore, be necessary to detect accurately the motion of the placing mechanism on this station.

(2) N/O Sub-Assembly
The problem with this operation is the tapered contact spring. The operation will not commence until the spring is available. If possible, its presence in the sub-assembly must be detected, or, at least, the probability of it being lost minimised by the design of the head.

(3) Placing of plunger sub-assemblies
The problem with these sub-assemblies is that during placing the contacts may move out of line relative to the plungers. As pointed out in section (3) this could be serious. However, it is really a question of designing

the picking heads to guarantee correct location of these related parts during placing, rather than a problem of control. Providing this can be assured, then placing problems only arise when there is misplacement due to the reasons discussed previously. These will be detected if the assembly movement is incomplete.

(4) Placing of insulator plates.
The insulator plates could be missing and remain undetected at the functional check. Therefore, the presence of these parts must be checked at assembly stage. It has been proposed that these plates be manufactured on the machine, in which case the detection may be simplified.

(5) Placing of the Contact Plates.
The positioning of the contacts must be accurate. Mispositioning of the contacts will be detected by the check on assembly motion. Any missing contact will be detected at the functional check.

(6) Placing of the cover.
This is a problem operation. It is also complicated because the helical springs and the rivets will probably be placed on the same station. Previous checks on assembly motions will ensure, as far as possible, that there is no obstruction to the cover assembly. However, it is possible that there will be an obstruction. It will be detected by the check on assembly motion, but any action to be taken on detection is discussed in section 5.

(7) Placing of the clamping screws.
As in the above operations incompletion of assembly motion will signal any misplacement, but it may be more of a problem to check that the parts are present on the final assembly. However, it is clear that some check will be required, either of the screwing operation, or of the actual placing.

(8) Placing of fixing screws
This is a pressing operation. There should be little problem.

SUMMARY, Section 4

A perfectly adjusted machine, supplied with 100% perfect parts should, theoretically, run without trouble. However, because of the possibility of bad components, and of the presence of odd parts in the machine it is probable that obstructions to the placing of parts in the machine will occur. It is, therefore, necessary to check the completion of assembly motions by detectors, and to design the assembly mechanisms so that they will suffer no damage if an obstruction is met.

It will also be necessary to provide additional detectors on the machine to check the presence in the assemblies of certain components.

5. ACTION TO BE TAKEN ON DETECTION OF A MIS-ASSEMBLY

The detection of a mis-assembly, by the methods discussed, can result in one of two actions.

The first is that on detection of an assembly error the particular module concerned can be stopped, and visibly marked, so that any error or obstruction can be corrected by an operator. The second course of action is to build into the machine a means of automatic rejection so that any switch assembly in which is detected an error at any stage is automatically removed from the machine as a reject.

In order that the second course of action can be justified it must be shown that the frequency of occurrence of detected errors is such that by stopping the machine at every detection the output of the machine is significantly reduced, thus raising the cost of the produced component.

The frequency of breakdown or mis-assembly due to wear or damage to the assembly mechanisms must, by the very nature of their design, be very low. Certainly not nearly enough to justify automatic rejection. However, it has been shown by the Economic Planning Committee (Ref. 4.) that even with a high percentage of perfect parts the number of different components required for these switches reduces considerably the number of successful assemblies. From their figures, which were based on the assumption of assembly rejection process, it is clear that the expected frequency of bad components will justify a method of automatic rejection.

Consideration of each of the assembly stages shows that in all cases except one the assembly mechanism can place the particular component even if its correct location has not been found. The assembly can then be rejected. The one exception is in the placing of the cover. On this station the cover, main springs, and rivets are placed. The rivets cannot be fixed unless the cover locates perfectly in position. If it does not, then there is a problem. The assembly cannot be sent for rejection as it stands because it contains springs in compression. Because of the necessity for removing assemblies upward from the platen it would seem impractical to mechanically hold the cover down until rejection. The only practical solution is to make an exception with this operation and stop the module, bearing in mind that all precautions have been taken at previous stations to reduce the chance of obstruction to the cover placing.

Automatic rejection will, therefore, be required whenever a bad assembly is detected, except in the case of the cover fitting.

6 METHODS OF REJECTION

It has been shown in section 5 that automatic rejection of bad assemblies is justified.

There are two ways of providing this rejection service. Firstly, each separate module could be fitted with its own rejection device. The device could be operated whenever there is a malfunction on that module. This would need very simple operating logic, and would mean that rejects were readily divided up into quantities with the same error. However, this individual provision of rejection mechanisms would be very costly, and although the total rejects from the whole machine justify automatic rejection, the rejects from any individual station would not justify the same treatment.

This leaves the second method, which is to provide one reject station at the end of the machine. It will be required that the machine remembers which assemblies need rejecting, so that action is taken when they reach the reject station.

It is possible to devise the logic circuitry to remember the detection of bad assemblies, and to count down and initiate the rejection cycle at the correct time. However, with a machine of the type proposed, using a free transfer system, the number of assemblies in process at any one time will vary. This, together with the need to allow for the possibility of more than one assembly awaiting rejection on the machine at any one time, would mean that the logic required would have to be so complex as to be an impractical proposition.

Another method, and one which would seem at this stage to be the most practical, is to design the platens in such a way that they can be physically marked. For example, they could be fitted with a tab which can be raised or lowered. If, during a particular run through of the machine, a bad assembly is detected, the tab is automatically raised at that station. This tab would then be detected at all subsequent stations, and no more assembly work would be carried out on that platen. When the reject station is reached, the tab would operate the reject mechanism, and then the tab would be lowered for the next run of the platen round the machine.

A further suggestion is that there be one station at the end of the machine for removing the assembly from the platen, be it good or bad. The position of the tab would determine whether the assembly was placed with the "good" or with the "bad".

7 NUMBER OF REJECTS

It is necessary to keep a check on the number of rejects that are detected as coming from any one assembly station. The number of rejects that result from bad components will be limited, and the probability of getting a certain number of rejects of this type in succession can be calculated.

If an assembly head is damaged, however, the number of rejects detected will be much higher. It is, therefore, recommended that a counter be included on each station to count sequentially the rejects detected during assembly. The counter should be reset when assembly is successful, and a warning should be given if the sequential number of rejects detected exceeds that which is predicted as probable being due to the component quality.

The following analysis calculates the number of successive defective assemblies a station must produce before it can be assumed to be damaged.

Assumptions made:

1 The head can only be damaged by trying to assemble defective components.

2 The probability of a mechanical or pneumatic breakdown of the head is very small compared with the probability of observing a defective component and, therefore, this is neglected.

3 A proportion of defective components damage the head.

4 A proportion of defective components do not damage the head, but cause defective assemblies which are detected.

5. A damaged head always produces defective assemblies.

Let P_1 = probability of defective component

P_2 = probability of the defective component damaging the head

P_3 = probability that the defective component produces a defective assembly.

n successive assemblies will be observed either:

1 if the head is undamaged and each of n successive components produce a defective assembly;

2. if the head is damaged by the r^{th} defective component fed into the head, the previous (r-1)th successive components not having damaged the head but having produced defective assemblies. (r = 1 to n)

Drawing CM/A1 summarises the assumptions in the form of a block diagram.

The probability of 1. occuring = P_1

$$P_1 = \left(\begin{array}{l} \text{probability of defective component x} \\ \text{probability of defective component not damaging head x} \\ \text{probability of producing defective assembly} \end{array} \right)^n$$

Therefore $P_1 = (p_1 (1-p_2)p_3)^n$ Let $k = (p_1 (1-p_2) p_3)$

$P_1 = k^n$

It has been assumed that $p_1 = 0.01$, $p_2 = 0.5$, and $p_3 = 0.5$

$k = (0.1x(1-0.5)x0.5) = 0.1x0.5x0.5$

Therefore $k = 0.025$ $k^2 = 0.000625$ $k^3 = 0.0000156$

for n = 1 $P_1 = 0.025$

n = 2 $P_1 = 0.000625$

n = 3 $P_1 = 0.0000156$

The probability of 2. occuring = P_2

$$P_2 = (p_1p_2) + (p_1 (1-p_2) p_3) p_1p_2 + (p_1 (1-p_2) p_3)^2 p_1p_2 + \dots\dots\dots + (p_1 (1-p_2) p_3)^n p_1p_2$$

$$= p_1p_2 (1 + k + k^2 + \dots + k^n)$$

Now $1 + k + k^2 + \dots + k^n = \frac{1 - k^n}{1 - k}$

Therefore: $P_2 = p_1p_2 \left(\frac{1 - k^n}{1 - k} \right)$

for n = 1 $$P_2 = 0.01 \times 0.5 \times \frac{(1-0.0125)}{(1 - 0.0125)}$$

$$P_2 = 0.005$$

for n = 2 $$P_2 = 0.01 \times 0.5 \times \frac{(1 - (0.025)^2}{(1 - 0.025)}$$

$$P_2 = 0.00512$$

for n = 3 $$P_2 = 0.01 \times 0.5 \times \frac{(1 - 0.025^3)}{(1 - 0.025)}$$

$$P_2 = 0.000512$$

Summarising the calculated values of P_1 and P_2 for n = 1 to 3 :

n	P_1	P_2
1	0.025	.005
2	0.000625	.00512
3	0.0000156	.000512

It can be seen from the above table that the probability of P_1 occuring is very much smaller than the probability of P_2

when n = 2 and 3 the difference increases as n becomes larger.

Therefore, if only three successive defective assembly operations are detected there is a high probability that the head is damaged. Even if the chosen values of p_2 and p_3 are inaccurate, the value of n for this application will remain the same as the difference between P_1 and P_2 will still be large.

It is, therefore, shown that the counter of defective assemblies on each assembly head should be set to record successive mis-assemblies, and, if there are three in succession, the head should be stopped and a warning given.

2. if the head is damaged by the r^{th} defective component fed into the head, the previous (r-1)th successive components not having damaged the head but having produced defective assemblies. (r = 1 to n)

Drawing CM/A1 summarises the assumptions in the form of a block diagram.

The probability of 1. occuring = P_1

P_1 = (probability of defective component x) n
(probability of defective component not damaging head x)
(probability of producing defective assembly)

Therefore $P_1 = (p_1 (1-p_2)p_3)^n$ Let $k = (p_1 (1-p_2) p_3)$

$$P_1 = k^n$$

It has been assumed that $p_1 = 0.01$, $p_2 = 0.5$, and $p_3 = 0.5$

$$k = (0.1x(1-0.5)x0.5) = 0.1x0.5x0.5$$

Therefore $k = 0.025$ $k^2 = 0.000625$ $k^3 = 0.0000156$

for $n = 1$ $P_1 = 0.025$

$n = 2$ $P_1 = 0.000625$

$n = 3$ $P_1 = 0.0000156$

The probability of 2. occuring = P_2

$$P_2 = (p_1 p_2) + (p_1 (1-p_2) p_3) p_1 p_2 + (p_1 (1-p_2) p_3)^2 p_1 p_2$$

$$+ \ldots\ldots\ldots + (p_1 (1-p_2) p_3)^n p_1 p_2$$

$$= p_1 p_2 (1 + k + k^2 + \ldots + k^n)$$

Now $1 + k + k^2 + \ldots + k^n = \frac{1 - k^n}{1 - k}$

Therefore: $P_2 = p_1 p_2 \left(\frac{1 - k^n}{1 - k} \right)$

for n = 1 $$P_2 = 0.01 \times 0.5 \times \frac{(1-0.0125)}{(1-0.0125)}$$

$$P_2 = 0.005$$

for n = 2 $$P_2 = 0.01 \times 0.5 \times \frac{(1-(0.025)^2}{(1-0.025)}$$

$$P_2 = 0.00512$$

for n = 3 $$P_2 = 0.01 \times 0.5 \times \frac{(1-0.025^3)}{(1-0.025)}$$

$$P_2 = 0.000512$$

Summarising the calculated values of P_1 and P_2 for n = 1 to 3 :

n	P_1	P_2
1	0.025	.005
2	0.000625	.00512
3	0.0000156	.000512

It can be seen from the above table that the probability of P_1 occuring is very much smaller than the probability of P_2

when n = 2 and 3 the difference increases as n becomes larger.

Therefore, if only three successive defective assembly operations are detected there is a high probability that the head is damaged. Even if the chosen values of p_2 and p_3 are inaccurate, the value of n for this application will remain the same as the difference between P_1 and P_2 will still be large.

It is, therefore, shown that the counter of defective assemblies on each assembly head should be set to record successive mis-assemblies, and, if there are three in succession, the head should be stopped and a warning given.

8. CONCLUSIONS

From the above consideration of the problems of detection and rejection of bad assemblies it is recommended that the following be designed into the control system.

(1) Detectors to check that the extreme limit of an assembly motion has been reached. If the limit is not reached, the cycle will not be stopped, but the assembly will be marked as a reject.

(2) Additional detectors should be provided for the assembly of the components listed in section 2 to guarantee their presence in the switch assemblies, if it is decided that this additional check is justified. A final decision would be determined by the actual assembly head design.

(3) It is necessary to provide automatic rejection facilities for mis-assembled switches. It is most practical and economical to provide one rejection station at the end of the machine and to physically mark the platen when an error in assembly is detected. The control circuit should contain logic to ensure that any marked platen is detected to ensure that no assembly time is wasted on intermediate stations, and that the assembly is rejected at the end.

If the cover does not locate during assembly, that module should be stopped, and a visible warning activated for the operator. It is probable that this station will have the longest operation, so any breakdown here will stop the whole machine. It is therefore necessary to ensure easy access to the assembly mechanism of this station.

(4) It is recommended that counters be included on each assembly station to record the number of successive rejects that are detected. If three successive mis-assemblies are detected on any one station there is a high probability that the station is damaged, and it should be stopped and a warning given.

APPENDIX 111

CALCULATIONS FOR CONVEYOR MOTIVATION

1 CALCULATION OF HORSE POWER OF MOTOR

For the calculations it was assumed that there is 6 ft between workheads, and the buffer stock is full before each workstation, and considering 10 buffer stocks, 60 ft length of belt.

Width of platens	= 5 "	
No of platens in buffer stock	$= \frac{6 \times 12}{5}$	= say 14 platens
Weight of platen	= 3.2 lbf	
Weight of fixture	= 0.6 lbf	
TOTAL weight of platen & fixture	= 3.8 lbf	
Weight of slots	= 0.071 lbf	
No of slots between workheads	= 36	

Friction force between slots and conveyor guides = $W_1 M_1$

$M_1 = 0.1$, Steel on P T F E

$W_1 = (3.8 \times 14 \times 10) + (0.071 \times 36 \times 10)$

$= 557.55$ lbf

∴ Frictional Force $= 557.55 \times 0.1$

$= 55.75$ lbf (248N)

Frictional force between platen and slots = $W_2 M_2$

$M_2 = 0.3$, steel on steel

$W_2 = (3.8 \times 14 \times 10) = 532$ lbf

∴ Frictional force $= W_2 M_2$

$= 532 \times 0.3$

$= 159.6$ lbf. (710N)

Total Friction Force = 159.6 + 55.75

= 215.35 lbf (958N)

Radius of Sprocket = 5.25 in.

$\therefore$ torque required = $\frac{215.35 \times 5.25}{12}$ = 94 lb ft (127.3 Nm)

For conveyor speed of 30 lbf, sprocket speed

= 11 rev/min

Horse Power required = $\frac{2 \times \pi \times 11 \times 94}{33000}$

Horse Power = 0.197 (147 W)

FOR A SAFETY FACTOR OF 2.5 the HORSE POWER OF MOTOR = 0.5 (370W)

2 CALCULATION OF PULLEY DIAMETERS AND DISTANCE BETWEEN CENTRES

The pulley diamter calculations are based on data given in the Fenner power transmission catalogue.

Ratios required from pulleys = 3.64, 2.73, 2.18, 1.82.

Slipping will occur at smallest dia. of V. pulley

Torque to be transmitted by belt = $\frac{94}{50}$ = 1.9 ft.lb.

Smallest diameter of pulley for this torque = 2.5 in

$\therefore$ for 3.64 ratio Dia. of motor pulley = 2.5

Dia. of gearbox pulley = 2.5 x 3.64
= 9.1 in

Pitch length of Alpha 425 wedge belt = 42.5"in

Pitch length of belt l = $2l + \frac{(0-d)^2}{4l} + 1.57\,(D+d) - 1$

Where C = Distance between pulley centres
D = Dia. of larger pulley
d = Dia. of smaller pulley

For l = 4.25, (1080 mm) D = 9.1 (231 mm), d = 2.5, (64 mm)

Calculated from (1) C = 11.68 in

Centre distances = 11.68 in (296 mm)

For 2.73 ratio D = 2.73d
from equation (1)

$$42.5 = (2\times 11.68) + \frac{(2.73d-d)^2}{(4\times 11.61} = 1.57\,(2.73d+d)$$

d = 3.15in (80 mm)

∴ D= 8.60in (218 mm)

For 2.18 ratio D = 2.18d

from equation (1)

$$42.5 = (2\times 11.68) + \frac{(2.18d-d)^2}{4\times 11.68} + 1.57\,(2.18d + d)$$

d = 3.7in (95mm)

∴ D = 8.06 in (205 mm)

For 1.82 ratio D = 1.82d
from equation (1)

$$42.5 = (2\times 11.68) + \frac{(1.82d - d)^2}{4\times 11.68} + 1.57\,(1.82d4d)$$

d = 4.25 in (108 mm)
∴ D = 7.74in (196 mm)

APPENDIX 1V

DETAILED DESCRIPTION OF PICK AND PLACE HEAD CONTROL CIRCUIT

The function of the pick and place head is to pick up a component or components from a position on the outside of the track and place them in the assembly which is positioned above the track. The flow chart and circuit for control of the head are shown in figures CM/10 and CM/13 respectively.

The linear motions of the pick and place head are performed using pneumatic cylinders. The jaws are simulated by one cylinder, the actual jaw mechanism being shown in reference 2, figure CM/13 The cylinder for the Y plane, being double acting, is controlled by a pneumatic valve. The direction of flow through the valve is controlled by a spool which is actuated via a diaphragm from outputs of the logic circuit. The minimum firing pressure of a diaphragm operated valve is 4 in. (102 mm) w.g. The reject, Z plane and jaw cylinders, being single acting, are actuated directly from step up relays which are controlled by out puts from the logic circuit. A control signal of greater than 3 in (75 mm) w.g. actuates a step up relay giving an 80 lb/in^2 (.55 N/mm^2) output.

The logic control of the head is carried out using the Maxalog fluidic system, developed by Maxam Power Limited. This uses the turbulence amplifier (T.A.) described in Appendix 1 as the basic logic element, the characteristics of which are shown in figure CM/A2. The T.A.'s are mounted in modular banks of 6, 12, or 20 elements, each bank having a common supply to all its T.A.'s. For each pick and place head two 20-unit banks are used such that T.A.'s are also available for the control of component escapements.

The sensing of motions is carried out using back pressure sensors in the stops, the principle of which is given in Appendix 1. The outputs of the back pressure sensors are fed directly into the control parts of the T.A.'s. The short delays required for this circuit are made using long lengths of tubing. The delay is 1 ms/ft (3.3 ms/mm).

When the output of a sensor or T.A. is required by the electronic control system, or to activate a light, it is passed through an air to electric relay shown in figure CM/A8.

Sequence of Control

When in use, with the station select switch on, the idle position of the pick and place head is in the place position with the head raised (Z up) and the jaws closed holding the component. The sequence of operation is as follows:

1) A signal to start the assembly comes from a limit switch, which is actuated when the jack is raised, holding the platen.

2) The head is lowered to the platen and the jaws are opened placing the component in the assembly. If the head does not go down a correct distance and actuate two sensors the component has not been placed correctly in the assembly and a cylinder is actuated, striking the reject pin on the platen. The signal of a reject also actuates a counter which, if it counts three consecutive rejects, sends a warning to hold the buffer stop out and actuate a warning light on the main control panel.

3) The signal to raise the head is delayed to allow the reject cylinder to operate when required. With the jaws open in the place position the head is raised which passes a signal that the assembly is complete, thus allowing the jack to be lowered if there is space in the buffer. The same signal also resets the reject counter if the assembly has been carried out successfully.

While the next platen is approaching the head the following operations occur:-

4) The jaws being open and the head raised, the pick and place unit is brought away from the track to the pick position. At this stage a reset signal is sent to the memory control of the reject counter.

5) With the head raised in the pick position, if the component is sensed in position, the head is lowered. If there is no component in the pick position the head is not lowered and the assembly start start signal, when the next assembly is in position, will remain on until an operator clears the fault.

6) When the head is lowered in the pick position the jaws are closed on the components.

7) The head is then raised in the pick position and the pick and place unit is brought over the track to the place position. When the signal is received to start assembly the above sequence is repeated.

If a head is to pick and place more than one component at a time, each component is sensed in its pick position and the output of all the sensors is fed through an AND gate to ensure that all the components are ready to be picked. The jaws, when required, are adapted to pick more than one component, the jaw signals also being fed through an AND gate to ensure that all jaws operate correctly.

The two banks of T.A.'s are contained in a metal cabinet to shield them from contamination. Each bank occupies a volume approximately 12 x 3 x 3 in (300 x 75 x 75 mm). The valve is approximately 2.5 x 2.5 x 3 in (60 x 60 x 75 mm) each step up relay 1.5 x 1.5 x 3 in (38 x 38 x 75 mm), and they are mounted on a plate with the T.A. cabinet, figure CM/A3. The front of the cabinet is detachable so that it is easy to alter the control sequence when required.

When the station select signal is turned off the pick and place unit stops when lowered in the pick position with the jaws open. In this state the main air can be turned off.

If it is necessary to place parts in the side of an assembly the T.A.'s can be easily connected to perform the required logic. The circuit for such a system is shown in figure CM/A4.

APPENDIX V

DETAILED DESCRIPTION OF PLATEN CONTROL OPERATION

The function of the platen control system is to stop a platen, lift it from the conveyor so that the assembly operation can be carried out and lower it back on to the conveyor on completion. If a reject assembly is detected no assembly operation is performed and the platen is allowed through without being operated on. The flow chart for control of the platen and the electronic circuit are shown in figures CM/06 and CM/08.

The buffer stop, station stop and jack are pneumatic cylinders. The buffer and station stops each consist of two cylinders, positioned so that they can operate from both sides of the conveyor. In each case both cylinders operate off one valve.

All the cylinders are controlled by solenoid operated high pressure valves which are controlled from a special reed relay operated amplifier described in Appendix V11. The valves are spring return, therefore the logic controlling them contains memory circuits to maintain the required direction of air flow.

Integrated circuit logic (ref. 14) is used for the control system. The characteristics of the elements used are shown on figure CM/A5, and the logic functions are in Appendix V111.

The sensing of motion is carried out using micro switches which are positioned on the conveyor module as shown in figure CM/A6.

The following operations are standard for the platen control of each head, starting with the stated initial conditions.

Initial conditions with the machine off:

(1) empty station
(2) jack retracted
(3) station stops extended
(4) buffer stops extended

When the machine start button is pressed it re-sets the buffer F/F which retracts the buffer stops allowing a platen to enter the station. On entering it passes a reject sensor which distinguishes between normal and reject platens.

A normal platen moving into the station hits the head sensor and immediately hits the station stop, bringing the platen to rest. A signal from the head sensor sets the buffer F/F which causes the buffer stop to extend, stopping any following platens and at the same time giving a signal to set the jack F/F which sends the jack up. The jack going up removes the platen from the head sensor. When the jack has located the platen a sensor is activated which sends an assembly start signal to the head control.

The assembly complete signal from the head control resets the jack F/F causing the jack to lower, and also sets the slave inhibit F/F, so when the jack arrives down and hits the jack and head sensors it resets the mast inhibit F/F and is stopped from going up again. Activation of the head sensor resets the buffer F/F which retracts the buffer stops. When there is room in the succeeding buffer the station stop is withdrawn allowing the platen to leave. As the rear of the platen leaves the head sensor the master inhibit F/F is reset ready for the next platen to be sensed. When the platen hits the buffer full sensor the station stop is extended ready to stop the next platen.

If a reject platen is sensed at the station it sets the slave inhibit F/F which resets the master inhibit F/F and prevents the jack from going up. It also inhibits the buffer F/F from being set and the buffer remains retracted allowing the following platen to enter. When there is room in the succeeding buffer the station stop is retracted allowing the reject platen to go through. The cycle is then the same as before.

If the machine is restarted with a platen in the station the start signal resets the master inhibit F/F. This prevents a further assembly operation taking place and retracts the buffer and station stops allowing the platen through ready for the machine cycle to restart.

The reject counter consists of two flip flops coupled together to count to binary 11 (decimal 3). Its principle of operation is shown in Appendix V111.

I

If the assembly cycle detects a reject, a signal is sent to the counter circuit which adds one to the number already stored. After each acceptable assembly the counter is reset to zero. If three consecutive rejects are counted a signal is sent to the control circuit which inhibits further platens from entering the station. For restarting the station, the counter is manually reset by the operator.

When the station is not selected, the signal from the station select logic is removed. This prevents the buffer and jack F/F being set so the sequence is the same as if a reject was detected. For machine run down the buffer F/F is prevented from resetting, causing the buffer stop to remain extended, stopping further platens entering the station.

APPENDIX VI

SWITCH SELECTION

Drawing CM/A7 shows the suggested circuit for providing the two facilities of assembly selection, and station programming. The selection switch can be turned to one of six positions. Five of these select various combinations of assembly operations, and the sixth enables other station combinations to be programmed.

With the switch in positions one to five, a logic 1 signal is sent along one of five supply lines on the programming plug board. On each of these lines there are a number of tapping points, such that the insertion of plugs enables the logic 1 signal to be transmitted through an OR gate to an output socket. The OR gate is to prevent feedback of the signal to other supply lines.

There is one output line which provides a station select signal for each station but the rest can be connected to any station function, either to activate an electric device, or through a solenoid valve to activate a pneumatic device. In this way the number of functions which can be controlled on any station is variable. The drawing is shown with the circuit programmed for the production of the five varieties of heavy duty switch.

With the switch in position six, the programming position, a logic 1 signal is sent through the supply line to the station select button switches on the control console. The depression of the button for any station will automatically provide a station select signal to that station. Any other functions that are required from the programme switch can be selected by joining the button output to the appropriate supply gate, with linked plugs. This facility means that the console can be tuned up to produce any combination of output signals completely independent of the programmed combinations from the plug board, and can, therefore, enable completely different station combinations to be tried. It also provides the facility for running individual stations independently if required.

The drawing is shown with the programme buttons connected to produce NO/NO switches.

APPENDIX V11

INTERFACE SYSTEMS USED

Air to Electric Relay

Referring to figure CM/A8, the air to electric relay has two air supply ports which control the position of the metal shim. When the signal is "off", a bias pressure of 1 in (25 mm) WG holds the shim off the electrical contacts. When a signal is put on the relay greater than 1 in (25 mm) WG, the shim makes contact thus giving an electrical signal.

The relay should be mounted vertically such that, when air is off the shim does not rest across the contacts.

Step Up Relay

The step up relay, manufactured by Maxam Power Limited, gives the required high pressure output 80 lbf/in^2 (.55 N/mm^2), from a low pressure signal of greater than 3 in (77mm) W G. It therefore has four ports.

1) Exhaust
2) High Pressure Inlet
3) Low Pressure Inlet
4) High Pressure Outlet

The response time of the relay is 33 ms for operation and 10 ms for shutting off.

Reed Relay Operated Amplifier

The circuit diagram is shown on figure CM/A9. A positive logic 1 signal is applied to the input lifts point A + ve which switches the transistor ON which causes the relay to energize. When the logic 1 signal is removed point A goes - ve which switches the transistor OFF causing the relay to de-energize.

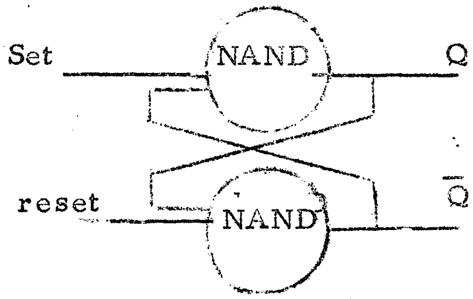
APPENDIX VIII

LOGIC FUNCTIONS

A	B	C
0	0	1
0	1	1
1	1	0
1	0	1

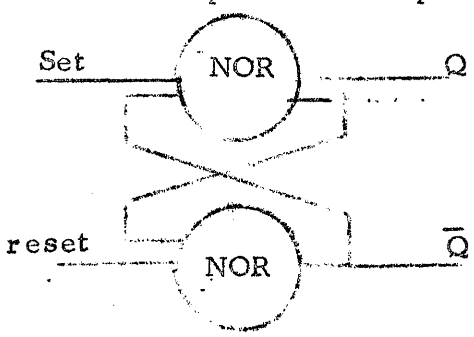
A	B	C
0	0	1
0	1	0
1	1	0
1	0	0

Cross Coupled NAND flip flops



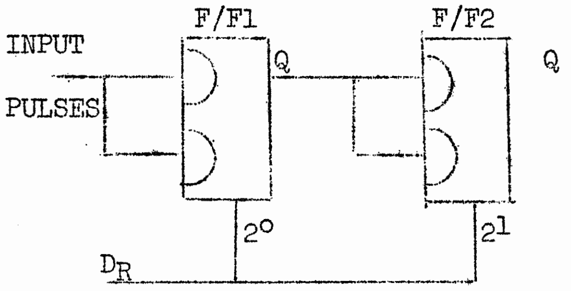
Set	Reset	Q	Qn+1
0	0	—	—
0	1	0	1
		1	1
1	1	0	0
		1	1
1	0	0	0
		1	0

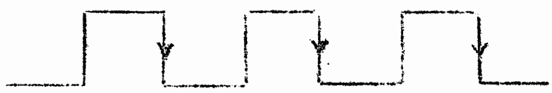
Cross Coupled NOR Flip Flop



Set	Reset	Q	Qn+1
0	0	0	0
		1	1
0	1	0	0
		1	0
1	1	—	—
1	0	0	1
		1	1

BINARY COUNTER





INPUT PULSES

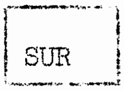
Consider both F/F to be set with zero on the Q output. On the first negative going pulse (indicated by the arrow) F/F 1 will change to 1, F/F2 remaining set at 0. On the second pulse F/F1 changes to 0 and F/F2 to 1 indicating a decimal count of 2. The third pulse sets the first flip flop to 1, F/F2 remains unchanged and the counter now contains decimal 3. A logic 0 on the D_R line resets the counter to zero irrespective of the input pulse.

LIST OF FIGURES

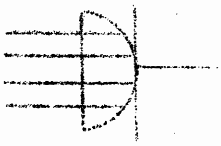
LIST OF FIGURES (continued)

SYMBOLS USED ON FIGURES

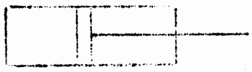
Back pressure sensor



Step up relay

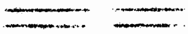


4 input turbulence amplifier



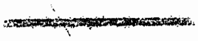
Air cylinder

Low pressure diaphram activated spring return valve



Interruptible jet

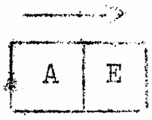
low pressure line



high pressure line

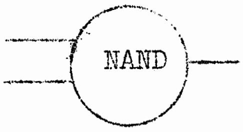
4 way spring return solenoid valve

pressure switch



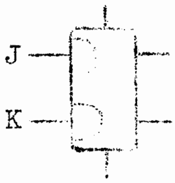
Air to electric interface

electricity to air interface



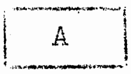
NAND gate

NOR gate



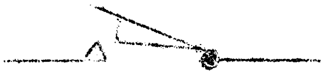
JK Flip Flop

transformer

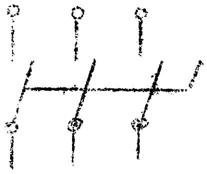


relay coil

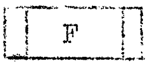
relay contacts



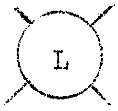
limit switches



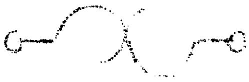
disconnect switch



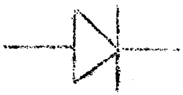
fuses



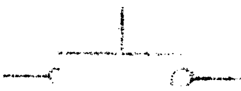
lamp



thermal overload relay



diode



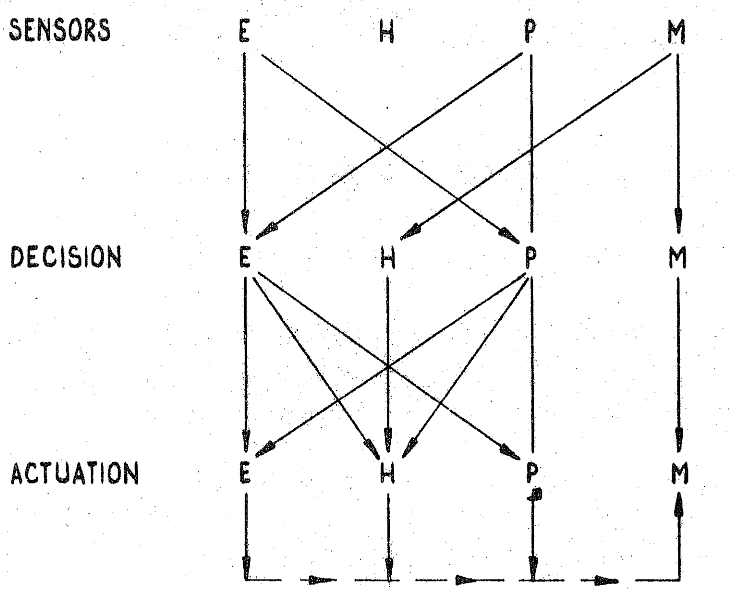
push button switch

ELECTRICAL	HYDRAULIC	AIR	MECHANICAL	
PHOTO-ELECTRIC MICRO-SWITCHES FIELD INTERFERENCE (METALS ONLY)	NOT APPLICABLE	PILOT VALVES BACK PRESSURE INTERRUPTABLE JET	LEVER	SENSOR
SOLID STATE RELAY REED SWITCHES	SPOOL VALVES	FLUIDICS (MOVING & NON-MOVING)	CAM, GEARS	LOGIC
MOTORS STEPPING MOTORS SOLENOIDS	MOTORS CYLINDERS	MOTORS CYLINDERS STEPPING MOTORS	LEVERS	ACTUATION

1968/69 GROUP DESIGN PROJECT

TITLE - POSSIBLE CONTROL ELEMENTS

DRG. Nº CM 01

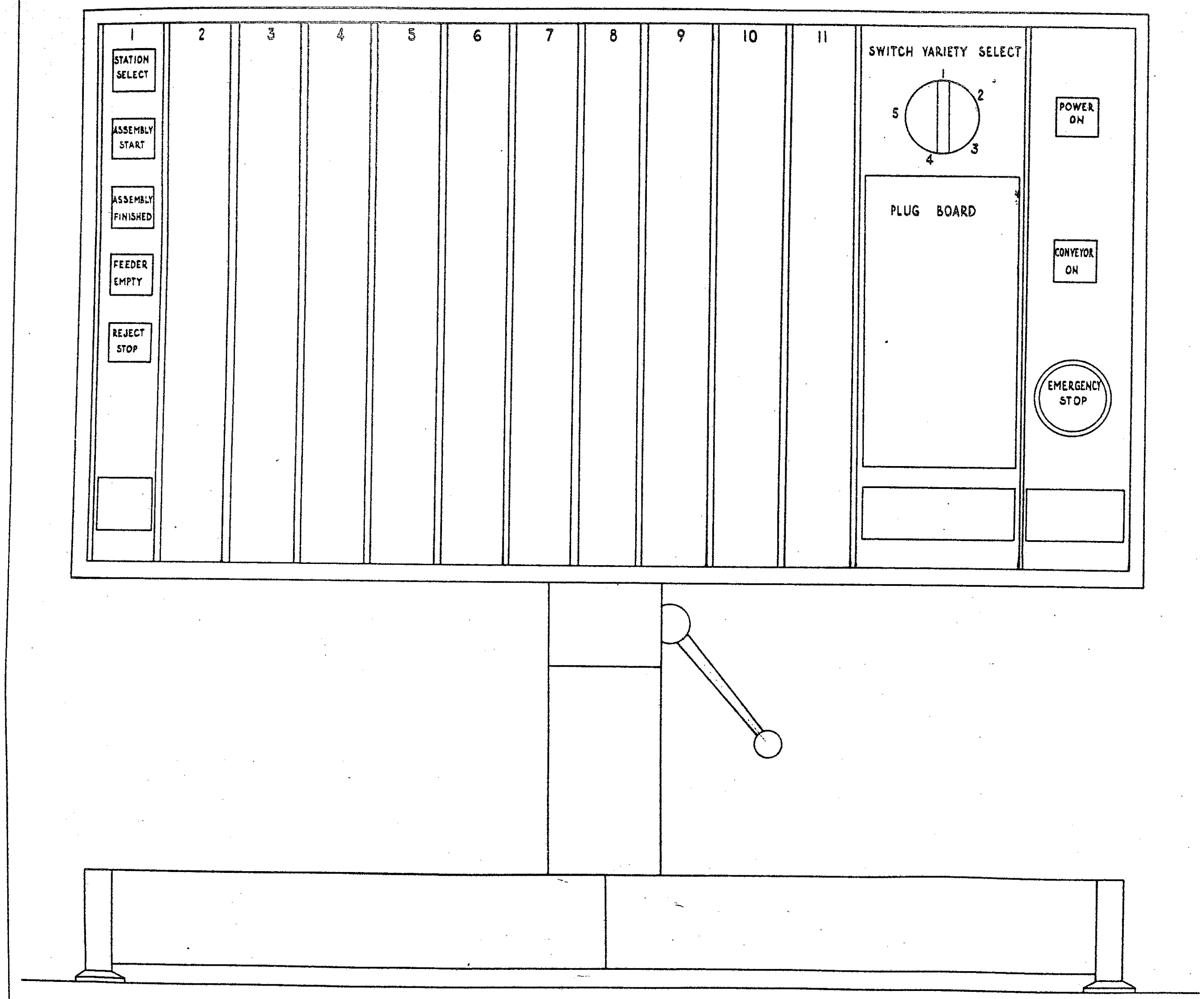


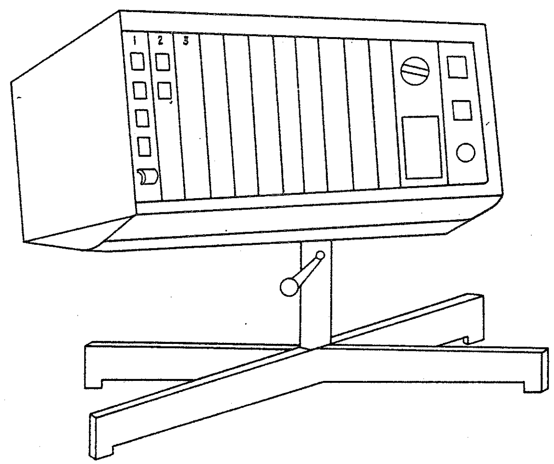
E - ELECTRICAL
H - HYDRAULIC
P - PNEUMATIC
M - MECHANICAL

1968/69 GROUP DESIGN PROJECT

TITLE :- PROBABLE INTERFACE COMBINATIONS

DRG. Nº CM 02





GENERAL ARRANGEMENT

1968/69 GROUP DESIGN PROJECT	
TITLE:- CENTRAL CONTROL PANEL	DRG. Nº CM 03

		2				3		4		5		6		8	9	10			
	TYPE	PRINTING				PLUNGER N.O.		CONTACTS		INSULATOR		PLUNGER N.C.		CLAMPING SCREWS	CLAMPING SCREWS	INSPECT			
		A		B		A	B	A	B	A	B	A	B	A	B	A		B	
		NO	NC	NO	NC											NO	NC	NO	NC
1	NO/NO	1	0	1	0	1	1	1	1	0	0	0	0	1	1	1	0	1	0
2	NO/–	1	0	0	0	1	1	1	0	0	0	0	0	1	0	1	0	0	0
3	NO/NC	1	0	0	1	1	0	1	1	0	1	0	1	1	1	1	0	0	1
4	–/NC	0	0	0	1	1	0	0	1	0	1	0	1	0	1	0	0	0	1
5	NC/NC	0	1	0	1	0	0	1	1	1	1	1	1	1	1	0	1	0	1

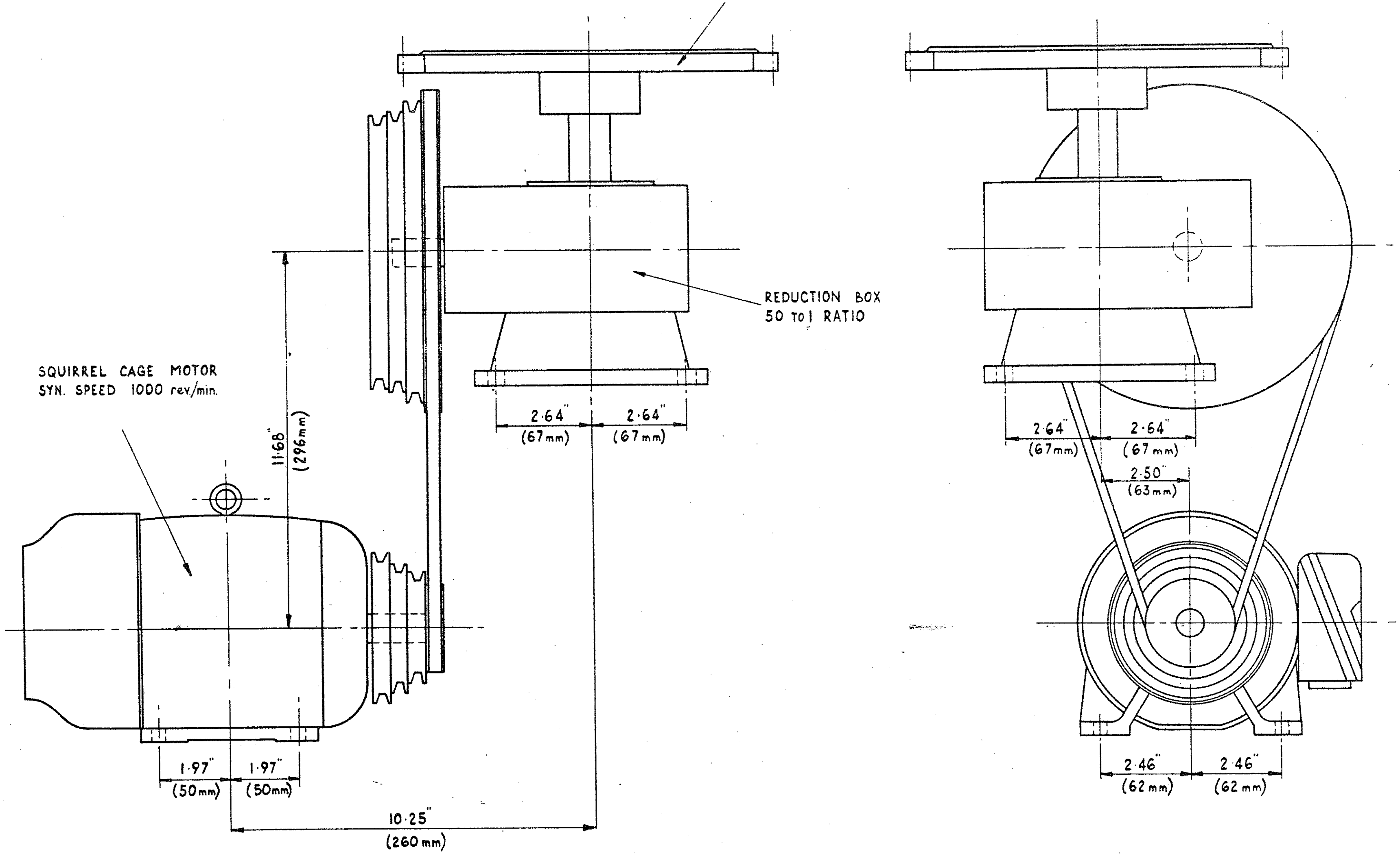
A B

CONTACT BLOCK

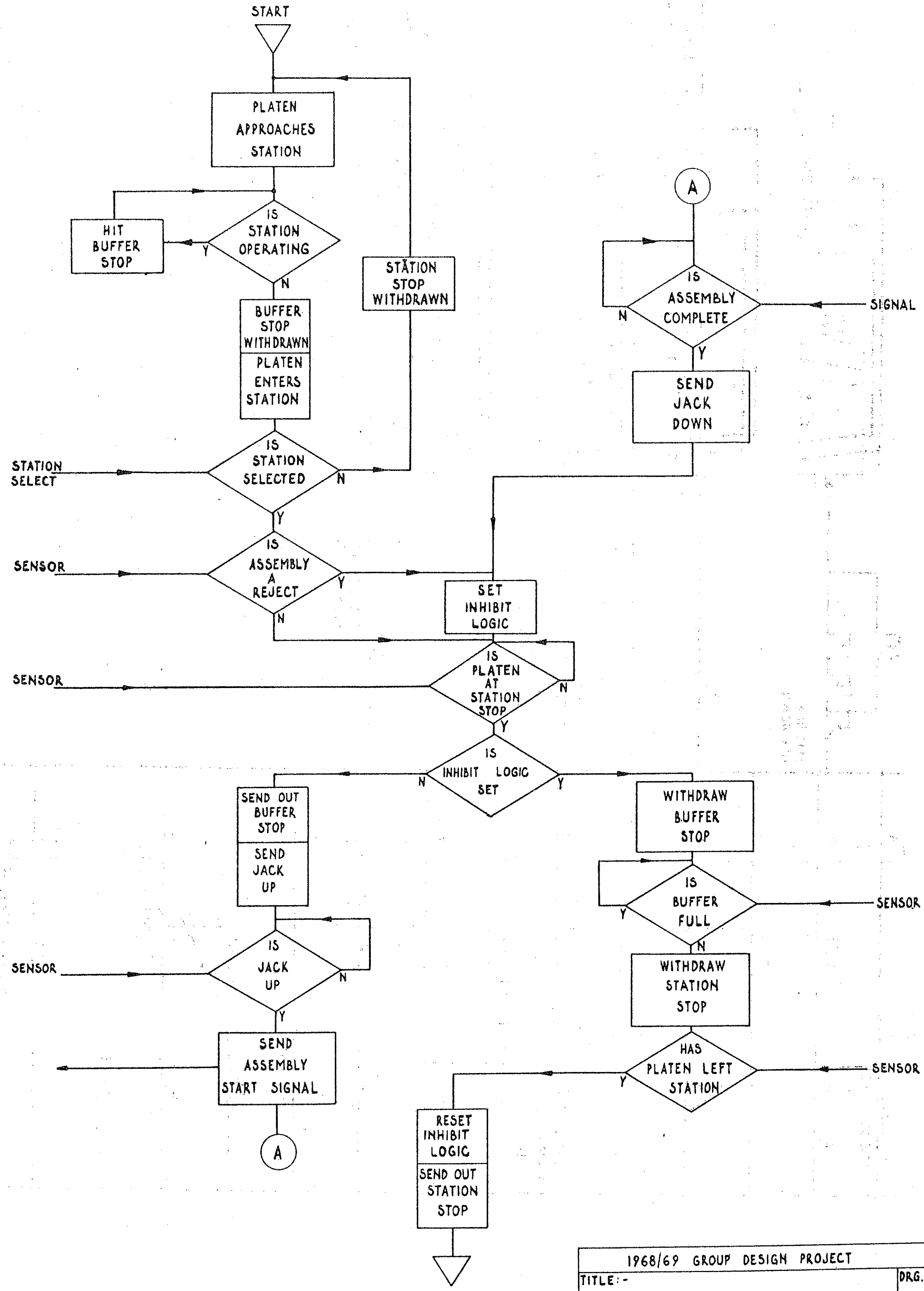
1968/69 GROUP DESIGN PROJECT

TITLE:- STATION COMBINATIONS FOR

DRG. No CM 04



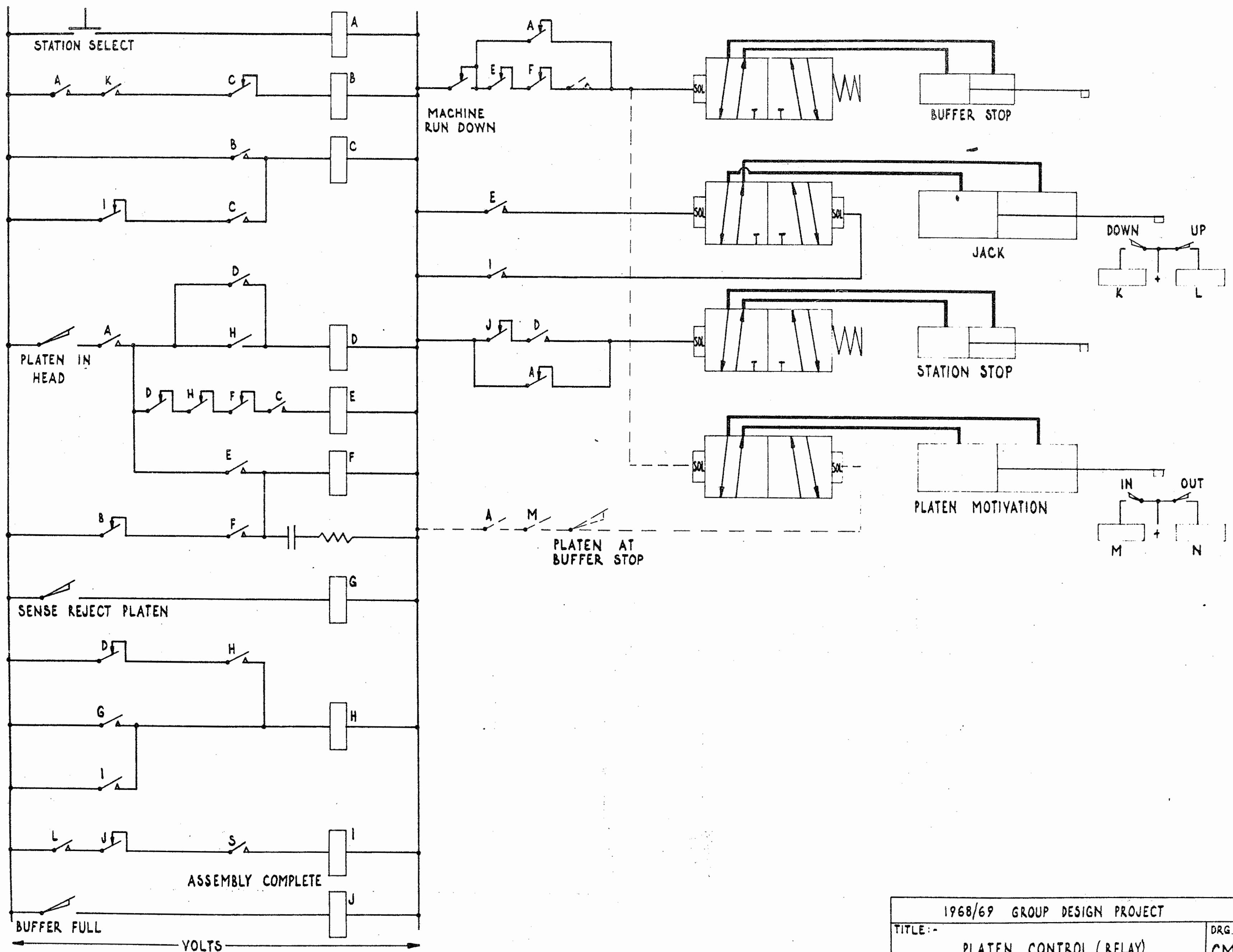
1968/69 GROUP DESIGN PROJECT	
TITLE:- CONVEYOR DRIVE	DRG. Nº CM/05



1968/69 GROUP DESIGN PROJECT

TITLE:- PLATEN CONTROL FLOW CHART

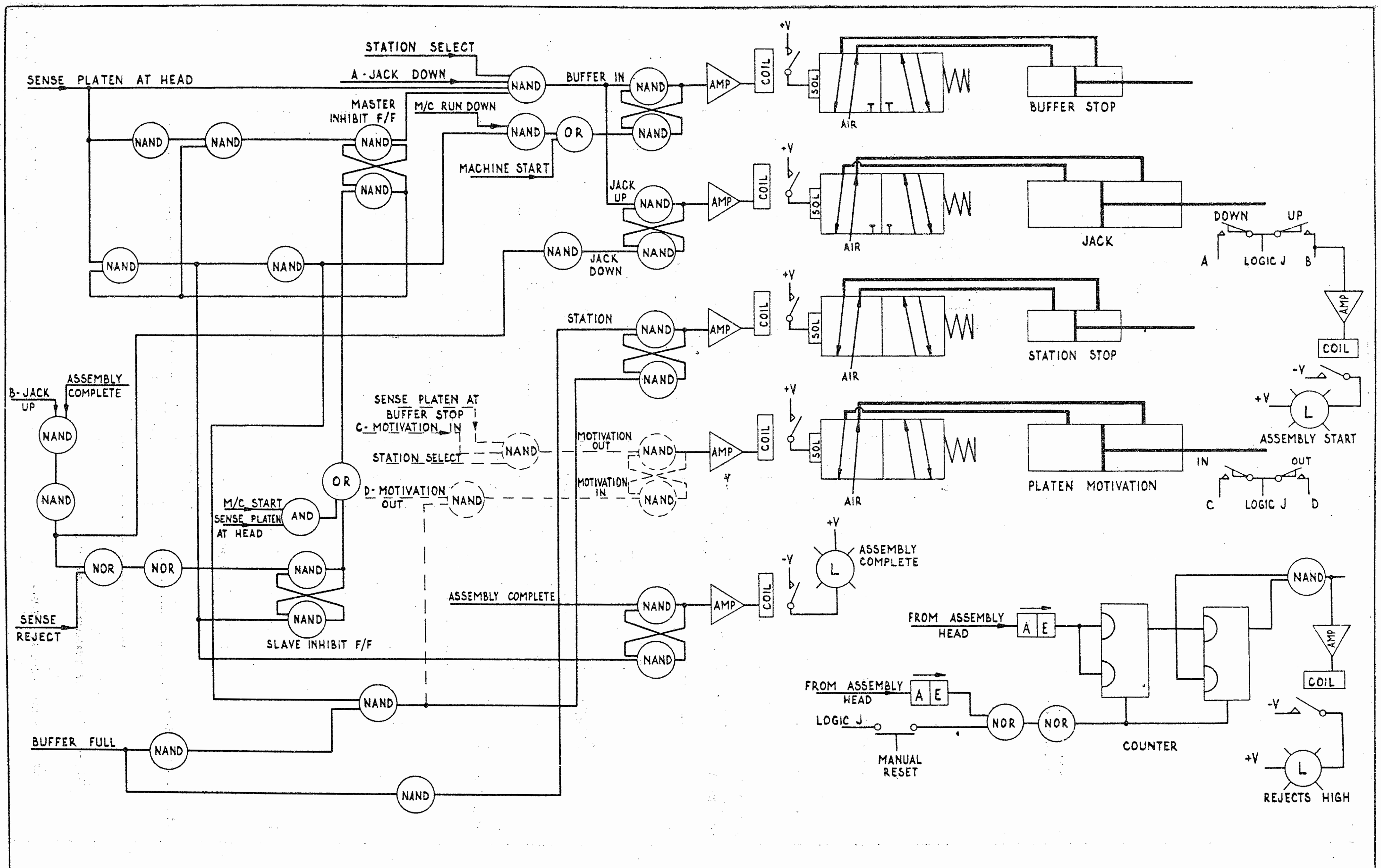
DRG. Nº CM 0



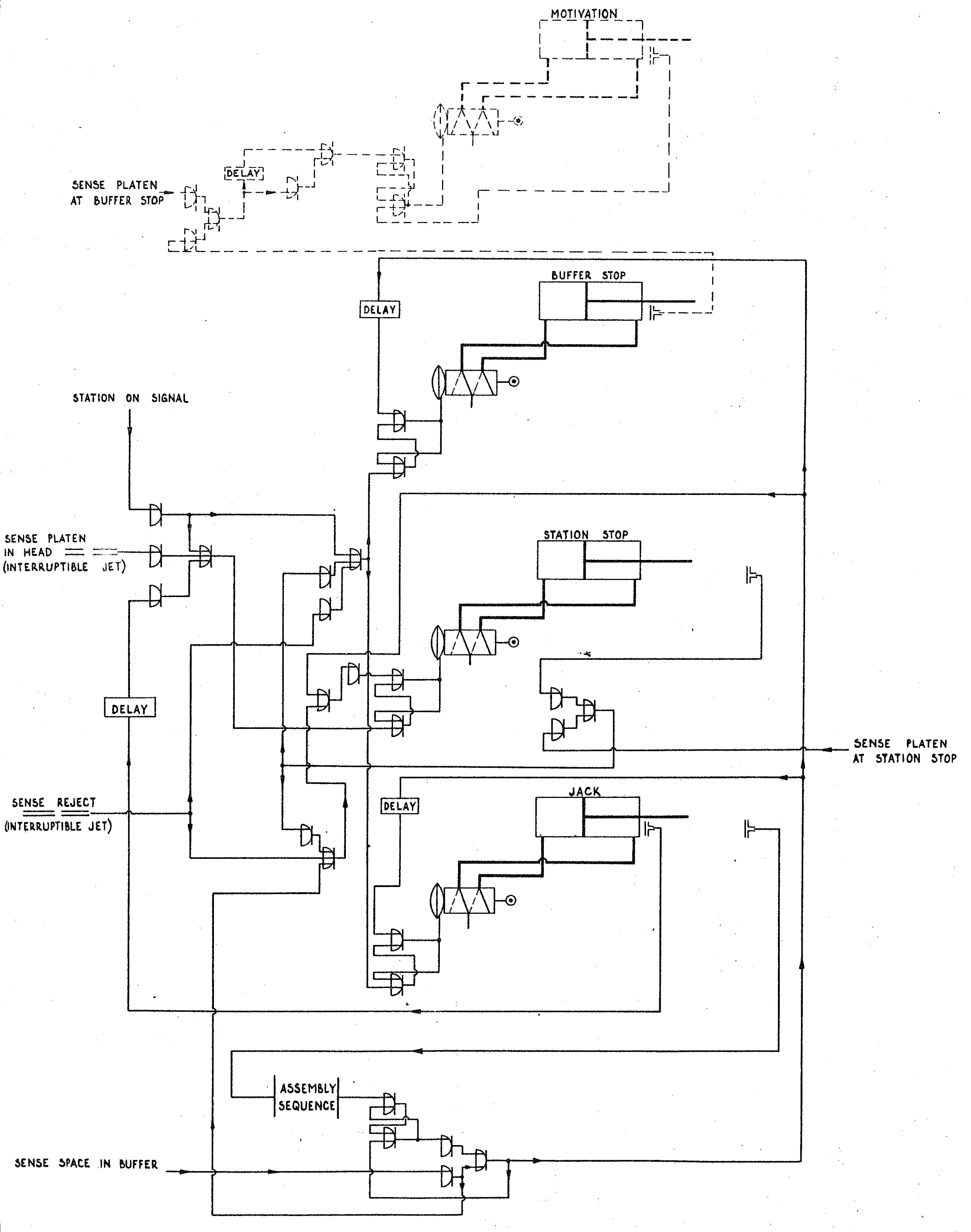
1968/69 GROUP DESIGN PROJECT

TITLE:- PLATEN CONTROL (RELAY)

DRG. Nº. CM07



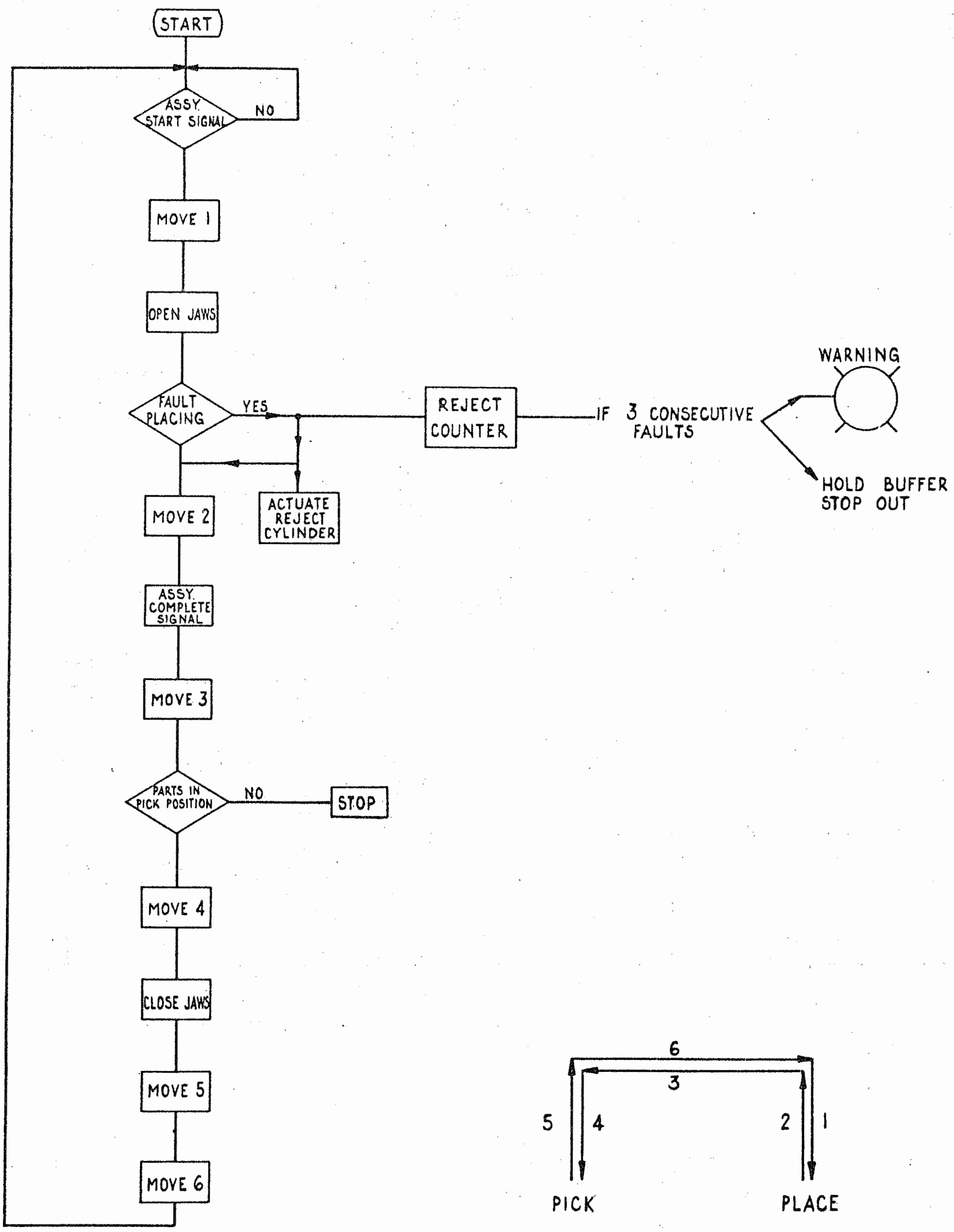
1968/69 GROUP DESIGN PROJECT



- 4 - INPUT TURBULENCE AMPLIFIER.

- BACK PRESSURE SENSOR.

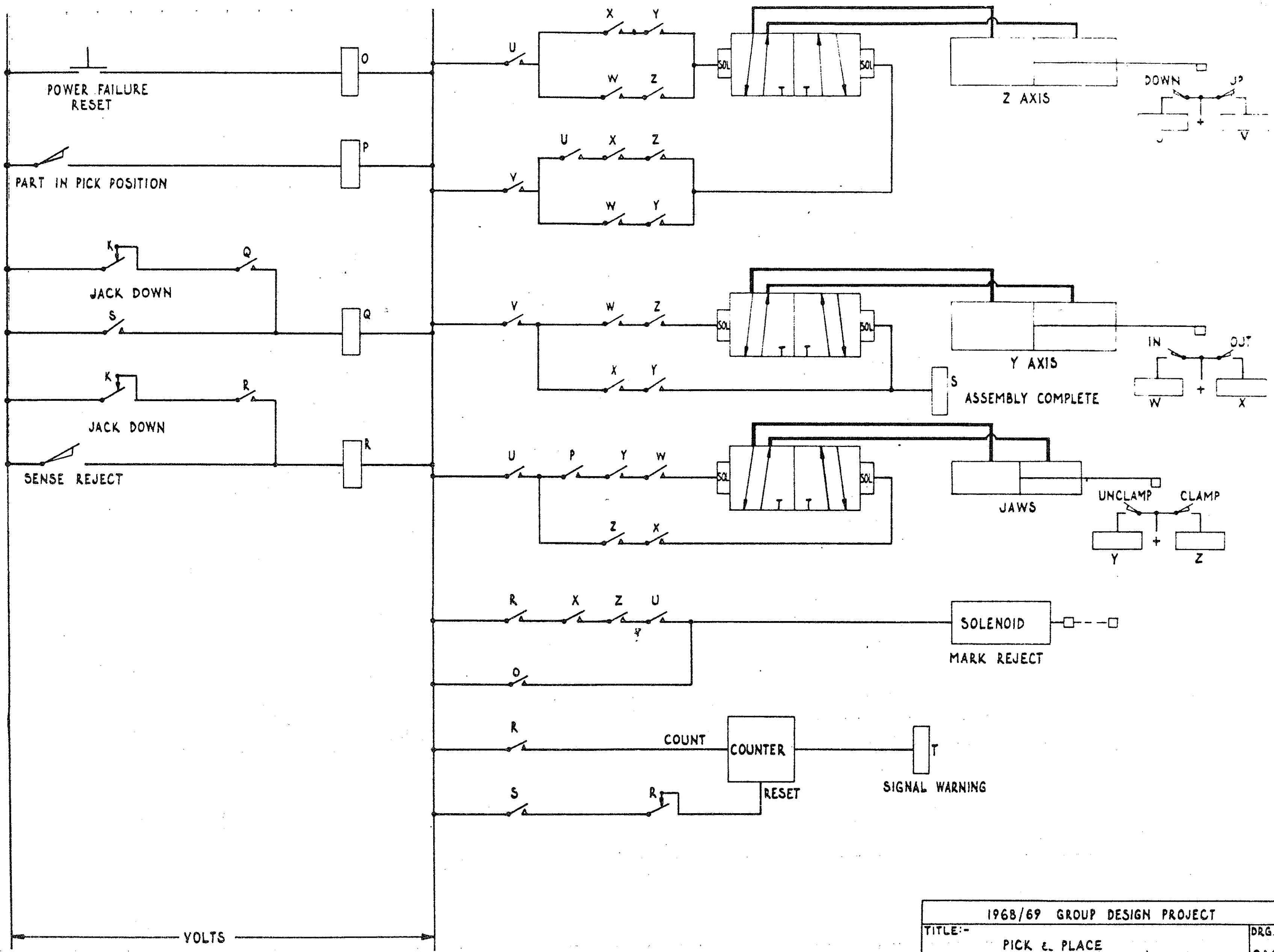
1968/69 GROUP DESIGN PROJECT	
TITLE: PNEUMATIC CONTROL OF PLATEN	DRG. No. CM 09



1968/69 GROUP DESIGN PROJECT

TITLE:- FLOW CHART FOR CONTROL OF PICK & PLACE HEAD

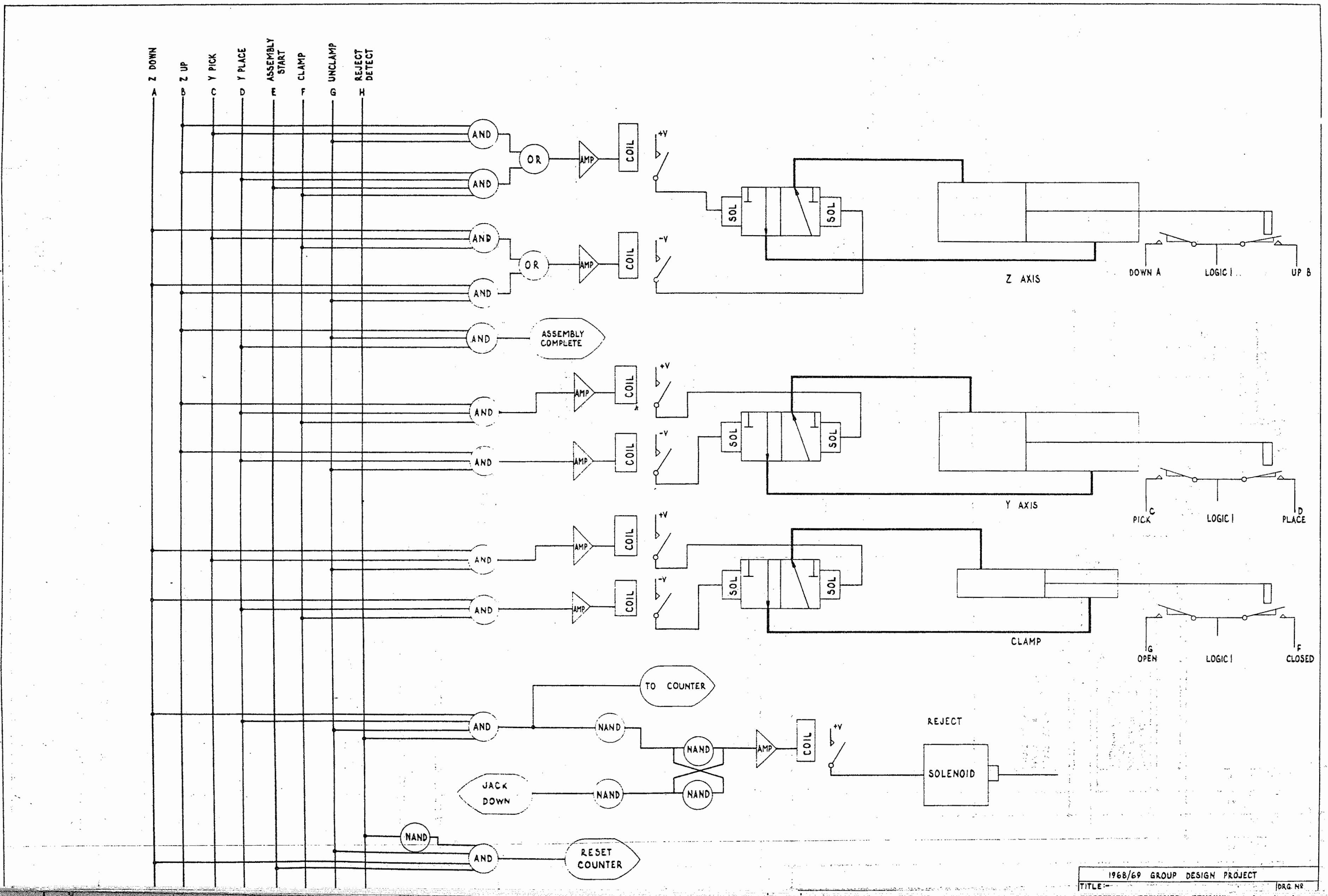
DRG. Nº CM 10

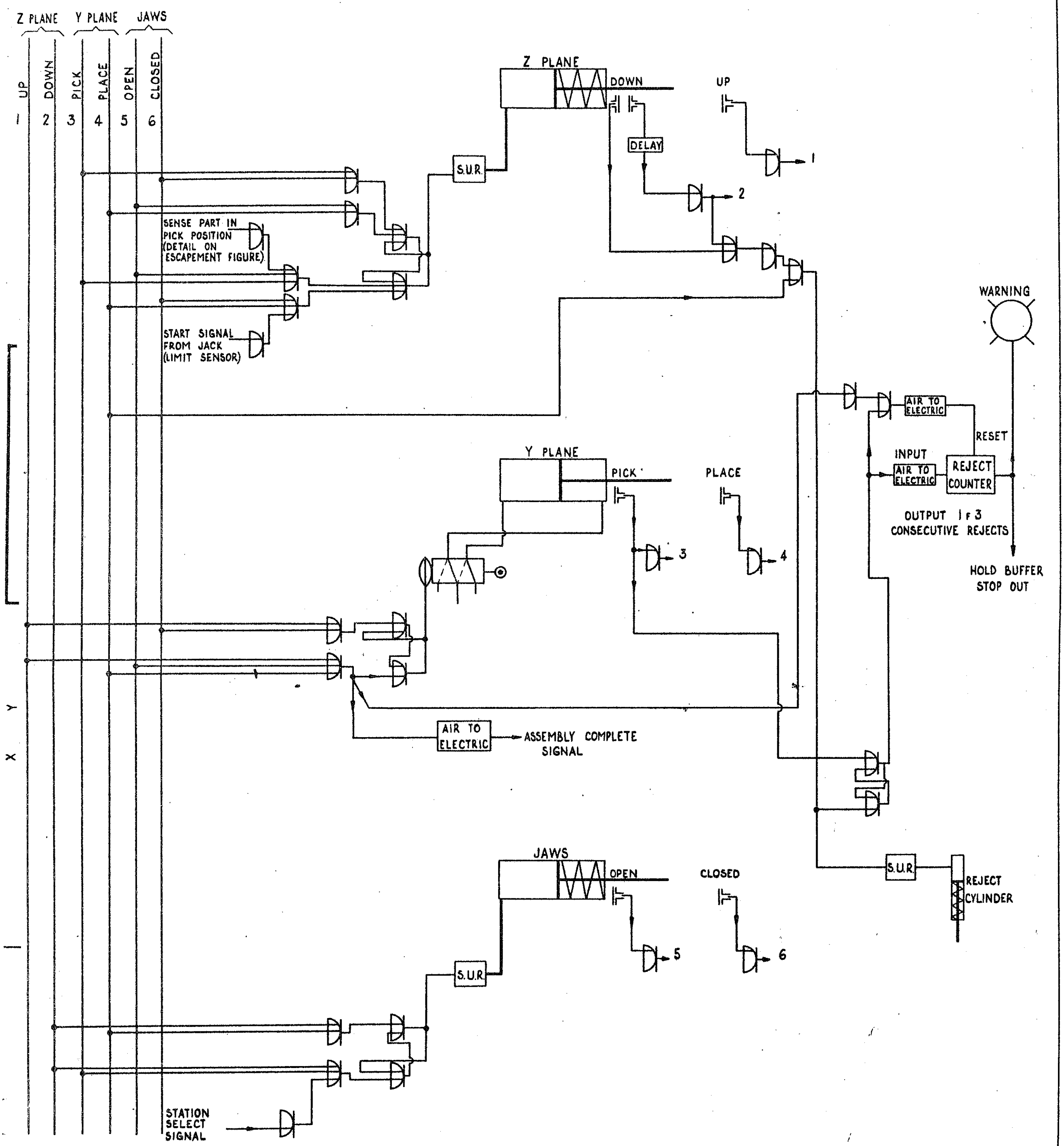


1968/69 GROUP DESIGN PROJECT

TITLE:- PICK & PLACE HEAD CONTROL (RELAY)

DRG. Nº CM 11


Z DOWN
Z UP
Y PICK
Y PLACE
ASSEMBLY START
CLAMP
UNCLAMP
REJECT DETECT
A
B
C
D
E
F
G
H
AND
OR
AMP
COIL
+V
-V
SOL
Z AXIS
DOWN A
LOGIC 1
UP B
ASSEMBLY COMPLETE
Y AXIS
PICK C
LOGIC 1
D PLACE
CLAMP
G OPEN
LOGIC 1
F CLOSED
TO COUNTER
NAND
REJECT
SOLENOID
JACK DOWN
RESET COUNTER
1968/69 GROUP DESIGN PROJECT
TITLE:-
DRG No



- BACK PRESSURE SENSOR.

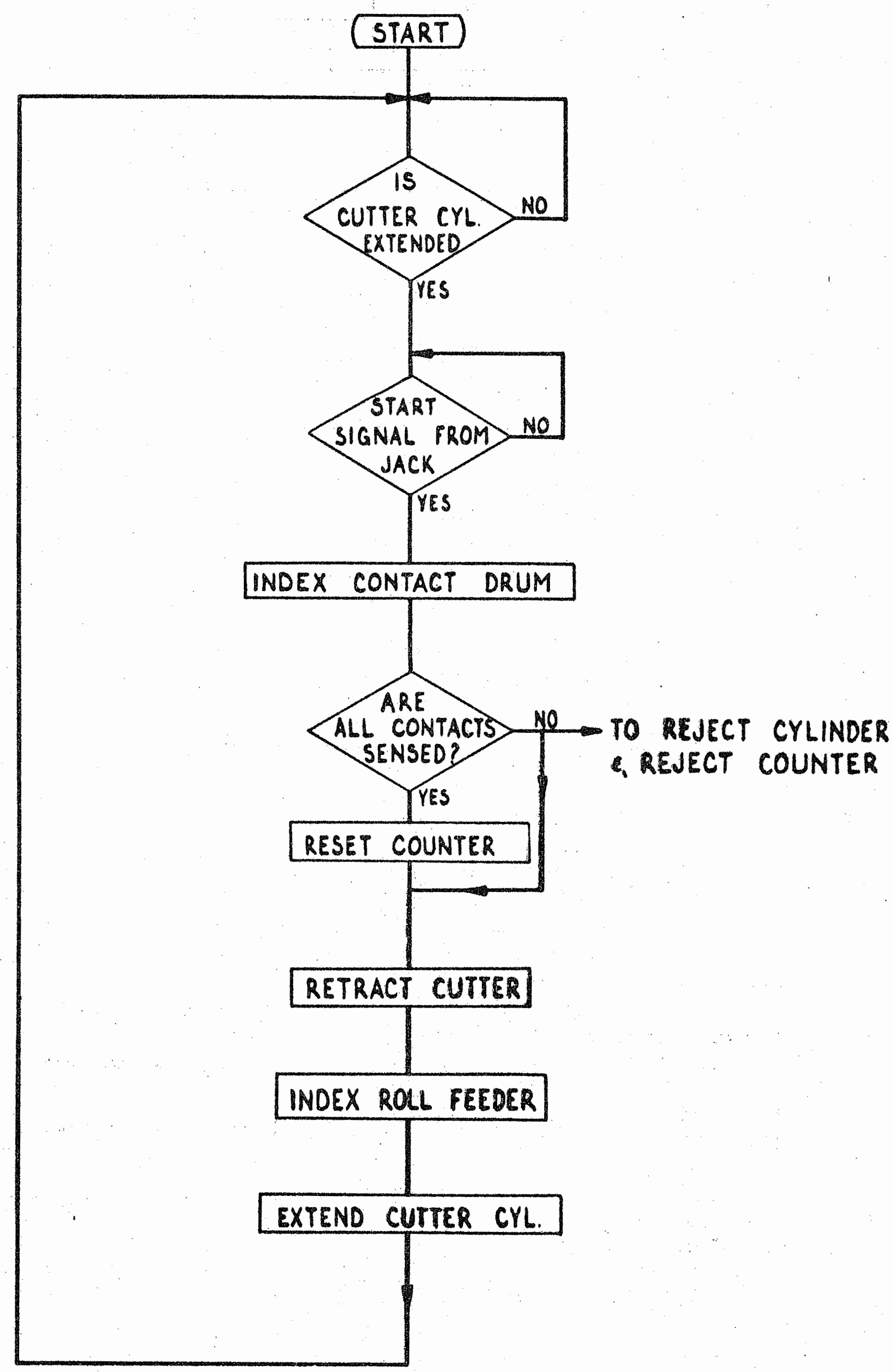
- 4-INPUT TURBULENCE AMPLIFIER. (SUPPLY PRESSURE 6-8 IN. W.G. (150-200 M.M. W.G.).

S.U.R. - STEP-UP RELAY.

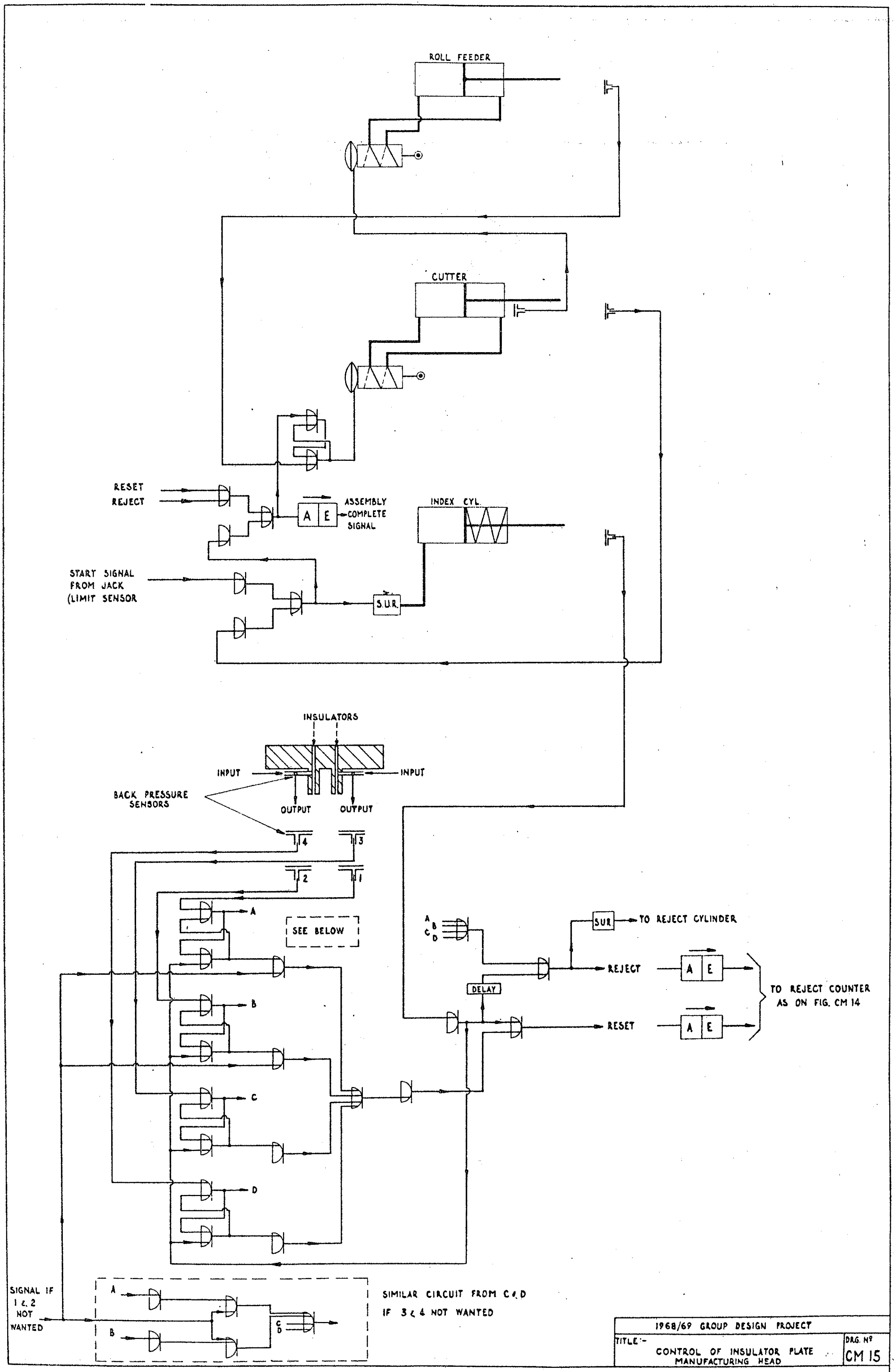
- LOW PRESSURE LINE 4-5 IN. W.G. (100-125 M.M. W.G.)

- HIGH PRESSURE LINE 80 LBF/IN² (55 N/MM²)

1968/69 GROUP DESIGN PROJECT	
TITLE:- PICK & PLACE HEAD CONTROL (PNEUMATIC)	DRG. Nº CM/13



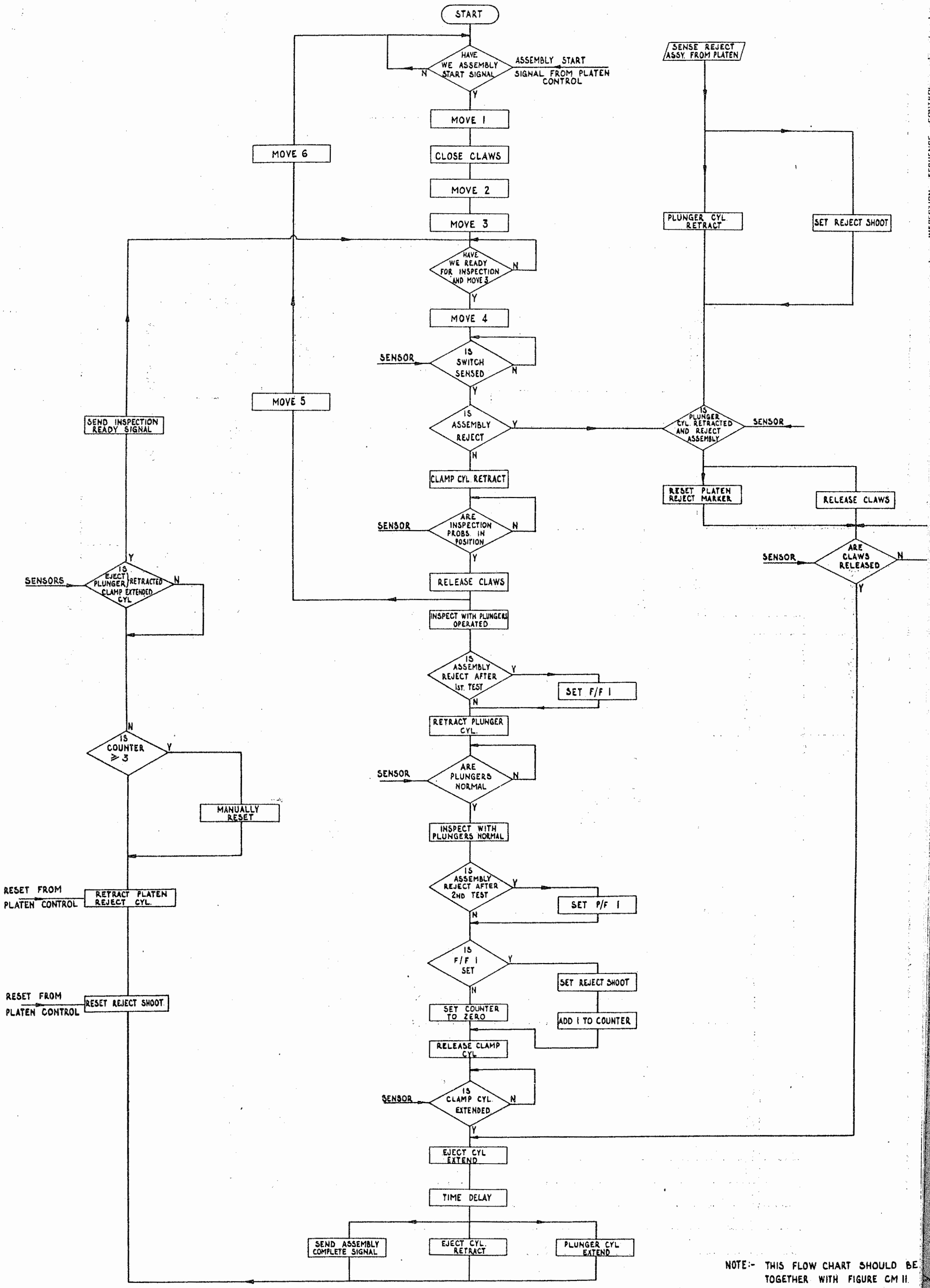
1968/69 GROUP DESIGN PROJECT	
TITLE:- FLOW CHART FOR INSULATOR PLATE MANUFACTURING HEAD	DRG. Nº CM 14



1968/69 GROUP DESIGN PROJECT

TITLE:- CONTROL OF INSULATOR PLATE MANUFACTURING HEAD

DRG. Nº CM 15

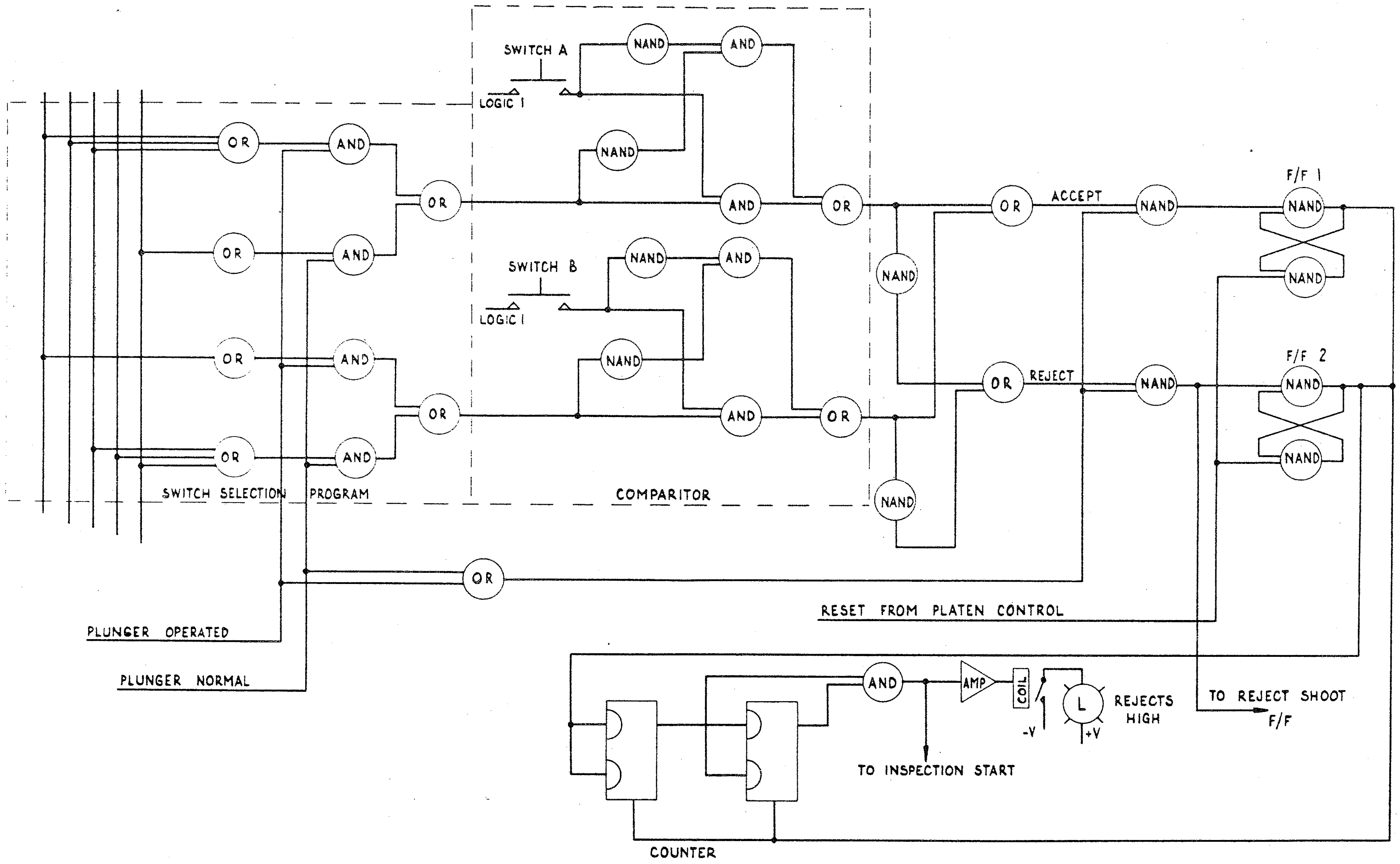


NOTE:- THIS FLOW CHART SHOULD BE TOGETHER WITH FIGURE CM II.

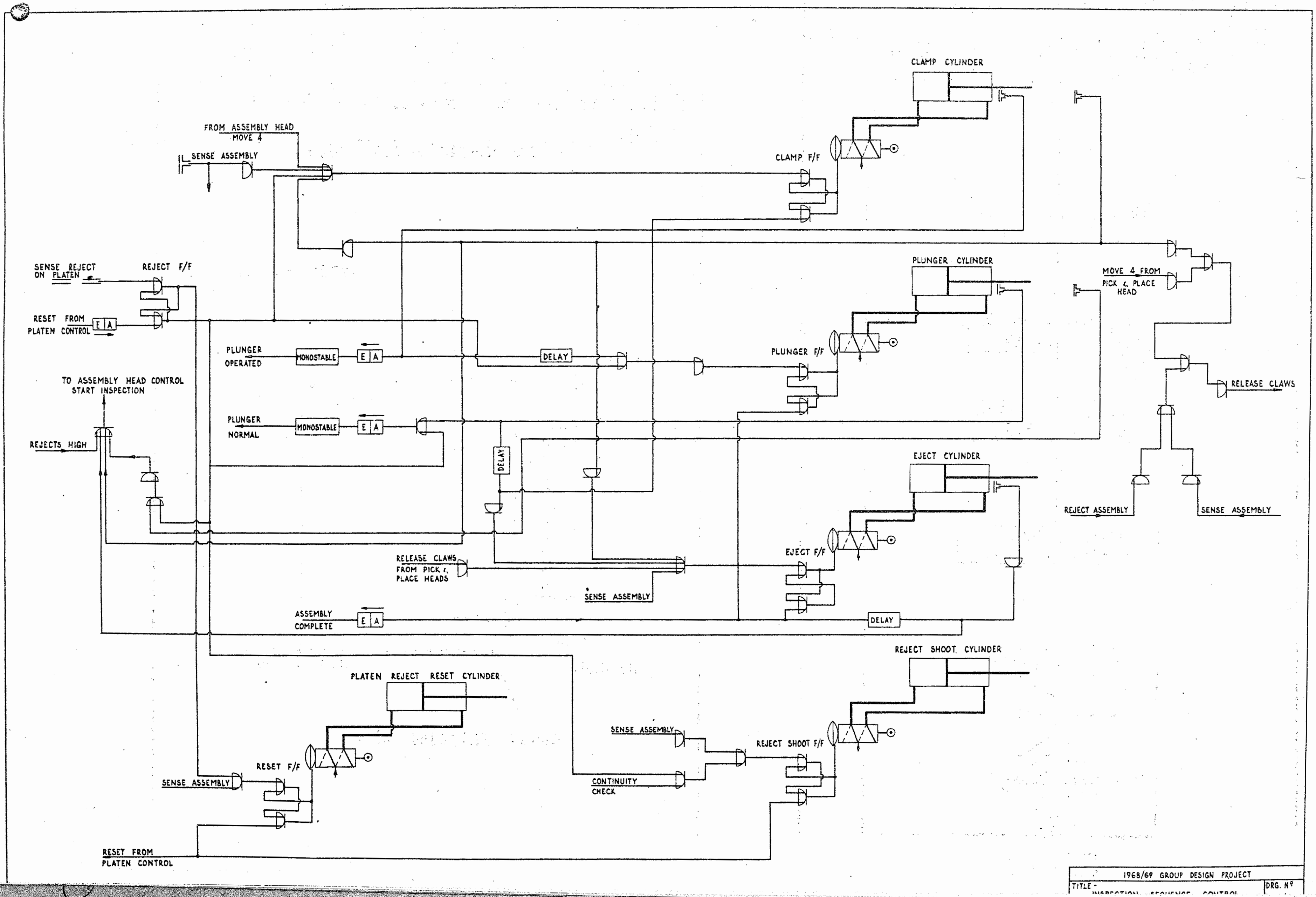
1968/69 GROUP DESIGN PROJECT

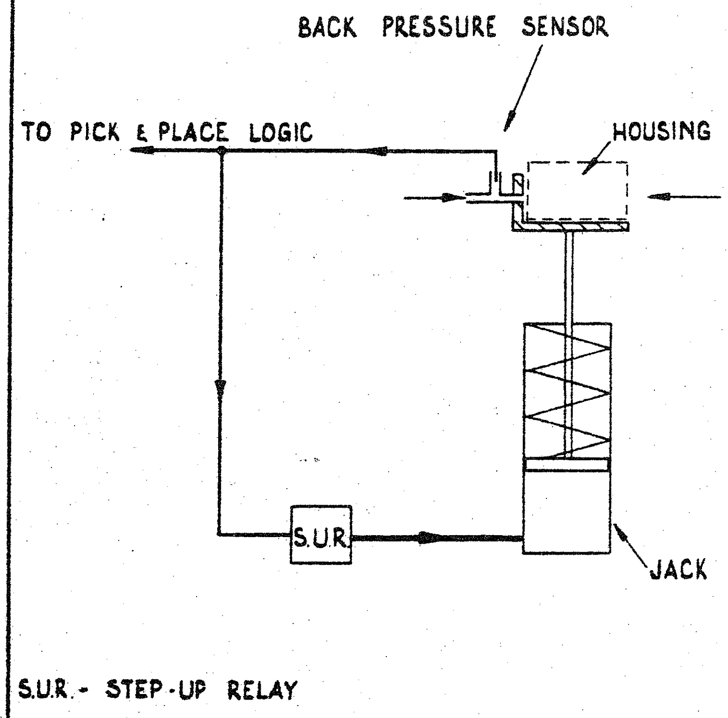
TITLE:-

INSPECTION STATION FLOW CHART



1968/69 GROUP DESIGN PROJECT	
TITLE :- CONTINUITY CHECK CONTROL CIRCUIT	DRG. Nº CM/17

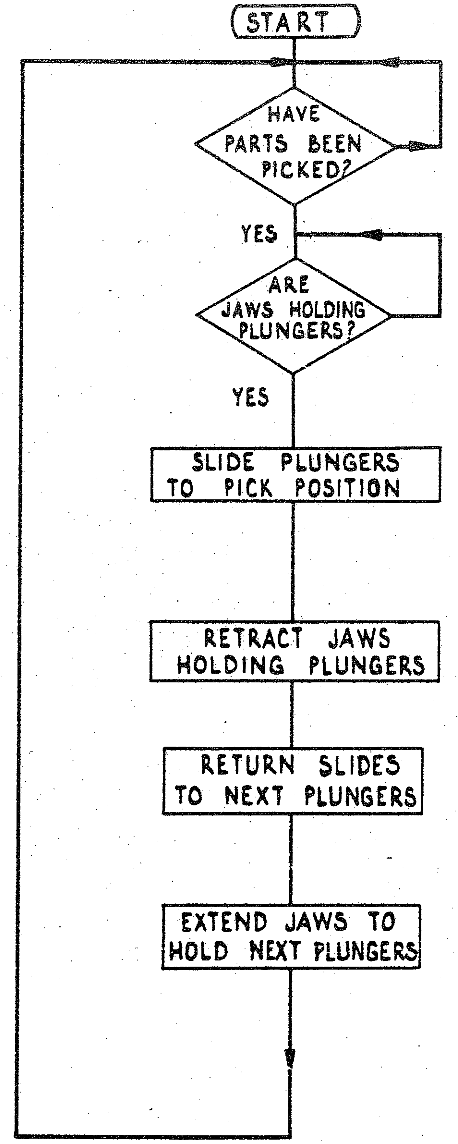

CLAMP CYLINDER
FROM ASSEMBLY HEAD
MOVE 4
SENSE ASSEMBLY
CLAMP F/F
SENSE REJECT ON PLATEN
REJECT F/F
RESET FROM PLATEN CONTROL
E A
PLUNGER CYLINDER
MOVE 4 FROM PICK & PLACE HEAD
PLUNGER OPERATED
MONOSTABLE
DELAY
PLUNGER F/F
RELEASE CLAWS
TO ASSEMBLY HEAD CONTROL START INSPECTION
PLUNGER NORMAL
REJECTS HIGH
EJECT CYLINDER
REJECT ASSEMBLY
SENSE ASSEMBLY
EJECT F/F
RELEASE CLAWS FROM PICK & PLACE HEADS
ASSEMBLY COMPLETE
REJECT SHOOT CYLINDER
PLATEN REJECT RESET CYLINDER
REJECT SHOOT F/F
CONTINUITY CHECK
RESET F/F
RESET FROM PLATEN CONTROL
1968/69 GROUP DESIGN PROJECT
TITLE -
DRG. Nº



1968/69 GROUP DESIGN PROJECT

TITLE:- CONTROL OF ESCAPEMENT FOR HOUSING

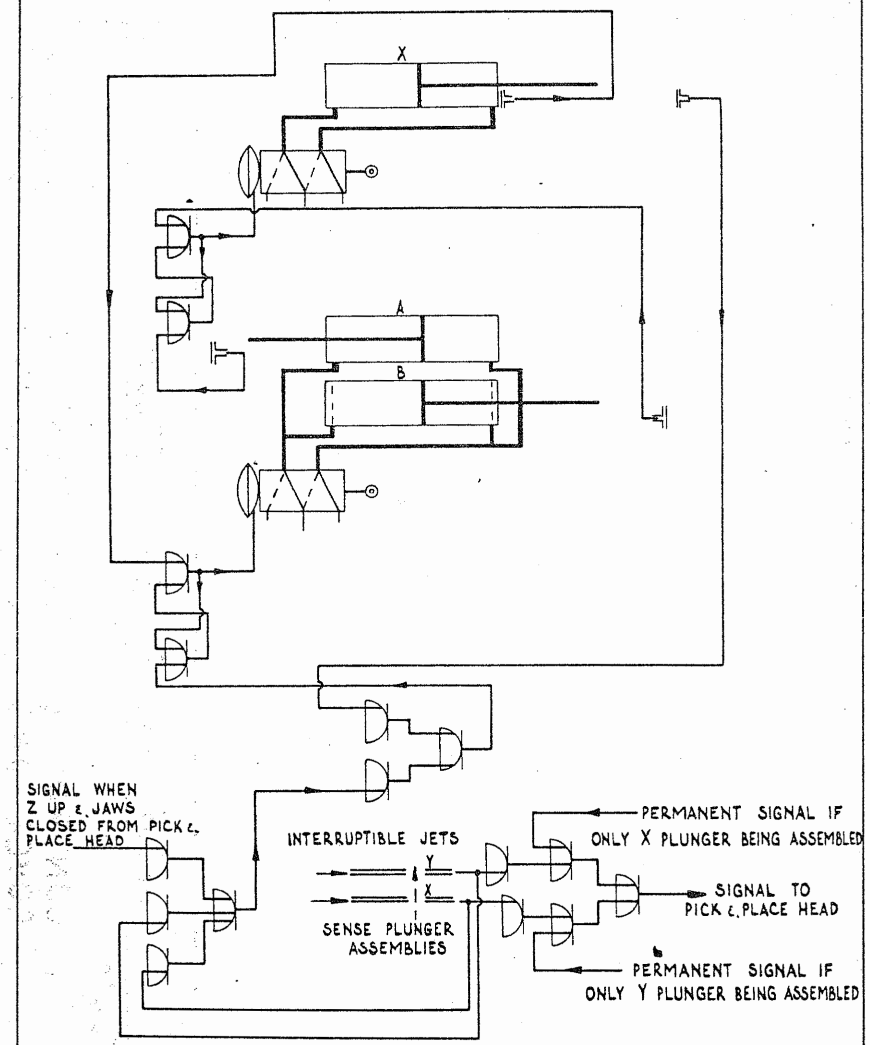
DRG. Nº CM 19



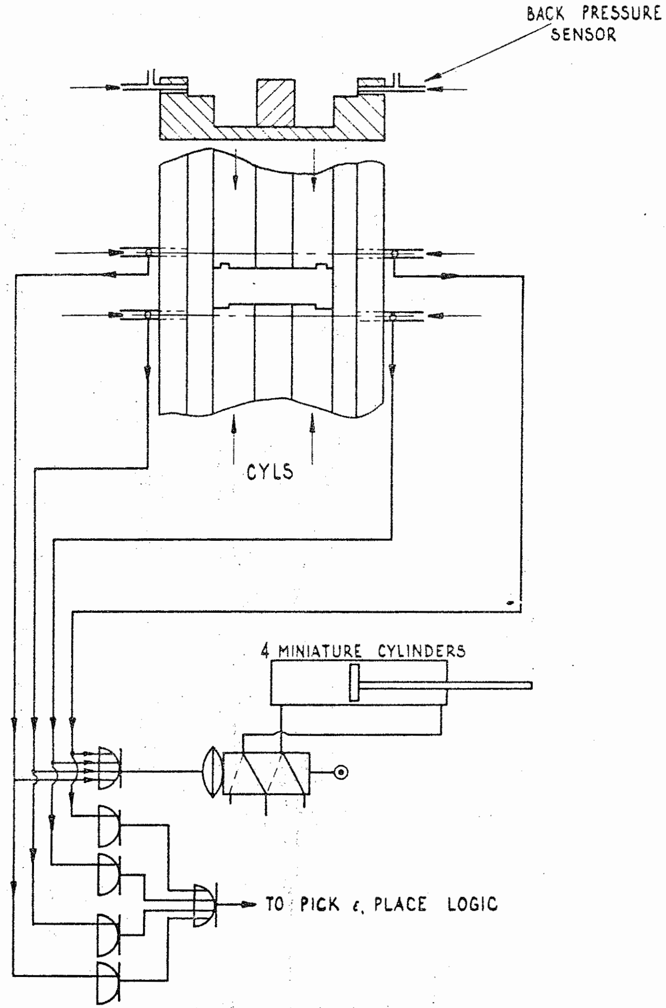
1968/69 GROUP DESIGN PROJECT

TITLE:- FLOW CHART FOR ESCAPEMENT OF PLUNGERS

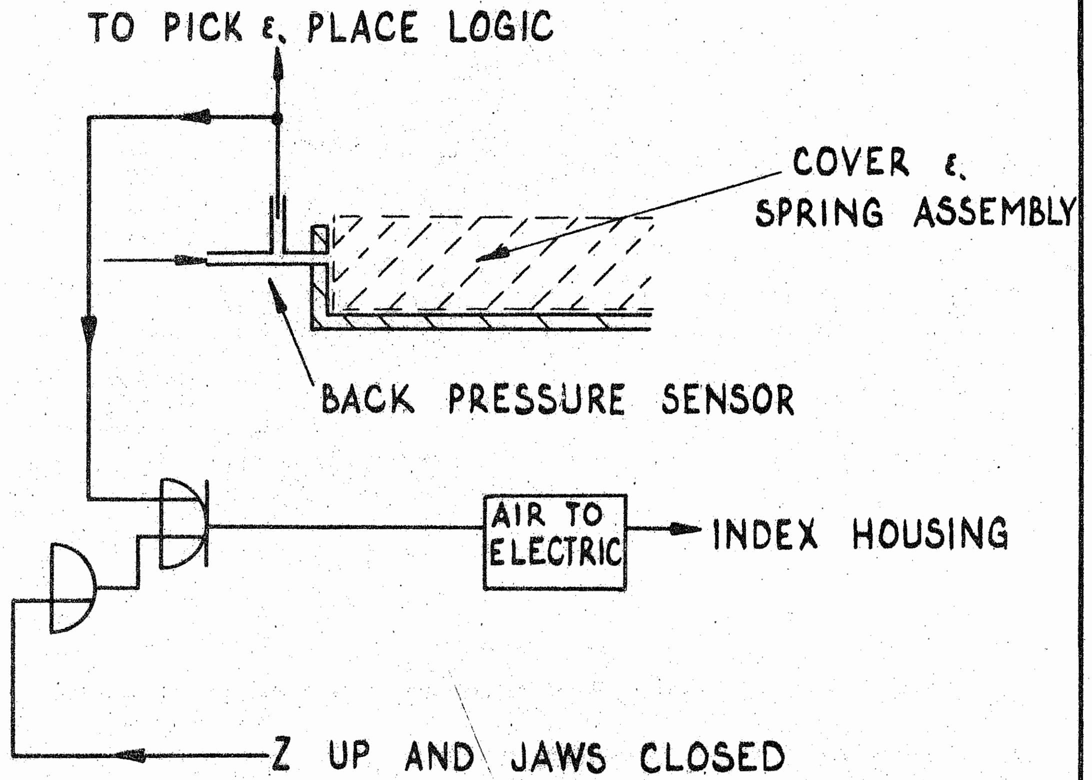
DRG. Nº CM 20



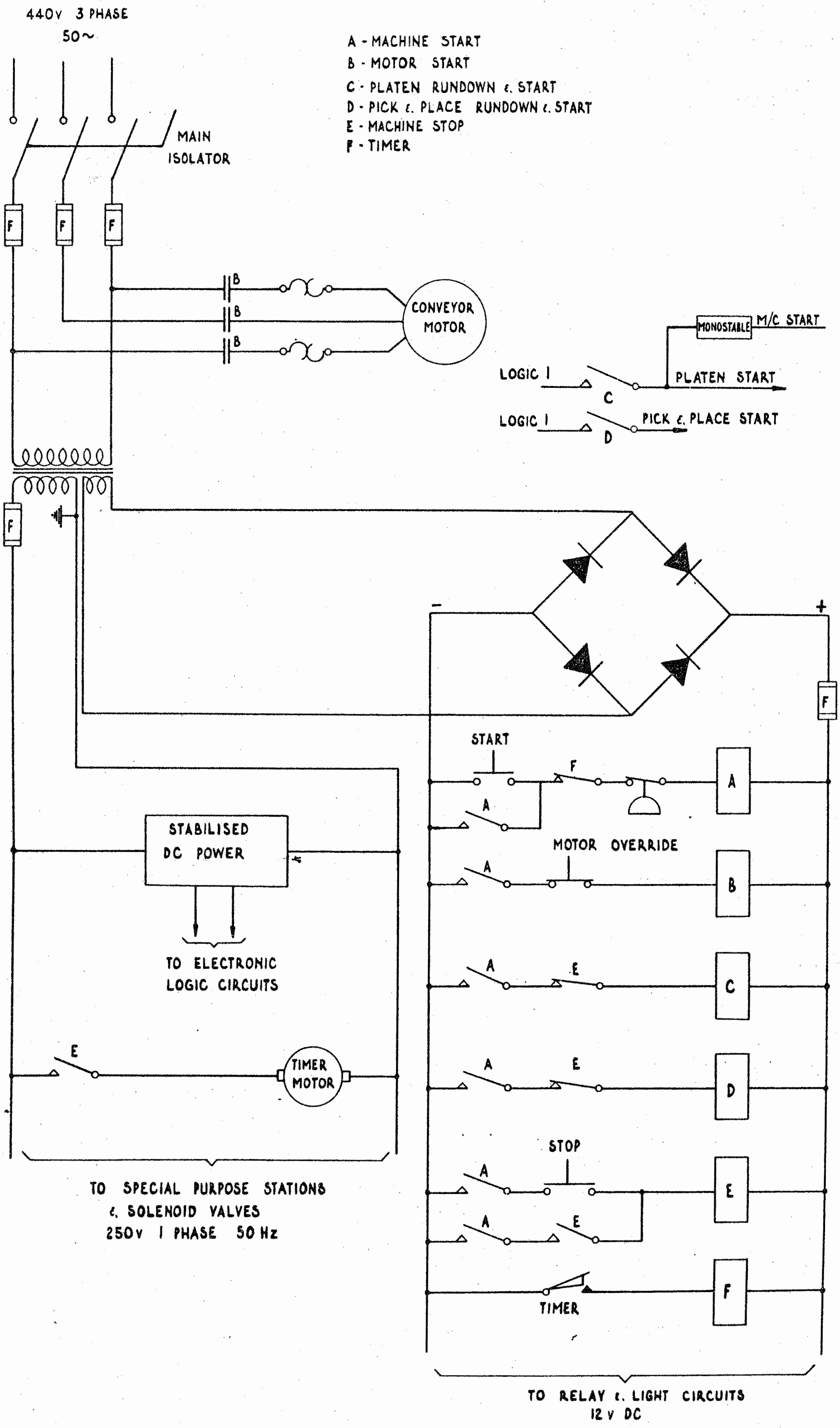
1968/69 GROUP DESIGN PROJECT	
TITLE:- ESCAPEMENT CONTROL FOR PLUNGER ASSEMBLY	DRG. Nº CM 21



1968/69 GROUP DESIGN PROJECT	
TITLE:- CONTROL OF ESCAPEMENT FOR CONTACTS	DRG. Nº CM 22



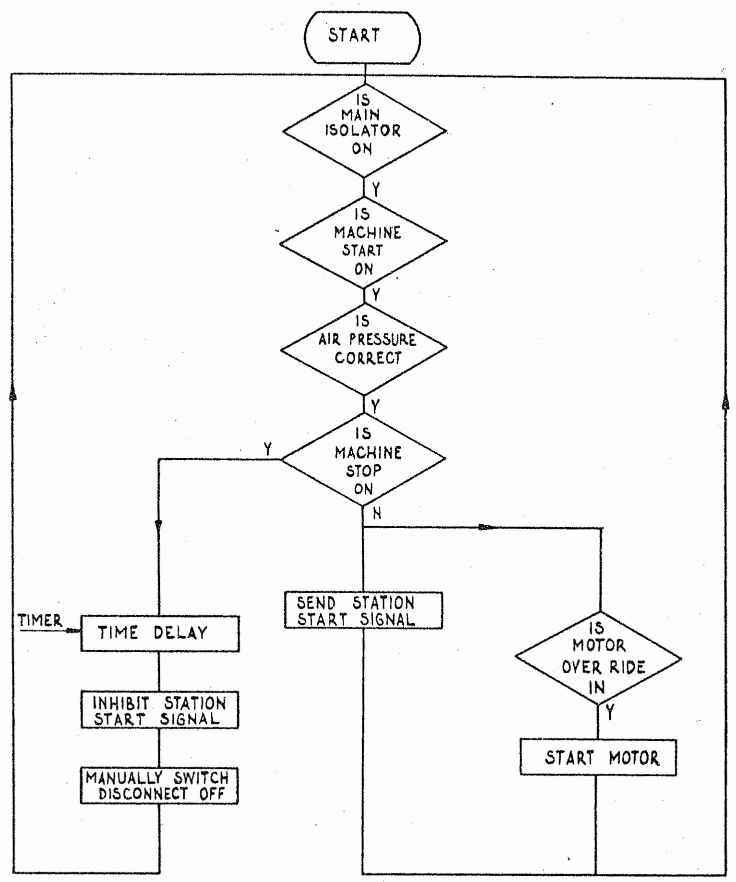
1968/69 GROUP DESIGN PROJECT	
TITLE:- CONTROL OF ESCAPEMENT FOR COVER AND SPRING ASSEMBLY	DRG. Nº CM 23



1968/69 GROUP DESIGN PROJECT

TITLE:- ELECTRICAL POWER SUPPLY DISTRIBUTION & STOP, START SEQUENCE.

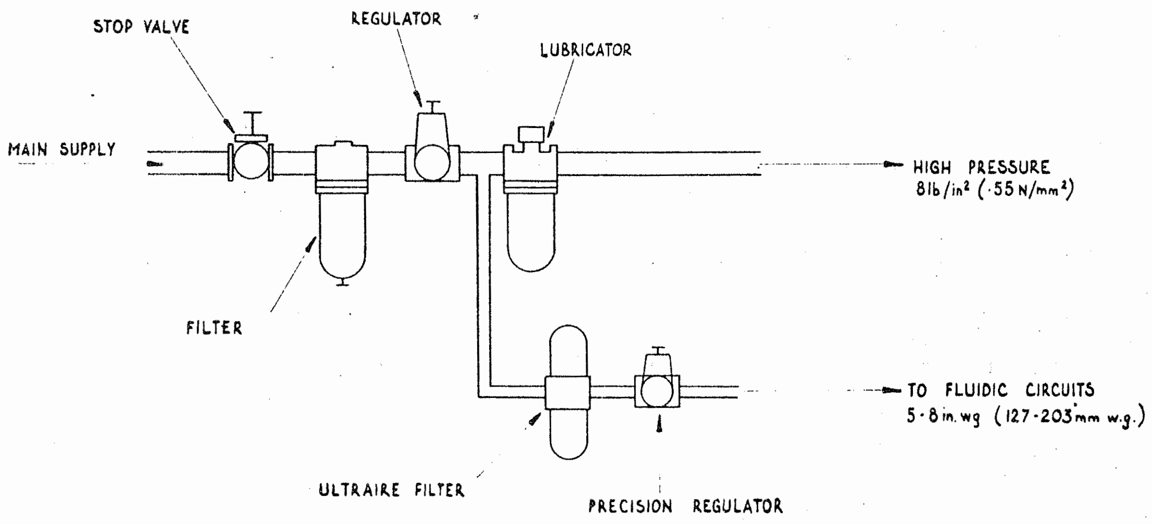
DRG. Nº CM24



1968/69 GROUP DESIGN PROJECT

TITLE:- MACHINE RUNDOWN & START FLOW CHART

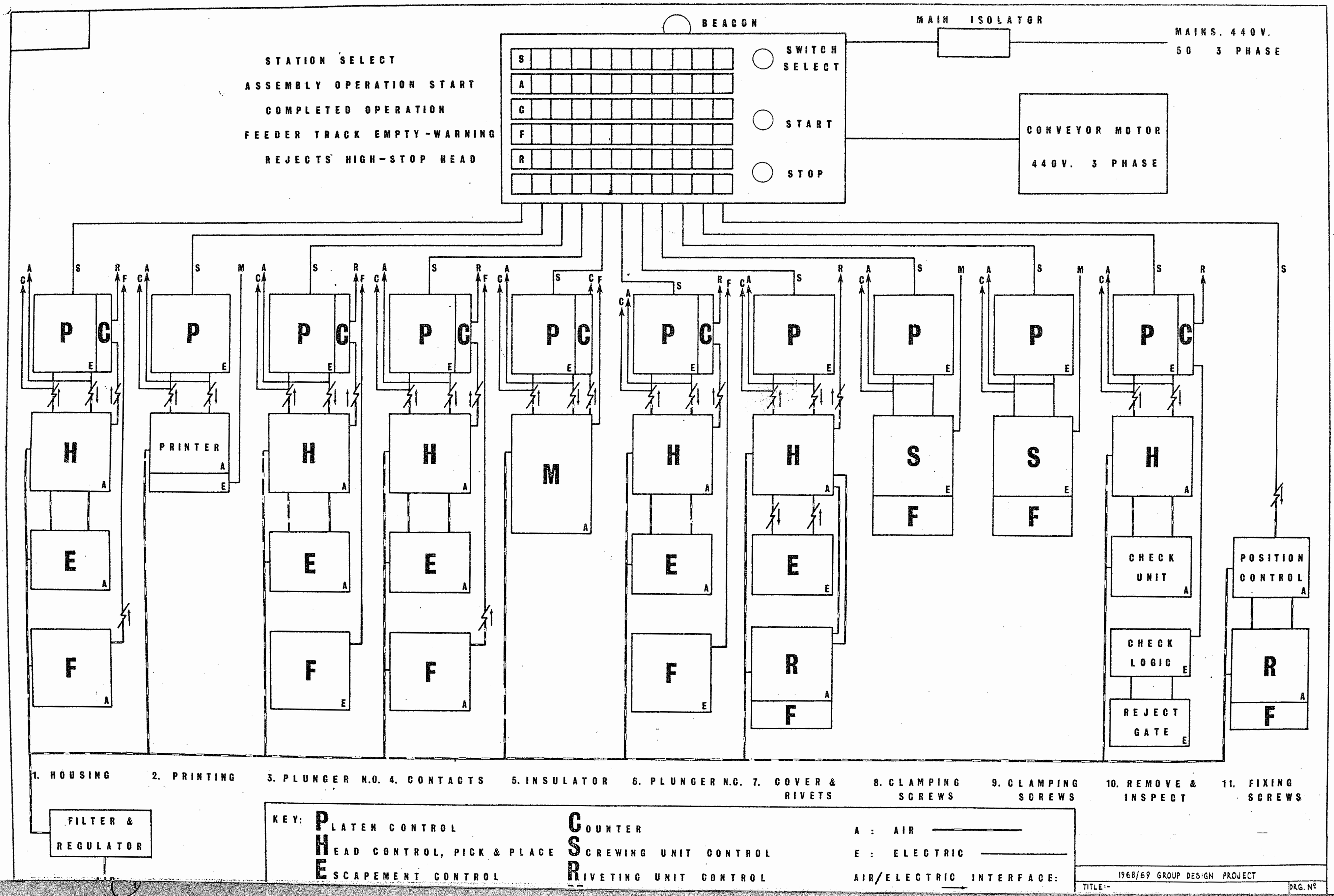
DRG. Nº CM 25

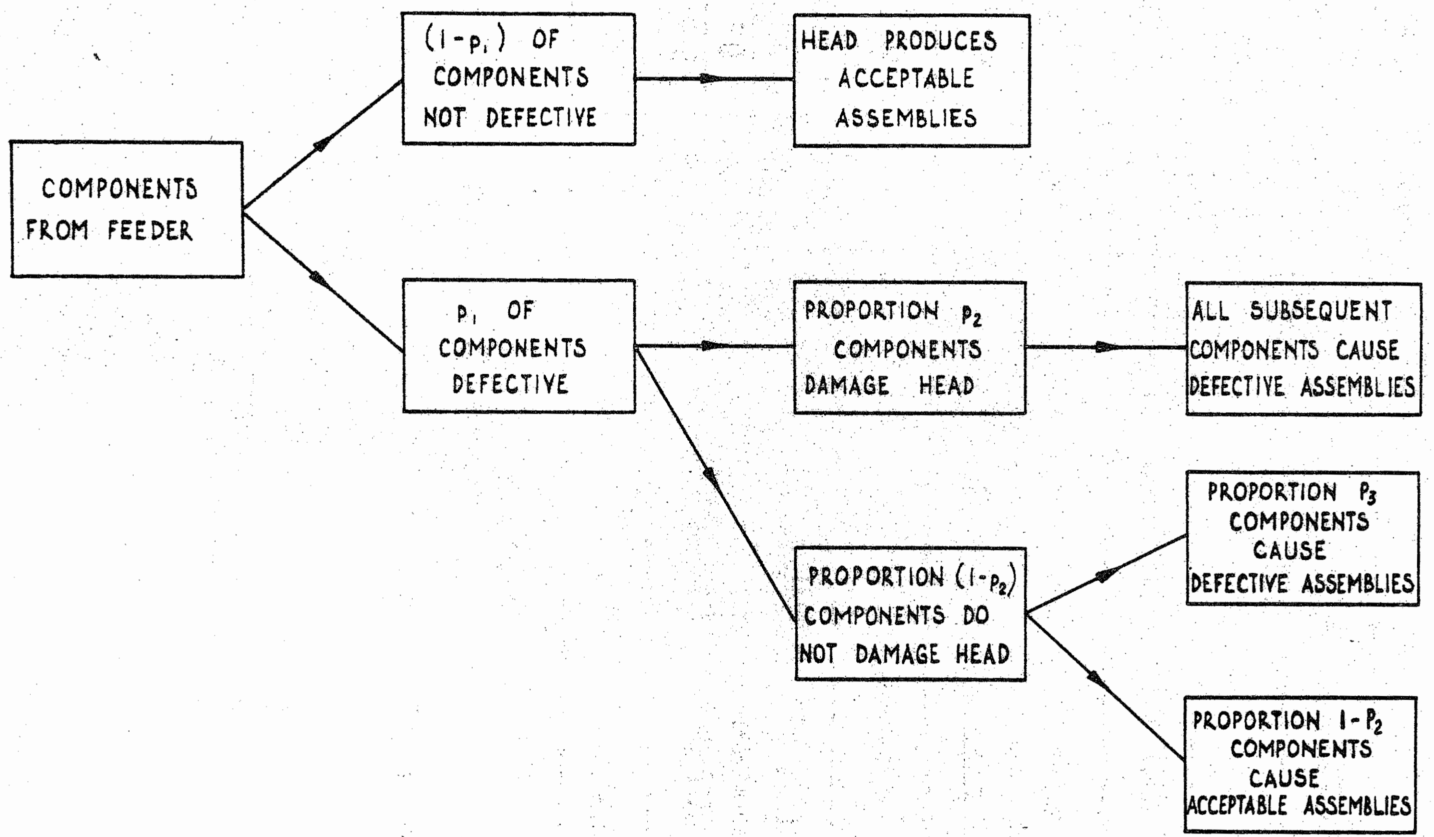


1968/69 GROUP DESIGN PROJECT

TITLE:- PNEUMATIC POWER DISTRIBUTION

DRG Nº CM 26


BEACON
MAIN ISOLATOR
MAINS. 440V.
50 3 PHASE
STATION SELECT
ASSEMBLY OPERATION START
COMPLETED OPERATION
FEEDER TRACK EMPTY-WARNING
REJECTS HIGH-STOP HEAD
SWITCH SELECT
START
STOP
CONVEYOR MOTOR
440V. 3 PHASE
PRINTER
CHECK UNIT
CHECK LOGIC
REJECT GATE
POSITION CONTROL
1. HOUSING
2. PRINTING
3. PLUNGER N.O.
4. CONTACTS
5. INSULATOR
6. PLUNGER N.C.
7. COVER & RIVETS
8. CLAMPING SCREWS
9. CLAMPING SCREWS
10. REMOVE & INSPECT
11. FIXING SCREWS
FILTER & REGULATOR
KEY:
PLATEN CONTROL
HEAD CONTROL, PICK & PLACE
ESCAPEMENT CONTROL
COUNTER
SCREWING UNIT CONTROL
RIVETING UNIT CONTROL
A : AIR
E : ELECTRIC
AIR/ELECTRIC INTERFACE:
1968/69 GROUP DESIGN PROJECT
TITLE:-
DRG. Nº



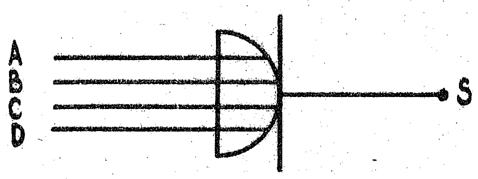
1968/69 GROUP DESIGN PROJECT

TITLE :- PROBABILITY BREAKDOWN BLOCK DIAGRAM

DRG. Nº CM A1

PARAMETER		MINIMUM	NOMINAL	MAXIMUM
SUPPLY PRESSURE P_s	in. (w.g.)	4·7	6·3	8·3
	mm (w.g.)	119·3	160·0	210·8
SUPPLY FLOW	$ft^3/hr.$	0·63	0·64	0·74
	$m^3/hr.$	0·014	0·018	0·021
INPUT POWER (MILLIWATTS)		5	8	12·5
MAXIMUM OUTPUT PRESSURE P_o	in. (w.g.)	2·35	3·75	5·3
	mm (w.g.)	59·6	95·2	134·6
MAXIMUM OUTPUT FLOW Q_o	$ft^3/hr.$	0·39	0·49	0·57
	$m^3/hr.$	0·011	0·013	0·016
MAXIMUM OUTPUT POWER (MILLIWATTS)		0·6	1·1	1·9
MINIMUM FAN-OUT FACTOR		4	4	4
MAXIMUM FAN-OUT FACTOR		6	6	6
MINIMUM CUT-OFF CONTROL FLOW	$ft^3/hr.$	0·050	0·060	0·074
	$m^3/hr.$	0·0014	0·0016	0·0021
MINIMUM CUT-OFF CONTROL PRESSURE	in. (w.g.)	0·83	1·02	1·3
	mm (w.g.)	21·0	25·9	33·0
MAXIMUM SIGNAL TRANSPORT TIME DELAY (MILLISECONDS)		2	2	2

STANDARD NOR LOGIC SYMBOL



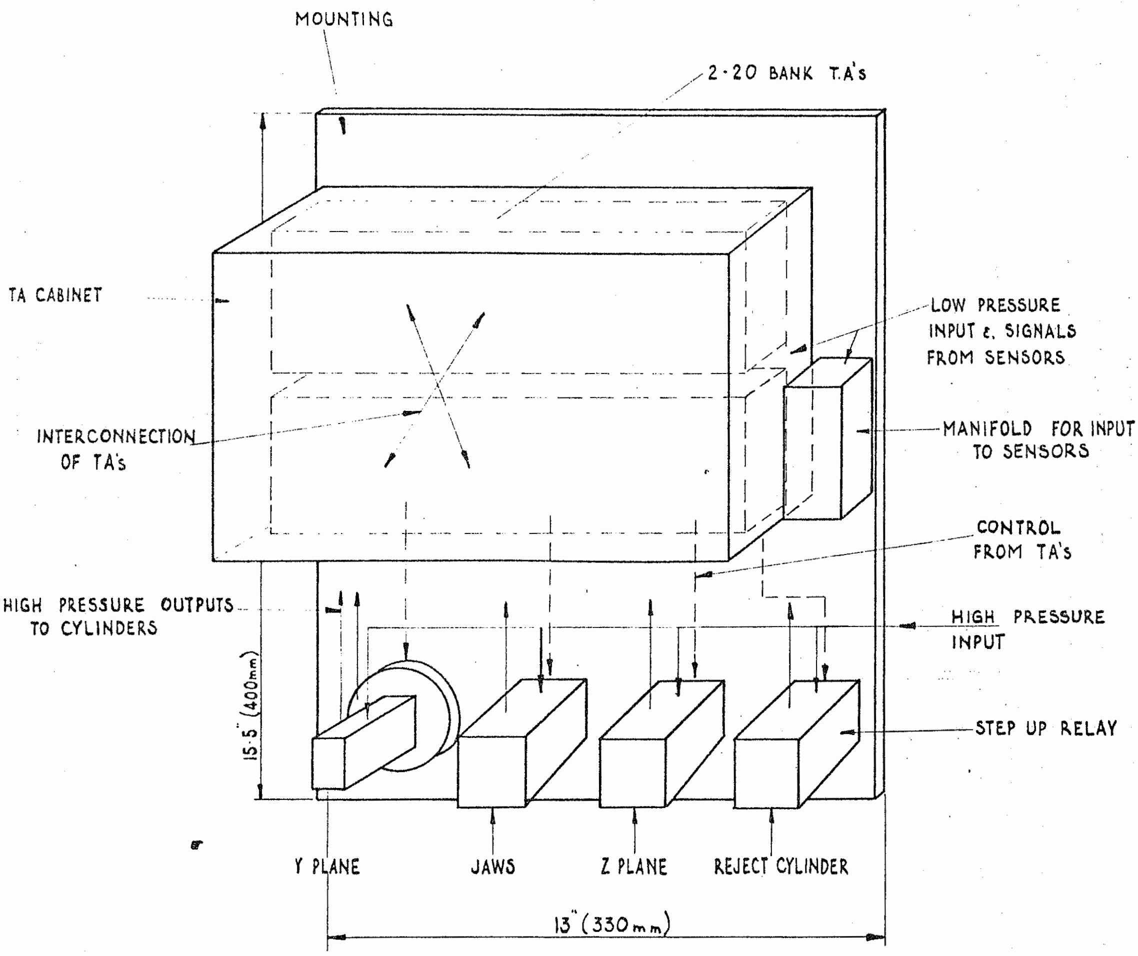
$$S = A + B + C + D \equiv A \cdot B \cdot C \cdot D$$

BY COURTESY OF MAXAM POWER LTD.

1968/69 GROUP DESIGN PROJECT

TITLE :- PERFORMANCE DATA FOR PLANAR TA's.

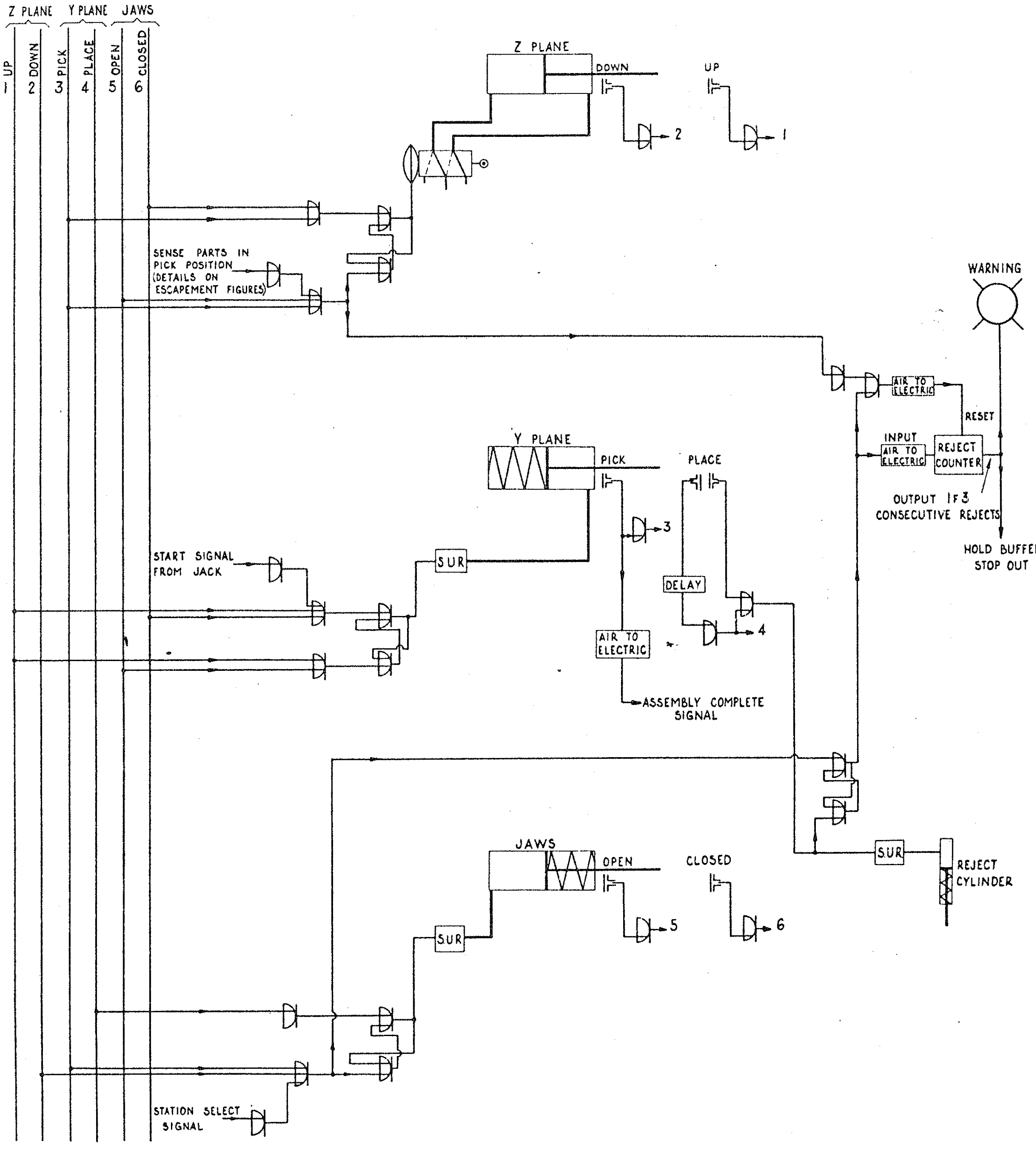
DRG. N° CM A2



TURBULENCE AMPLIFIERS - MODULAR BANK - 20 UNIT MAXAM POWER LTD.
PART Nº 7089 P 99912

VALVES - DIAPHRAGM ACTUATED. SPRING RETURN KAY PNEUMATICS
PART Nº KV 28/025 LP

1968/69 GROUP DESIGN PROJECT	
TITLE:- PICK & PLACE HEAD CONTROL UNIT	DRG. Nº CMA3



- BACK PRESSURE SENSOR.

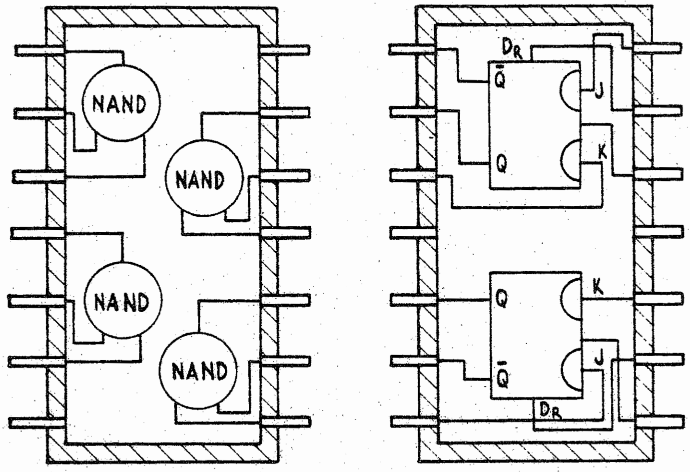
- 4-INPUT TURBULENCE AMPLIFIER (SUPPLY PRESSURE 6-8 IN WG (150-200 MM WG)

S.U.R - STEP-UP RELAY

- LOW PRESSURE LINE 4-5 IN W.G (100-125 MM WG)

- HIGH PRESSURE LINE 80 LBF/IN² (·55 N/MM²)

1968/69 GROUP DESIGN PROJECT	
TITLE:- CONTROL OF PICK & PLACE HEAD FROM SIDE	DRG. Nº CM A4



QUADRUPLE 2-INPUT POSITIVE NAND GATE

DUAL FLIPFLOP

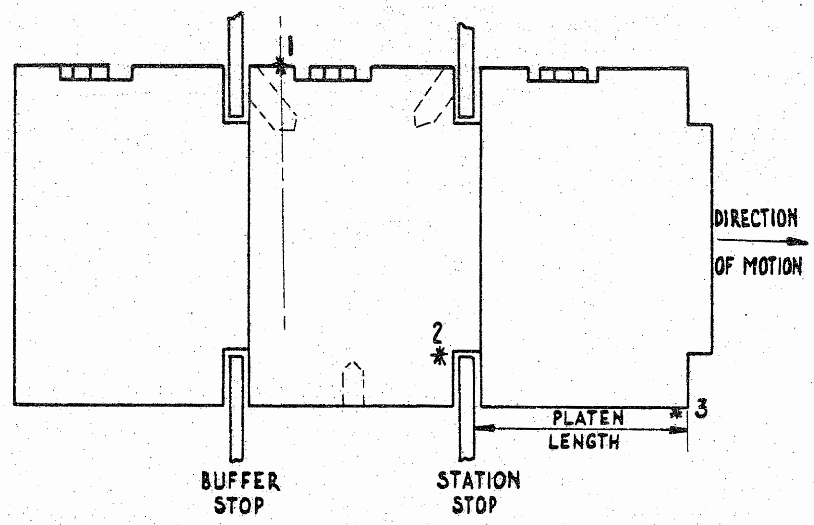
TYPICAL CHARACTERISTICS

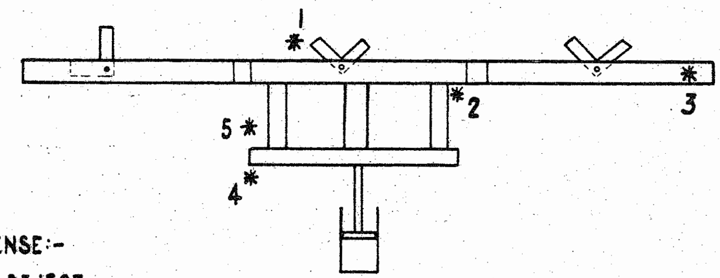
PARAMETER	NAND GATE	FLIP FLOP
PROPAGATION DELAY	18 n sec	40 n sec
POWER DISSIPATION	10 mw	60 m w
FAN OUT	8	8
D-c NOISE MARGIN	1 v	1 v
SUPPLY VOLTAGE	4·75 TO 5·25 v	4·25 TO 5·25
TEMPORATURE RANGE	0° TO +70°C	0° TO 70°C
LOGIC 0	0 TO 0·2 v	0 TO 0·2 v
LOGIC 1	24 TO 35 v	2·4 TO 3·5 v

1968/69 GROUP DESIGN PROJECT

TITLE:- CHARACTERISTICS OF INTEGRATED CIRCUIT ELEMENTS

DRG. Nº CM A5





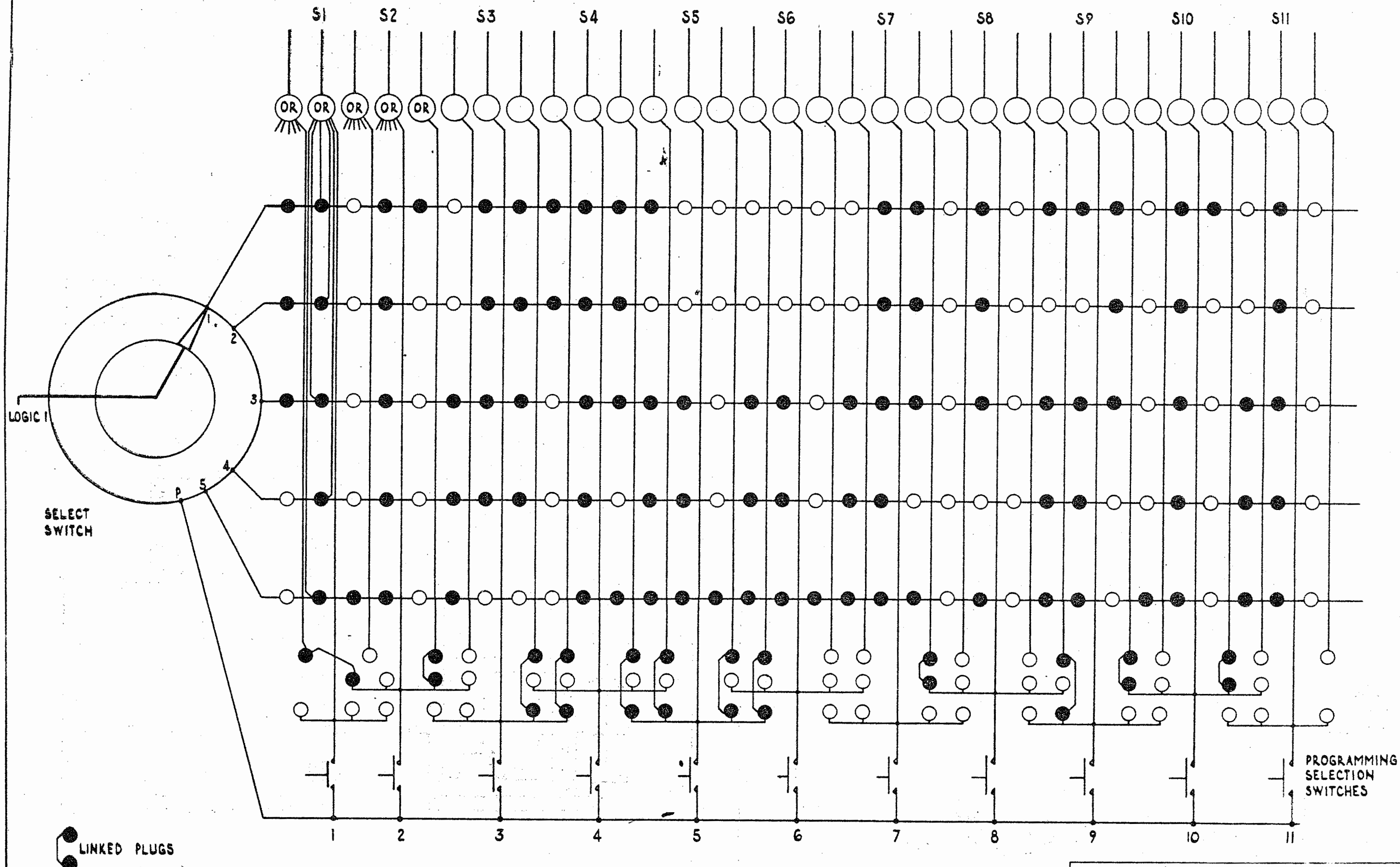
SENSE:-

1-REJECT
2-IN STATION
3-BUFFER FULL
4-JACK DOWN
5-JACK UP

1968/69 GROUP DESIGN PROJECT

TITLE:- SENSING POSITIONS FOR PLATEN CONTROL

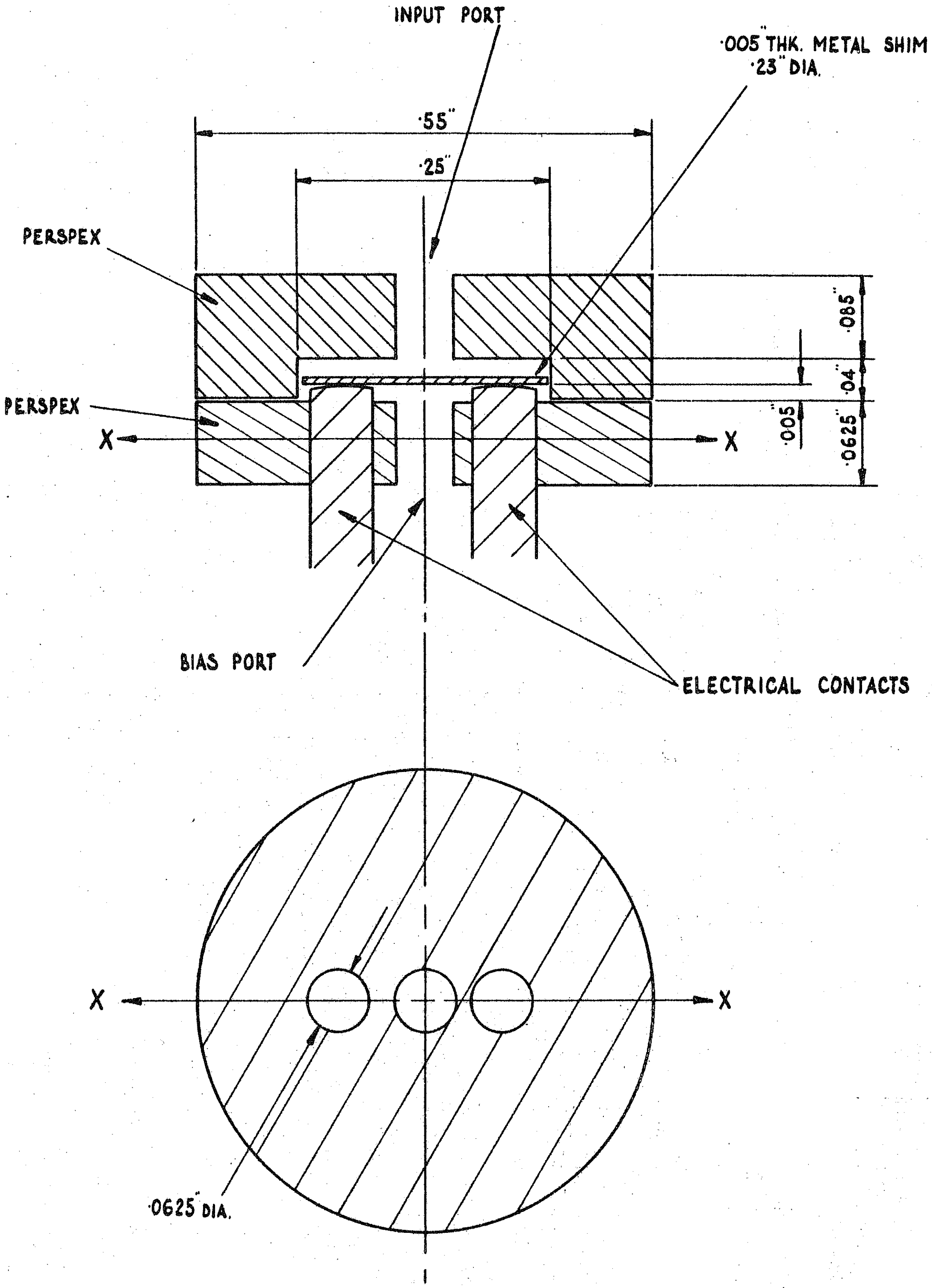
DRG. Nº CM A6



1968/69 GROUP DESIGN PROJECT

TITLE:- SWITCH SELECTION PROGRAM CIRCUIT

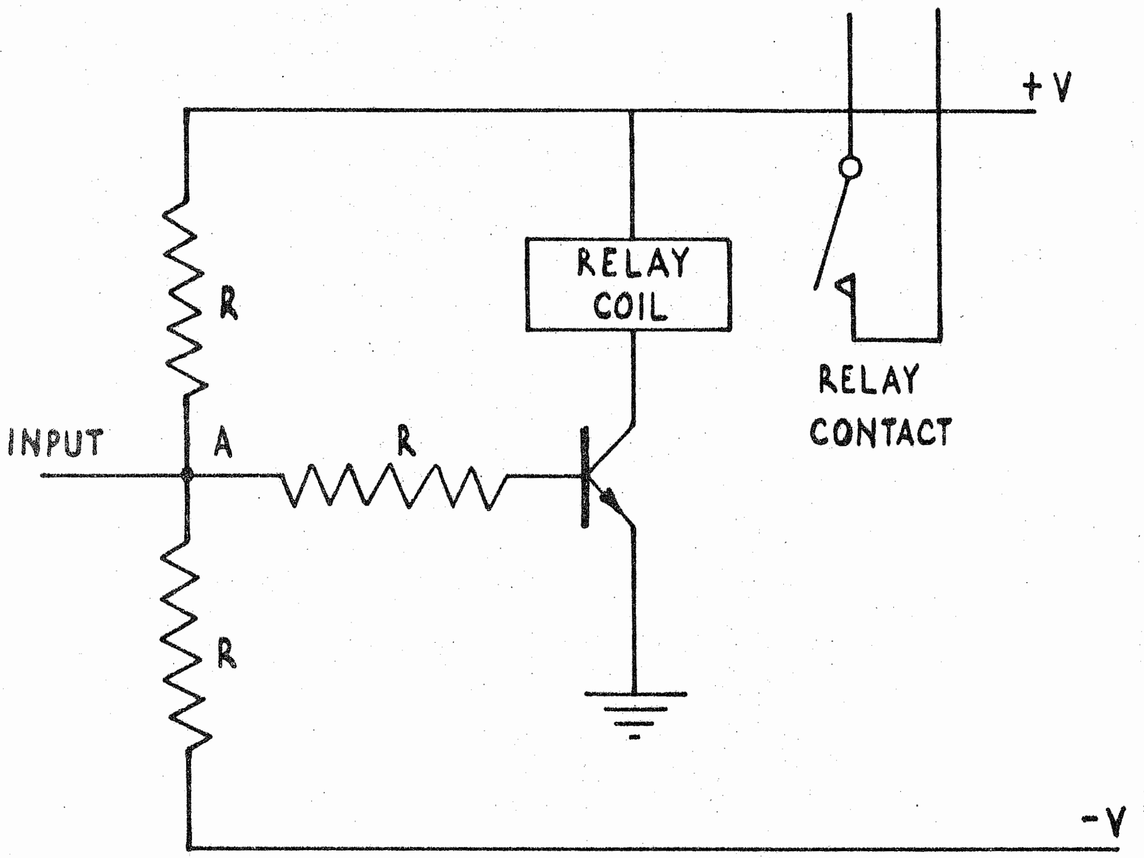
DRG. No CM A7



1968/69 GROUP DESIGN PROJECT

TITLE :- AIR TO ELECTRIC RELAY

DRG. Nº CM A8



1968/69 GROUP DESIGN PROJECT

TITLE:- REED RELAY OPERATE AMPLIFIER

DRG. Nº CM A9