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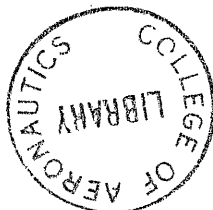
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ERGONOMICS AND SYSTEMS DESIGN LABORATORY

CRANFIELD



An appraisal of the Sciaky 300 KVA
projection/spot welding equipment

- by -

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1. SUMMARY

Using the Systems Design Procedure developed at Cranfield, an appraisal of the Sciaky Welding Equipment has been carried out.

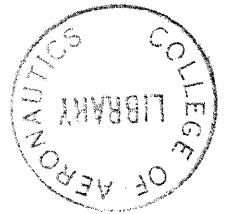
In particular, the interface on the electronic control cabinet has been redesigned, five solutions of varying engineering complexity and cost being presented.

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4. ACKNOWLEDGEMENTS

The members of the project group would like to express their gratitude to Mr. Singleton and Mr. Gardiner for their help and guidance, and to Mrs. Sally Mills for successfully deciphering our handwriting in order to type the minutes of the project meetings. We should also like to thank members of the staff of the Welding Laboratory for their co-operation.

5. DURATION OF PROJECT

The group held a weekly project meeting over a period of 15 weeks. The function of these meetings was to ensure that work on the project was up to schedule, and to allocate work for future meetings.

6. MEMBERS OF THE GROUP

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7. INTRODUCTION

The Welding Laboratory at The College of Aeronautics, Cranfield, has in its possession a Sciaky 300 KVA Projection/Spot Welding machine.

The equipment consists of an electronic control cabinet and the actual welding machine.

Fig. 1 shows a photograph of the equipment

Fig. 2 shows a photograph of the electronic control cabinet

Fig. 3 shows a plan view of the layout of the equipment.

The equipment is of non-standard design, some features having been added in order to facilitate more precise control of the variables involved in welding. For example, the extra equipment provides a higher degree of control of the amount of heat applied between the electrodes and also of the duration of heat application. These special facilities are located on the electronic control cabinet. The controls for the actual welding operation - raising and lowering electrodes, initiating weld, etc. - are located on the front of the welding machine.

The terms of reference of the project group were as follows:-

To critically appraise the Sciaky 300 K.V.A. Projection/Spot Welding Equipment as used by a concept-type operator who is primarily concerned with setting-up operations for research and demonstration purposes; also to examine, at a less thorough level, the maintenance capabilities and operating conditions of the machine. The appraisal and redesign will be concentrated mainly on the man/machine interfaces of the welding equipment. In order to give this task of re-designing the man/machine interfaces a sound basis, the Systems Design Procedure, developed at Cranfield was employed.

The next section of this report gives a brief description of this procedure.

8. A DESCRIPTION OF THE SYSTEMS DESIGN PROCEDURE

8.1 INTRODUCTION

As man's society has grown more and more complex, larger and more intricate systems have developed. For example, government has developed from family government through all the intermediate stages to national government; also with the growth of towns and cities, more complex systems of communications have grown up. The growth of such systems has brought about the need for a more overall view and long range development of systems. That there is such a need is evident when one examines the chaos of our road systems, which has sprung up mainly because of immediate needs to connect various parts of the country, rather than through any idea of long-term requirements.

Systems engineering has been developed and used in an attempt to help remedy such situations. It questions the need, for example, of a piece of hardware - which may be a road or a particular design of control knob - so that development inconsistent with overall systems goals is eliminated. It directs research into the type and design of system required before development begins and makes for efficient use of resources.

Noteworthy features of the systems engineering philosophy are that it treats man as an integral part of a system; it places great emphasis on the objectives of the system and how these are achieved rather than on details of the mechanisms involved in the system. Basically, the method employs a synthetic approach, logically building up a system from the definition of objectives and at the same time taking the characteristics of both human and hardware components into account. There remain, of course, all the pure engineering problems of designing an effective hardware system.

The method can also be used to modify an existing system, should time and cost restrict one to a part of the system rather than the whole.

8.2 THE PROCEDURE

Fig. 4 is a diagrammatic representation of the Systems Design Procedure. We shall now go through the sequence of operations, expanding where necessary.

1. Definition of Objectives

This is a statement of what the system is required to achieve. It is often represented by a one-block diagram showing the desired outputs of a system, given certain inputs.



2. Separation of functions

This process involves the delineation of the various functions in the systems which will achieve the objectives of the system. At this stage of the procedure separation of functions may be fairly coarse. As we become more conversant with the system, this separation of functions may become more refined.

3. Allocation of functions

Having separated the functions, the next step is to allocate these functions to man or machine. Since the capabilities of man and machines are different, it is necessary to decide which to use in order to fulfill any particular function. For example, the timing of application of heat for welding is better left to a machine than to a human operator. On the other hand, the inspection of a completed weld is best left to the man.

From this point the procedure divides into two main lines: the hardware line and the human operator line. Work on both these lines occur simultaneously, with connecting information channels as shown on the diagram. Also the following procedures are carried out for each of the three main features of the system; i.e. the setting up, operation and maintenance of the system.

4. Specification of Hardware Sub-systems

Since we now know what the hardware is to achieve, it is necessary to specify the hardware which will achieve the desired objectives.

5. The design of hardware follows on naturally from this specification. On a parallel track we are also concerned with:

6. Task description

For this we must define the task of the human operator part of the system. If we are designing a new system this description will, primarily, be synthesised. If some form of hardware, whether newly designed or old, is present, the task description stage will be helped since it is easier to see what the human operator has to do when he can try out the job on some hardware. The task description is essentially the first part of the human operator specification. The second part is:

7. The job specification:

That is, having said what the human operator must do, we now have to decide who or what type of human operator(s) must do it. To be able to do this we must have information on the population available. If the men available are not exactly of the right type we may have to re-allocate some of the function, or design a suitable training programme.

Once we have the Task Description and Job Specification, we are in a position to start the next step in the procedure. This is:

8. The design of man/machine interfaces

At this stage we know what needs to be done and by whom and we know what hardware we are going to use. It remains, therefore, to design interfaces between man and machine so that the system can operate satisfactorily.

In parallel with this operation we must define:

9. Selection criteria and decide on:

10. The training required for the selected operator.

We may also find that:

11. The design of job aids, such as handbooks, instructions, etc., will facilitate the performance of the various operations.

All that remains to be done, now, is to bring all these parts of the system together to complete the whole system. This process is called:

12. Systems integration and is self-explanatory.

Finally, some sort of systems evaluation is desirable. Often, however, it is very difficult, especially in a field situation, to perform this evaluation in anything like the detail required. Frequently, the assumption has to be made that, if the parts of the system are sufficiently efficient, then the sum of these parts is somewhere near the optimum required. This is not always a valid assumption.

The normal form of systems evaluation is for the manufacturer to sample customer response to his goods.

9. APPLICATION OF THE PROCEDURE TO THIS PROJECT

9.1 INTRODUCTION

Since the terms of reference of the project were to concern ourselves mainly with the redesign of the man/machine interfaces certain steps in the procedure have been omitted. For example, the present design of hardware has been accepted. Further instances of non-complete application of the procedure will become apparent. The reasons for these omissions were mainly concerned with the limited time available for the project.

Often the sequence of events as given in Chapter 8 was not followed exactly. However, since the procedure is fairly flexible and many of the operations are carried out in parallel, this does not matter.

We shall now go on to see how the Systems Design procedure was applied to this project.

9.2 Definition of objectives:

The objectives of this particular welding equipment are as follows:

1. To provide facilities for the spot and/or projection welding of a wide variety of metals.
2. To provide a high degree of control over the numerous variables involved in such welding, in order that involved research may be carried out by a suitably qualified investigator.

9.3 Separation of functions:

The main functions involved in this welding system are:-

1. The provision of power for heat application and for timing controls.
2. The provision of means for cooling various parts of the system.
3. The provision of means for application of varying amounts of pressure to a specimen situated between the electrodes.
4. The provision of means for inserting and locating the specimen to be welded.
5. The provision of means for the setting and control of the variables involved in welding.
6. To provide a means for monitoring of the system.

9.4 Allocation of functions

Functions are allocated to either man or machine. In this case, the allocation of function at present employed was accepted with only a few minor alterations.

Thus machines will perform the following functions:

1. The provision of power for heating and timing.
2. The provision of means for cooling.
3. The provision of means for pressure application.
- 4(a) The provision of a site for location and insertion of specimens.

The functions performed by a human operator are:

- 4(b) The insertion and location of specimens.
5. The setting and control of the welding cycle variables.
6. The monitoring of the system.

9.5 Specification and design of hardware sub-systems

The hardware sub-systems consist of the following:-

1. Electrical power for heating and timing.
2. Water for cooling.
3. Compressed air for pressure application, and movement of the electrodes.
4. A work table for location of the specimens.

These sub-systems are those used at present in the welding system. No attempt has been made to re-specify these sub-systems, nor to re-design them. Some re-design, however, may be caused by the re-distribution of controls on the man/machine interfaces. This re-design has not been considered and needs discussion with the relevant experts.

Fig. 5 is a functional diagram of the present (and proposed) system. On it are shown the main hardware sub-systems and their interconnections. Also shown is the interface between man and machine, and the complete welding cycle.

9.5 Task description

The task description for the system operators can be considered under four separate headings:

1. Getting off the ground.
2. Initial setting-up.
3. Operation.
4. Maintenance.

The following is a brief description of these four routines:

1. Getting off the ground:- The procedure for this stage is as follows:
 - Switch on compressor
 - Switch on electrical power
 - Turn on water supply and adjust rate of flow.
2. Initial setting-up:
 - Set supply pressure to required level.
 - Set back pressure to required level.
 - Set weld pressure to required level.
 - Set contact gauge pressure to required level.
 - Select required mode of operation of the machine (auto continuous/step by step, constant current/constant voltage).
 - Select heat and duration values for each phase of required weld cycle.
3. Operation:
 - Adjust workpiece in the machine.
 - Lower upper electrode until in contact with the workpiece.
 - Initiate weld.
 - When weld cycle complete raise upper electrode and move workpiece.
4. Maintenance: Maintenance falls into two distinct classes:
 - a) Preventative maintenance
 - b) Repair.

Preventative maintenance consists of checking, cleaning or lubricating particular machine parts at intervals specified by the maker.

Repair consists of systematic fault tracing and the correction of any faults which may occur. The procedures for fault tracing and the range of faults which can be corrected by the operator should be stated by the makers.

9.7 Job specification

Having determined the performance demands which must be made on systems personnel, we must now decide on the type of operators suitable for the job.

The two broad categories used in describing system personnel are as follows:

- a) Stimulus - Response
- b) Concept.

The stimulus response operator is the operator who is presented with clear concise instructions and has to act on them without necessarily understanding the reasons for what he is doing.

The concept operator is the operator who is presented with a more complete picture of the system and whose achievement of the required performance relies on him having a fuller understanding of that system.

The four routines and the personnel requirements are given below:

1. Getting off the ground: Selection of personnel and training can be made on the basis of using a stimulus-response operator.
2. Initial setting-up: Since users of this particular system will mainly be post graduate research students this routine can be designed for a concept operator.
3. Operation: Routine designed for a stimulus - response operator.
4. Maintenance: Routine designed for a stimulus - response operator.

In all four cases on-line training should be supplied in the form of job aids.

If one operator is required to carry out all routines he must be able to fulfill the concept operator requirements. In this system it is recommended that the first three routines be performed by a concept operator (e.g. a post graduate research student) and the fourth maintenance by a stimulus-response operator, (e.g. laboratory technician).

9.8 MAN/MACHINE INTERFACE DESIGN

1. General

The design of the man/machine interface, that is the array of displays and controls, is of great importance if the complete system is to function efficiently. It is necessary that the equipment be designed for use by the range of expected operators. To this end there are several general points which should be observed in the present case:

- a) Controls should be accessible and displays readily perceived by 90% of standing, British, male operators. Thus the controls should be between knuckle and shoulder height (i.e. between 30 and 52" above the floor level). The displays should be adequately illuminated and the lettering of sufficient clarity; this also implies that the lettering should be between 5 and 10 times brighter

(or darker) than the surrounds. The label should be above the corresponding control so that the hand does not obscure it when operating the control, and of course the control itself must be prevented from doing the same.

- b) Where discrete adjustment is required, bar knobs are preferable, whereas continuous adjustment calls for circular knobs. If concentric knobs are to be used, it is better that the outer (larger) knobs be used for the fine control. Obviously where a knob is required to indicate a positional setting, some form of index mark must be used; this must be both clear and unambiguous, i.e. there should be no parallax and if scales covering more than 180° are used, symmetrical bar knobs should be avoided.
- c) Directions of motion etc. should conform to British population stereotypes, e.g. 'up' should correspond with 'off' on a toggle switch, or numbers should increase in a clockwise direction. It is possibly useful to have circular scales which resemble clock faces in that zero should be at the top and the marking follows in the clockwise sense.
- d) Grouping of controls

There are three possible ways of grouping controls, each with some aspect to commend it.

Controls can be:

1. arranged in functional groups; e.g. all heat controls can be grouped together.
2. Controls can be grouped according to importance (or priority), e.g. the most important controls occupy the best positions for ease of operation etc.
3. Controls can be grouped according to the sequence of their setting or the sequence of the operation of the variables they control.

In all the following solutions, something of each of these methods of grouping is utilized. For example, controls are always grouped according to function, controls are generally grouped according to the sequence of operation of the variables they control, and finally the groups of controls are arranged in order of priority.

Thus each control panel contains controls which fulfil the same function e.g. heat controls; within each panel, the controls are grouped according to the sequence of operations of the variables they control e.g. 'Pre-heat, up slope, weld, down slope and post-heat' on the heat control panel. Finally the most frequently used control panels, the heat and timing controls are placed in the most suitable position for the operator.

2. Solutions

A succession of solutions for the electronics cabinet was produced which assigns varying weights to engineering effort required (i.e. to change from the existing design) and to ergonomic desirability. The solutions fall into three basic categories where:

Solution type A (Fig. 6) retains the existing chassis with the displays and controls re-arranged on the same panels as they are at present; the chassis¹ are re-deployed within the cabinet.

Solution type B (Figs. 7, 8 and 9); as A except that some inter-panel re-arrangement and greater engineering flexibility is allowed.

Solution type C (Figs. 10 and 11) allows maximum engineering flexibility.

3. Solutions A and B

a) Arrangement of chassis

The most undesirable feature of the existing design is that the 'electronic sequence' control panel, which has more displays and controls than any other, is situated almost in the bottom of the cabinet; this not only puts it outside the normal reach of the (standing) operator but almost certainly reduces its illumination as well. The distribution of the panels appears to bear little relationship with the functions of the equipment. The new arrangement places the panels with more controls at a height suited to the operator and bears a closer relationship with the function of the apparatus. The indicator lamps are now situated near the ground but this is not so critical because they do not require close attention. Some panels have been re-named according to function rather than hardware.

b) Test points

The position of the test points has been standardised at the top right hand corner of each panel. Those elements which are not used in the day-to-day machine setting are now at the top of each chassis.

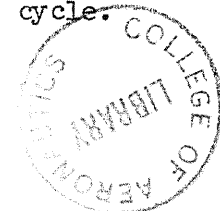
c) Arrangement of controls

The controls have been arranged on each chassis so that they conform to the sequence of the welding cycle (see Fig. 4).

4. Solution A (see fig. 6)

a) Heat selector chassis - renamed 'heat controls'

The heat controls have been arranged so that the left-hand sequence of the top row followed by the lower row corresponds to the welding cycle.



Since all the controls require continuous adjustment 'round' knobs are used. In addition, low torque switches are added to the 'up slope' and 'down slope' controls in place of the toggle switches. An illuminated panel is included as a warning against switching in 'slope-down' without 'slope-up'. Graduation marks have been added to the meter in order to ease the task of detecting the minimum deflection.

b) Electronic sequence control chassis - renamed 'Timing controls'

The cycles indicators are not relevant to the operation of the machine and should not be included on the man/machine interface. Coarse and fine controls are provided by the use of concentric knobs and colour should be used to differentiate those concerned with pressure from the heat controls; this colour coding may be extended to the titles. The fine control switches should be of low torque variety and the knobs provided with a good grip. The minimum basic setting up is achieved with the upper row of controls, and the remainder allow the higher measure of control. It is doubtful if the sequence indicator serves a useful function in normal use, but its possible value in fault finding is accepted and it is retained for this reason.

c) The remaining chassis'

No change is proposed at this stage for the remaining chassis.

5. Solution B1 (See fig. 7)

a) Timing controls

The on-off switches for 'up-slope' and 'down-slope' have been added to this panel which is otherwise the same as in solution A.

b) The remaining chassis

The remaining chassis are identical with solution A except that the 'off' positions have been removed from the 'up' and 'down' slope controls on the heat chassis.

6. Solution B2 (See fig. 8)

a) Heat controls

The left-right sequence is maintained but the use of vertical scales provides a quick, easy check and allows a more ready conception of the conditions demanded in the welding operation. These controls may conceivably take one of three forms:

- (i) A mask which is moved directly up a scale
- (ii) A knob under each scale which moves the mask
- (iii) A large coloured wheel, the edge of which protrudes through the panel.

b) The remaining chassis

The remaining chassis are identical with those of solution B1.

7. Solution B3 (See Fig. 9)

a) Heat controls.

The more conventional type of meter retained by the preceding solutions, is now replaced by one of the edgewise variety. This requires less panel space and need be no more expensive nor less accurate. Similarly, the knobs are replaced by 'thumbwheel' switches which gives a digital indication of their setting and allow a more convenient arrangement of the controls. They do, however, lack the quick indication of the state of the machine given by the analogue type displays, but this could be removed in part if all the scales were from say 0 - 99.

The left-hand sequence again corresponds to the welding cycle; this is indicated by the graphical representation of the heat versus time, which corresponds with the controls. Once more the minimum setting up is achieved with the upper row. The pre-heat and slope-set controls have been combined so that if pre-heat is switched in, they can not be set to different values. Also red lamps are included to warn against switching 'slope-down' in without 'slope-up'. A better arrangement would be to use some form of mechanical linkage between the two switches as well as the lamps.

b) Timing controls

The 'forge pressure delay initiate' switch is better grouped with the delay value control and has been removed from this panel. As with the Heat Controls, thumbwheels and graphical representations are used. Colour coding for head and pressure controls will be a useful addition. The step x step/auto continuous switch has been added to this panel and is grouped with the 'off' control.

c) Forge pressure delay chassis

The 'initiate' control has been added to this chassis and is placed in such a way as to allow the full titles to be used instead of the abbreviations. The value of the delay is set on three, decade, thumbwheels.

d) Electronic control chassis

The step x step/auto-continuous switch has been removed to the timing panel but the pressure switch is retained, although it is too low for normal use. It is assumed that this control is used infrequently; if not, it may be placed on the Heat Control panel. The three warning lamps are added to this chassis in preference to the even lower power pack.

e) NOTE

It should be noted that solution B3, although designed primarily for 'concept' operators is also suitable for 'stimulus-response' operators. The number of settings and the range of all the controls should be critically reviewed and the controls changed accordingly.

8. Solution C (See Figs. 10 and 11)

a) Hinged control panel

In this solution the controls for setting up are removed from the cabinet and mounted on a panel which is fixed by hinges to the side of the welding machine. The advantages of removing these controls from the cabinet are:

- (i) The cabinet can be placed well away from the machine. This saves workspace around the machine.
- (ii) All the maintenance checkpoints can be retained on the cabinet, separated from the operation and setting-up controls.

The advantages of the proposed control panel are:

- (i) During the setting up procedure, the operator need not move away from the machine. Whilst performing test welds on a specimen, he can adjust the heat and time controls very quickly and easily.
- (ii) When welding large specimens, the panel can be swung clear and located in one of a series of 'click-in' positions.
- (iii) After the setting-up procedure has been completed, the panel can be swung back against the side of the machine so that it takes up very little space.
- (iv) The controls, consisting only of potentiometers and switches can be maintained easily by removal of the back panel.

b) Description of panel

The controls are arranged from top to bottom in the welding sequence with the heat controls on the left and the timing on the right. The heat controls are mounted on a red background and the time controls on green. The controls are separated by alternate light and dark horizontal bands. The titles in the central column are on alternate light and dark grey backgrounds. The lettering should be in a colour which contrasts sufficiently with the backgrounds and this would probably be white.

Round knobs, 1" diameter, are used for the continuous scales and

tapered bar knobs, $1\frac{1}{4}$ " long are used for the step scales.

The 'set slope' control is incorporated in the pre-heat control in such a way that the pre-heat can be switched out if required. An illuminated warning panel guards against 'down slope' being used without 'up slope'.

Graphical representations of heat and pressure variations with time would be incorporated if necessary.

9. MACHINE INTERFACE

The operating controls, mounted on the front of the machine are as in Fig. 12 on the existing machine. The mean height of these controls is approximately 60" from the ground. This is a little high for the average operator but it is appreciated that, if they were mounted any lower, they may interfere with the operating space, particularly when large specimens are being used.

It is suggested that the operating controls be rearranged into a logical time sequence. Such a layout is shown in Fig. 13 where the controls are in a vertical time sequence. The toggle switches should not require more than 8-16 ozs for actuation and could possibly be changed to rocker switches with or without lamp indication. The push-button switches should require a maximum of 2 lbs pressure for actuation and should have a positive 'click' action. The buttons need not be recessed but this may be advisable as a safety precaution, and the button area should be adequate for the finger or thumb.

The work table height is adjustable and is, at present, approximately 36" from the floor. The optimum height for the operation is about 30".

An operator can be expected to lift (continuously) a maximum load of 45-100 lb. (depending on age) to this height. About two-thirds of this load is the optimum limit. Because of the nature of the operation the operator has to hold a specimen in position during the whole of the welding cycle. A maximum load, in the order of 20 lb. is therefore recommended to enable the operator to maintain a certain degree of control over the specimen. If the load exceeds this figure the assistance of another operator should be sought or a supporting surface set to the same height as the work table, should be used.

9.9 JOB AIDS

A job aid should be designed to support those performances by system personnel which are necessary for overall system performance. It should be developed as an alternative to training, providing means of acquiring the necessary system performance, and should complement any of the job training which the system personnel are given. The job aid should be designed on the basis of:

1. A complete knowledge of the system over which the system personnel exert control.
2. A description of the objective performance requirements for all personnel within the operational system.

The following are the areas which have to be considered when designing a job aid for this particular system:

- a) Machine Installation: Designed for the S-R operator, this section should give details of the machine fixing (the type of bed) and the water, air and electrical power connections.
- b) Initial Setting-up and Operation: Basically designed for the concept operator, this section should indicate the capabilities and limitations of the machine. It should contain a functional diagram, graphs of the operations cycle (Fig. 5) and a description of the system to enable the operator to understand fully the system in functional terms. Indication should be given in the job aid, as well as on the interface, of the units in which scales are marked (e.g. seconds, cycles etc.). In the present system the units of scale markings are not clear.
- c) Preventative Maintenance: This should contain details of what to do (cleaning, checking, lubrication, etc.) and how often it should be done. It is suggested that the latter figure should be given in terms of the number of welds rather than in terms of an absolute figure of time since different machines have different usage rates and will consequently require different preventative maintenance programmes. The machine in question is used intermittently and at a much lower rate than that of the standard production unit.
- d) Repairs: This section should be designed for the stimulus-response operator. It is suggested that a point should be determined beyond which it is impractical for the operator to correct faults. Such a point would have to be defined by someone with an intimate knowledge of the hardware.

For dealing with simple faults, not requiring the manufacturer's engineers, the job aid should list the most likely faults and the required remedial action. Electrical circuit diagrams should also be presented in the job aid as an aid to fault tracing, for the concept operator.

- e) Parts List: Diagrams of the hardware and the manufacturer's numbers of parts should be given as aids in identifying parts and re-ordering spare parts.

A job aid for the system can conveniently take the form of a handbook, although some parts of the handbook may be reproduced on the interface.

10. DISCUSSION

This chapter is concerned mainly with certain reservations the members of the project group have about the results of their work.

The first and most important is that we are not completely sure that we know how the present system is supposed to work. In our discussions with various members of the Welding Department we sometimes failed to find out why a particular control or indicator was used. Where we have been in doubt, we have made intelligent guesses, and Fig. 5, the Functional Diagram, is the result of these guesses (and of 'hard' information as well, of course).

We therefore expect the Sciaky designers et al to find some mistakes in our assumptions. We hope, however, that these will be minor in nature, and not affect our design solutions.

The second reservation is that our re-designs are intended primarily as guide-lines. We hope we have indicated general lines of attack rather than absolute, not-to-be deviated-from solutions. It is important, however, that deviations from our solutions be made with the principles we have laid down (in 9.8 in particular) borne in mind.

Thirdly we have not considered the cost of our solutions in anything but the most general manner. That is, we expect solution A to cost less than a B solution, but we have not estimated by how much.

Finally, the amount and type of operator training has not really been considered. This omission was caused mainly by the lack of time available. It is hoped, however, that for a concept-type operator, only a small amount of instruction will be required.

11. RECOMMENDATIONS

Three types of solution, A, B, and C have been presented so that the maker of the equipment has some choice if he decides to modify the existing equipment.

No detailed costing of the various solutions has been performed, so it is difficult to recommend any particular solution as the cheapest. However, each solution has something to recommend it. Solution A, for example, retains the existing allocation of controls to the five chassis. All that has been altered is the design of the controls and their distribution inside each chassis.

Solution B allow for some re-allocation of controls between chassis but this is usually not very extensive.

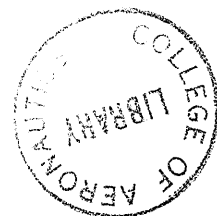
Solution C is not as radical a departure from the present system as it may at first sight seem. The existing control cabinet can be retained, with heat selector, electronic sequence and forge pressure delay chassis left blank. The swinging control panel is merely an extension of these chassis.

Thus without taking probable cost of modification into consideration, the project group favour something on the lines of solution C as being the most effective.

Ideally, of course, some sort of comparative evaluation of operator performance on each type of solution ought to be conducted. Unfortunately this is not within the scope of this project.

12. REFERENCES

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2. MORGAN, C.T. et al. (ed.)(1963) Human Engineering Guide to Equipment Designers (Los Angeles: Univ. California Press).
3. WOODSON, W.E. (1954) Human Engineering Guide for Equipment Designers (Los Angeles: Univ. California Press).



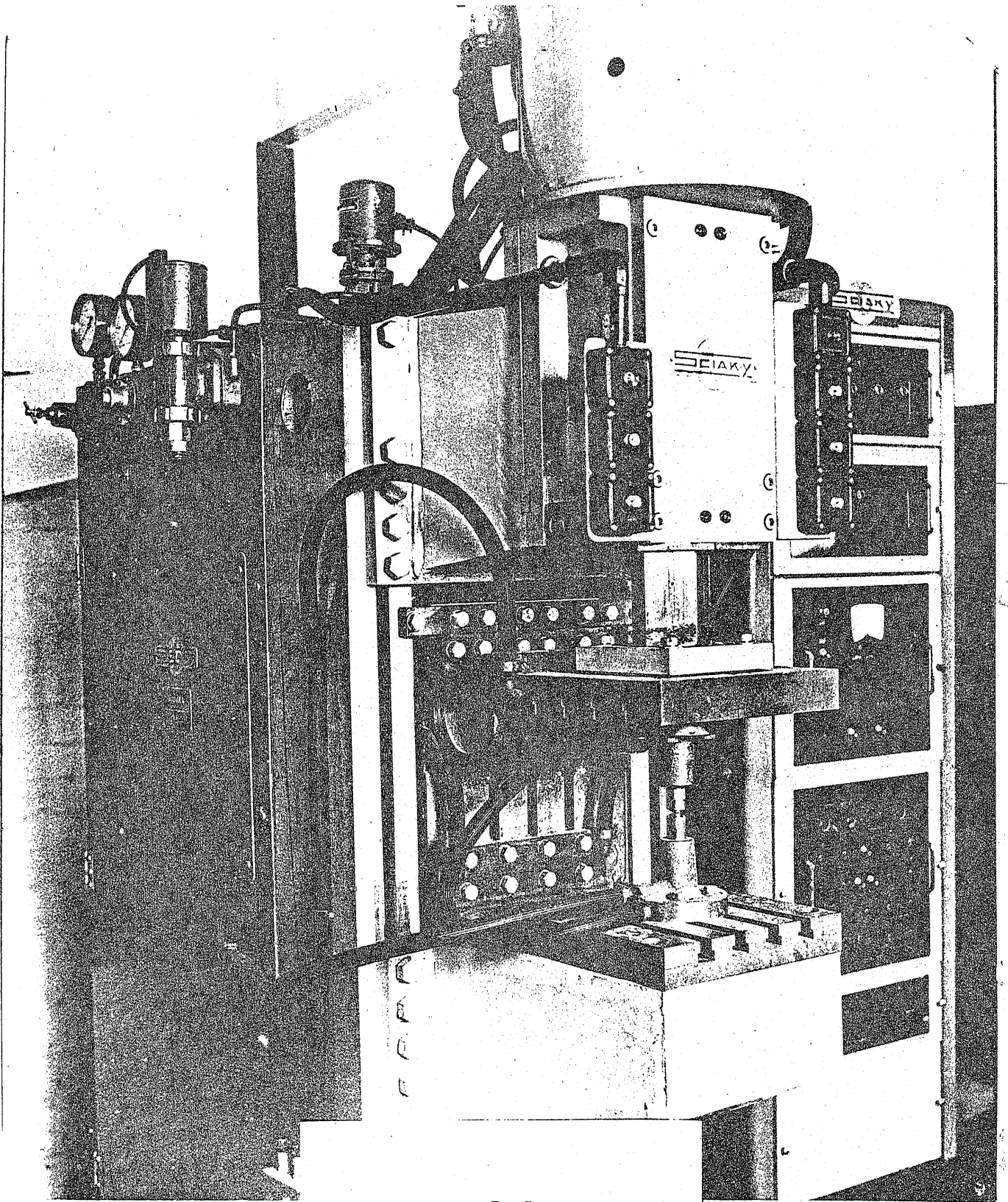


FIG 1

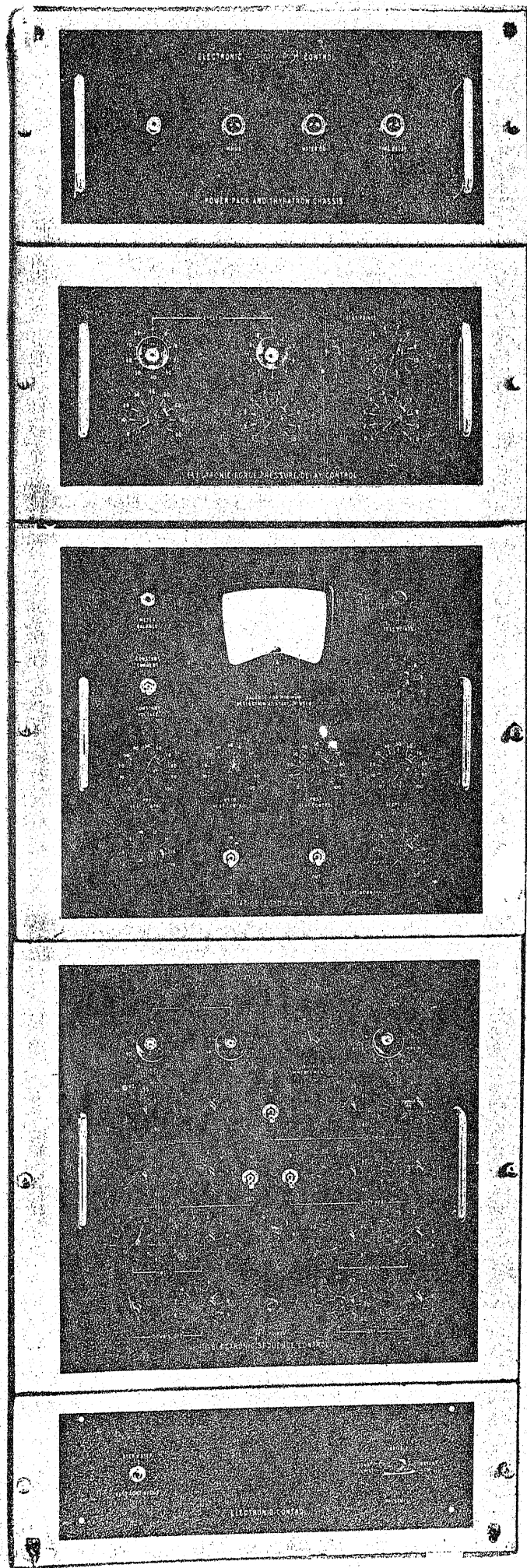


FIG 2

KEY

NO	MOVEMENT	PURPOSE
1	TO COMPRESSOR	TURN AIR ON
2	TO MAINS SWITCH	TURN ELECTRICAL POWER ON
3	TO WATER TAP	TURN WATER ON
4	TO SUPPLY PRESSURE VALVE	SET SUPPLY PRESSURE
5	TO BACK PRESSURE VALVE	SET BACK PRESSURE
6	TO WELD PRESSURE VALVE	SET WELD PRESSURE
7	TO CONTACT GAUGE	SET CONTACT GAUGE
8	TO CONTROL CABINET	SELECT HEAT & TIME VALUES
9	TO WELD CONTROL PANEL	READY TO START
10	FURTHER ADJUSTMENTS	OBTAIN CORRECT WELD
11	" "	" " "

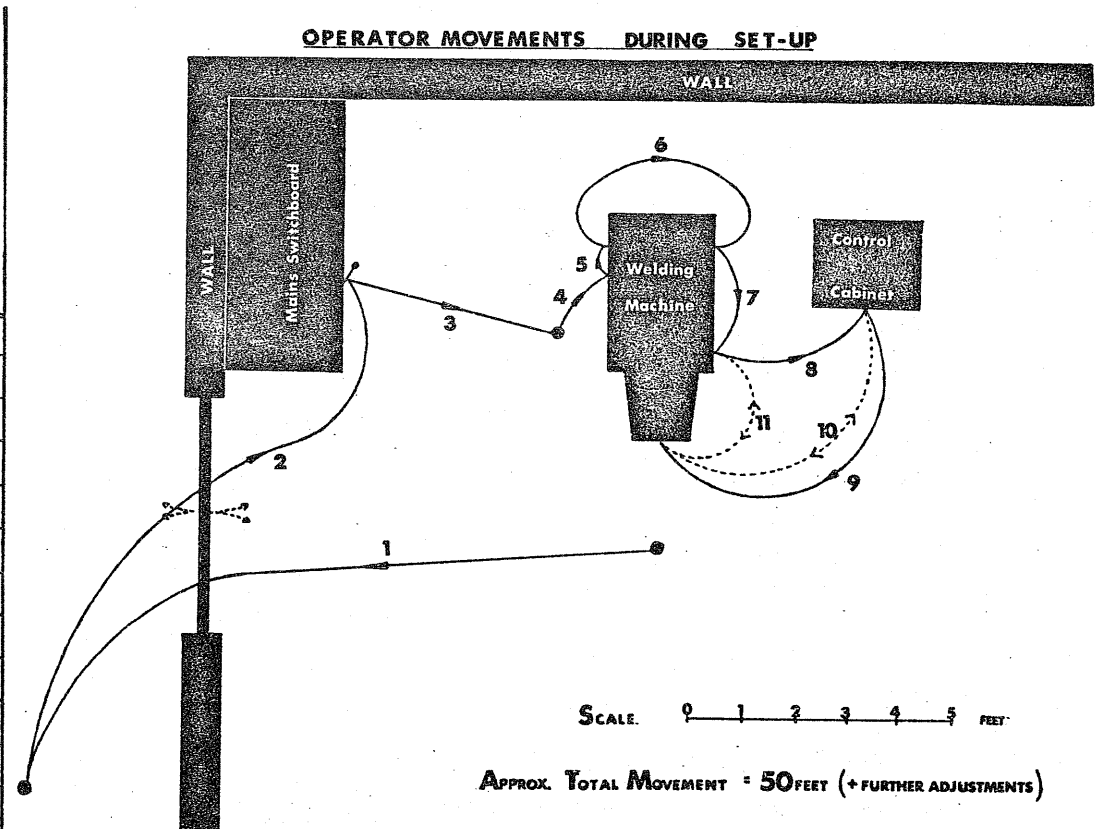


FIG 3

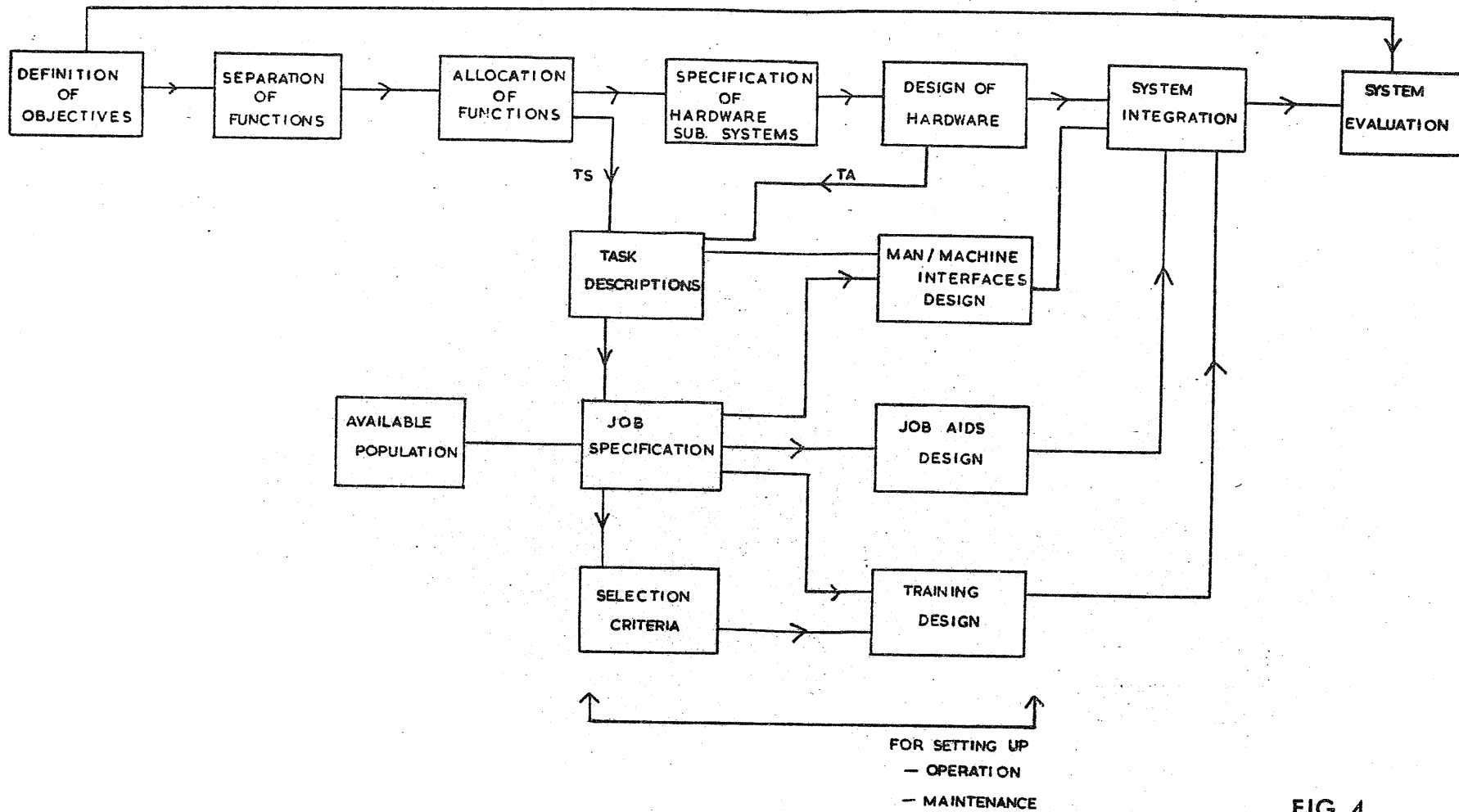


FIG 4

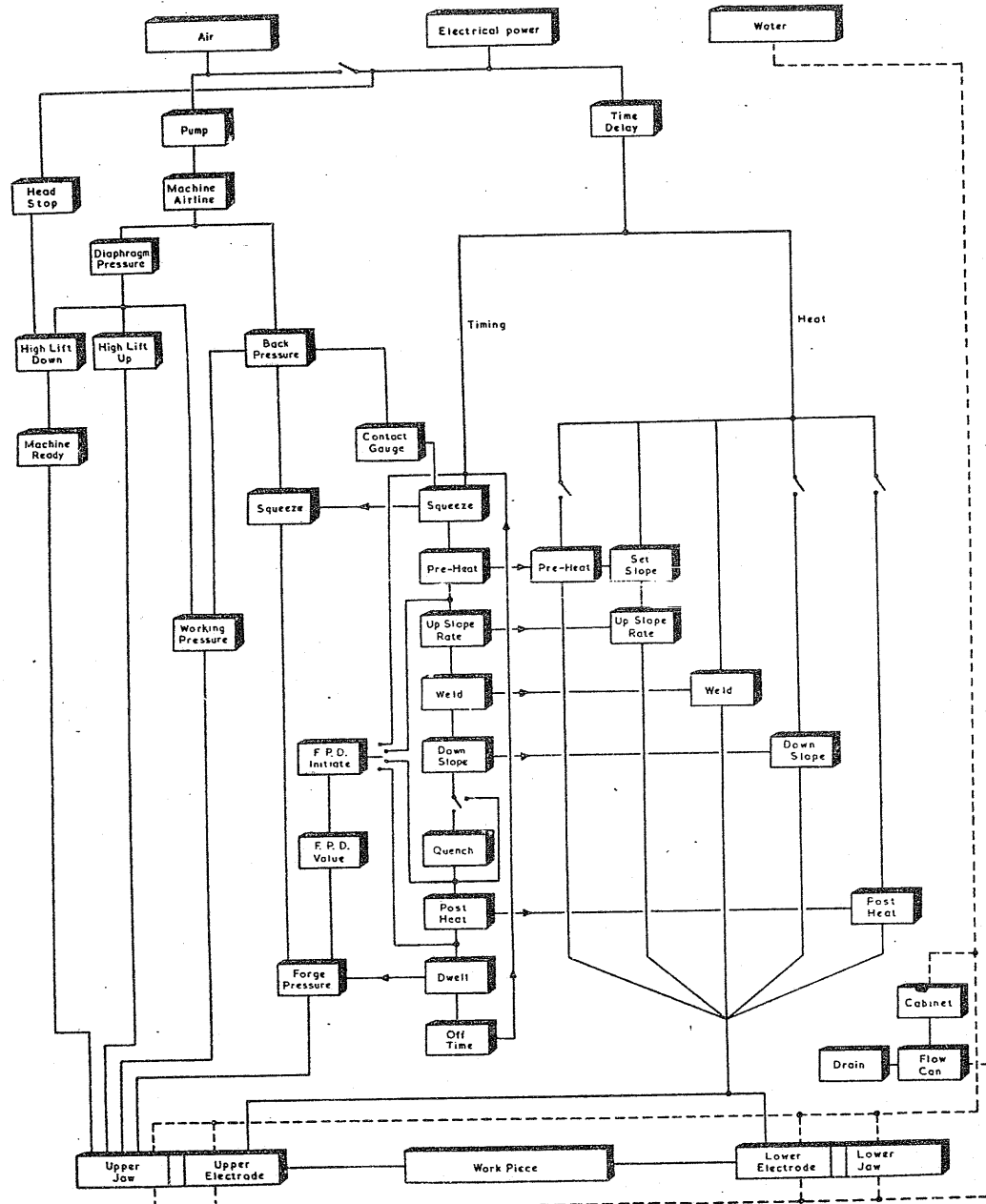
- Switch on/off
- Switch & Lamp on/off
- Knob, Lamp & Water Level Vary Flow
- Knob & Gauge Adjnt Pressure
- Lamp
- Knob & Gauge Adjust Pressure
- Cycles Indicators (2)
- Knob & Gauge Adjust Pressure
- Button Initiate High LR
- Buttons (2) Initiate High Lft, Down

- Switch Const. High / const. low / Variable
- Dial Set Contact Pressure
- Switch Const Voltage / Const. Current
- Button (2) / Pedal Initiate Weld
- Decade Sw. (2) Set Time
- Switch On / Off
- Switch Set Initial Value
- Decade Sw. (2) Set Power
- Decade Sw. (2) Set Time

- Set Rate
- Set Power
- Decade Sw. (2) Set Time
- Decade Sw. (2) Set Rate
- Decade Sw. (2) Set Time
- Select Forge Pressure Delay Initiate

- Switch In / out
- Decade Sw. (2) Set Time
- Decade Sw. (3) Set Time
- Set Power
- Decade Sw. (2) Set Time
- Decade Sw. (2) Set Time
- Switch Step x Step / continuous
- Decade Sw. (2) Set Time
- Sequence Indicator

FIG 5a



FUNCTIONAL DIAGRAM OF MACHINE OPERATION.

FIG 5b

HEAT AND PRESSURE VARIATIONS
DURING ONE MACHINE CYCLE

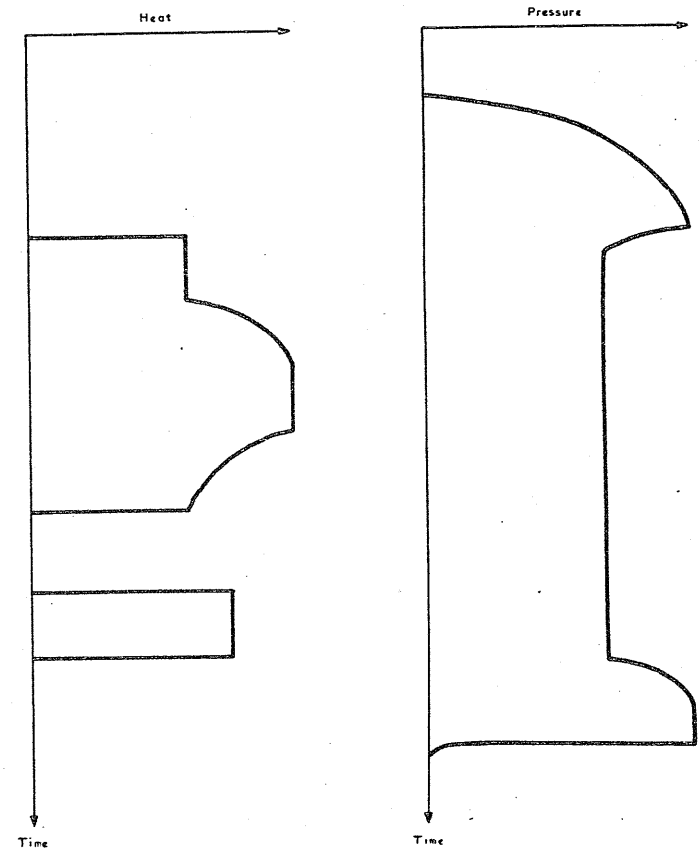


FIG 5c

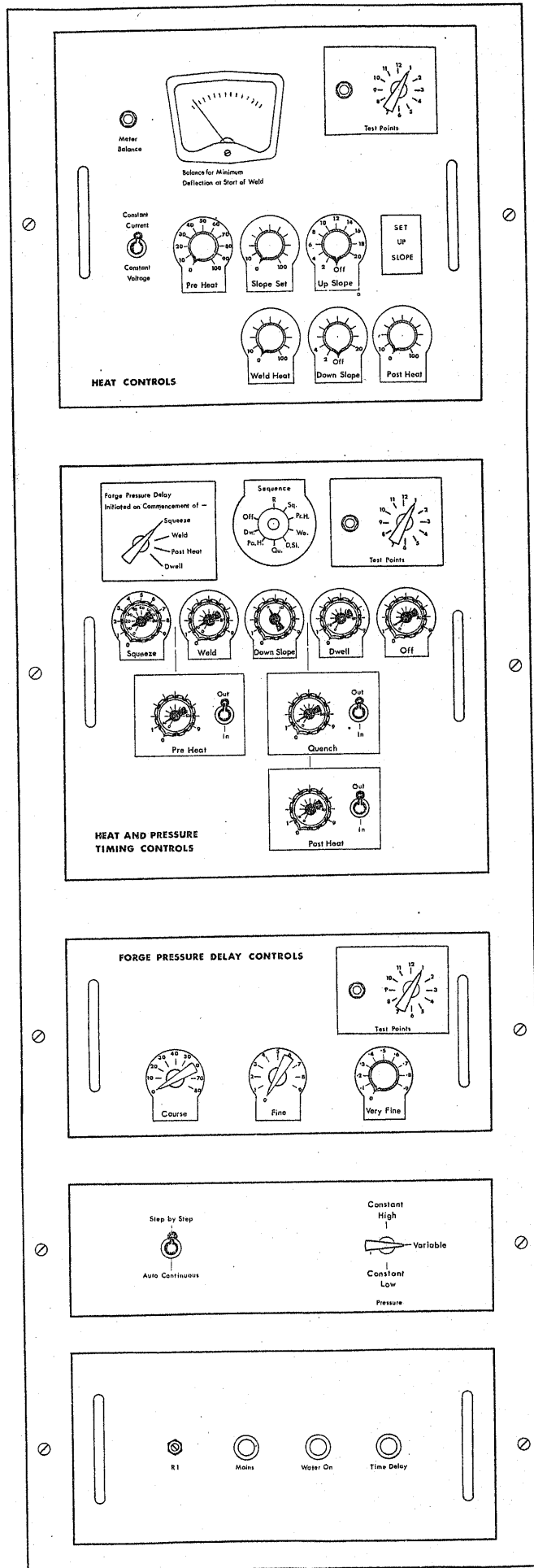


FIG 6

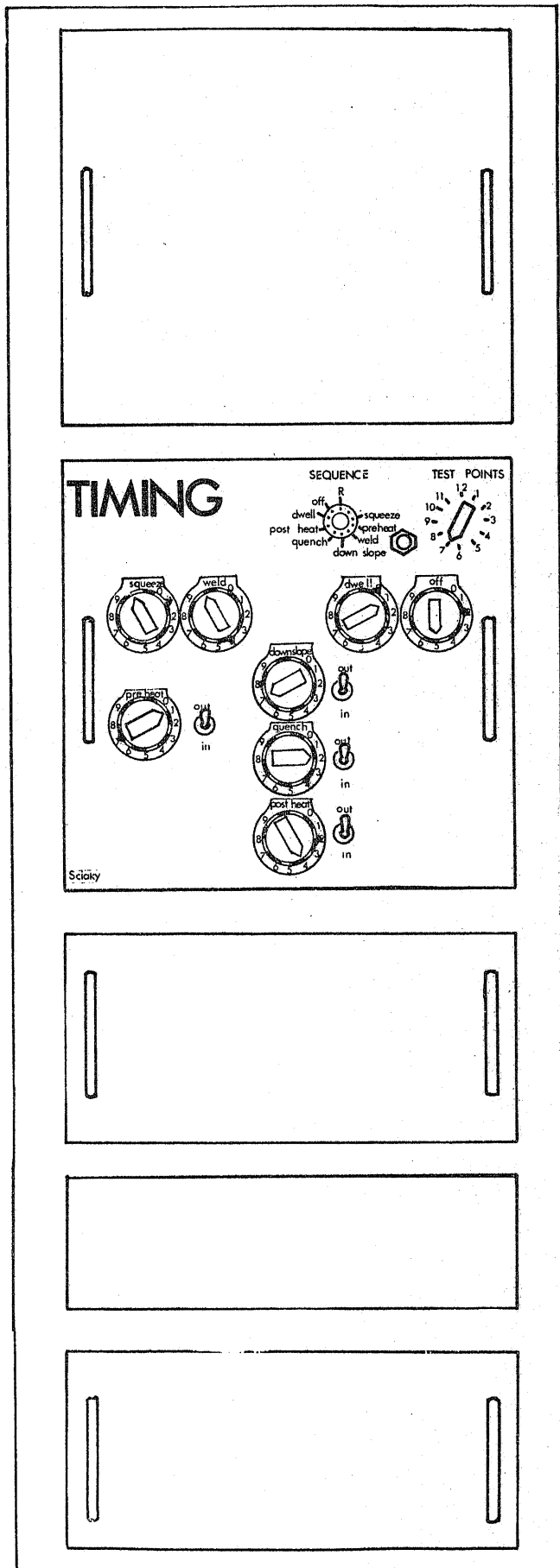


FIG 7

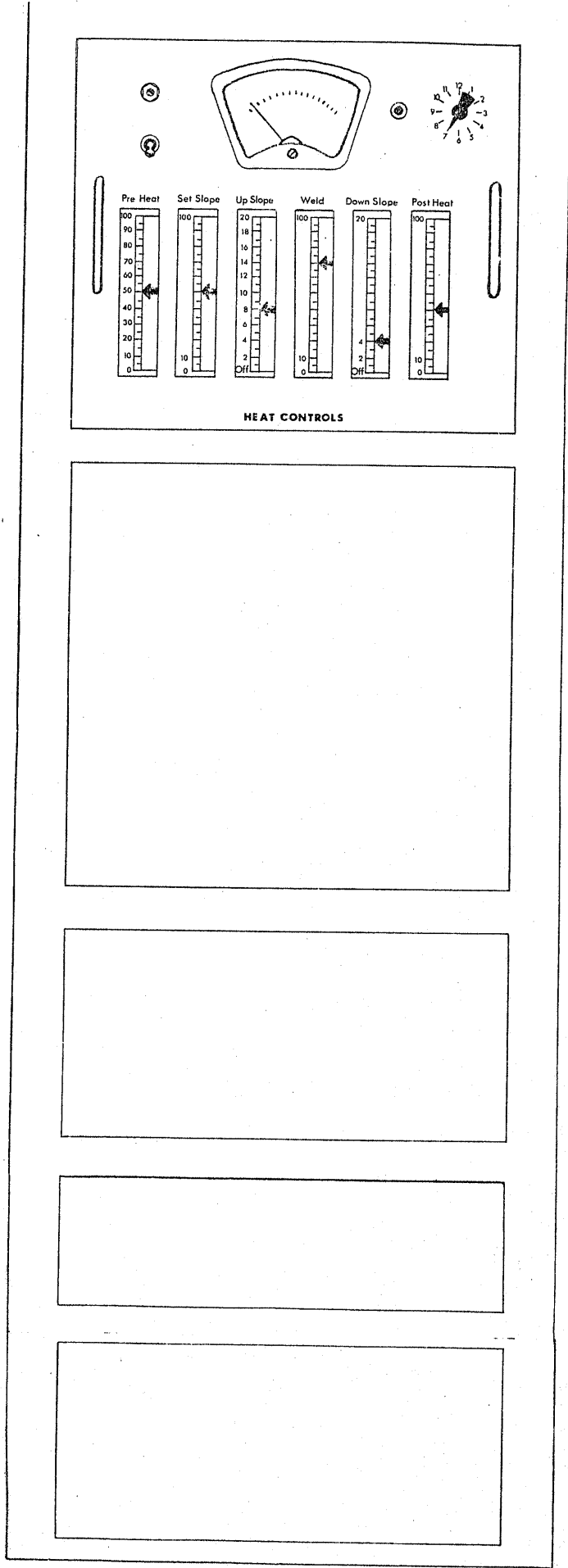


FIG 8

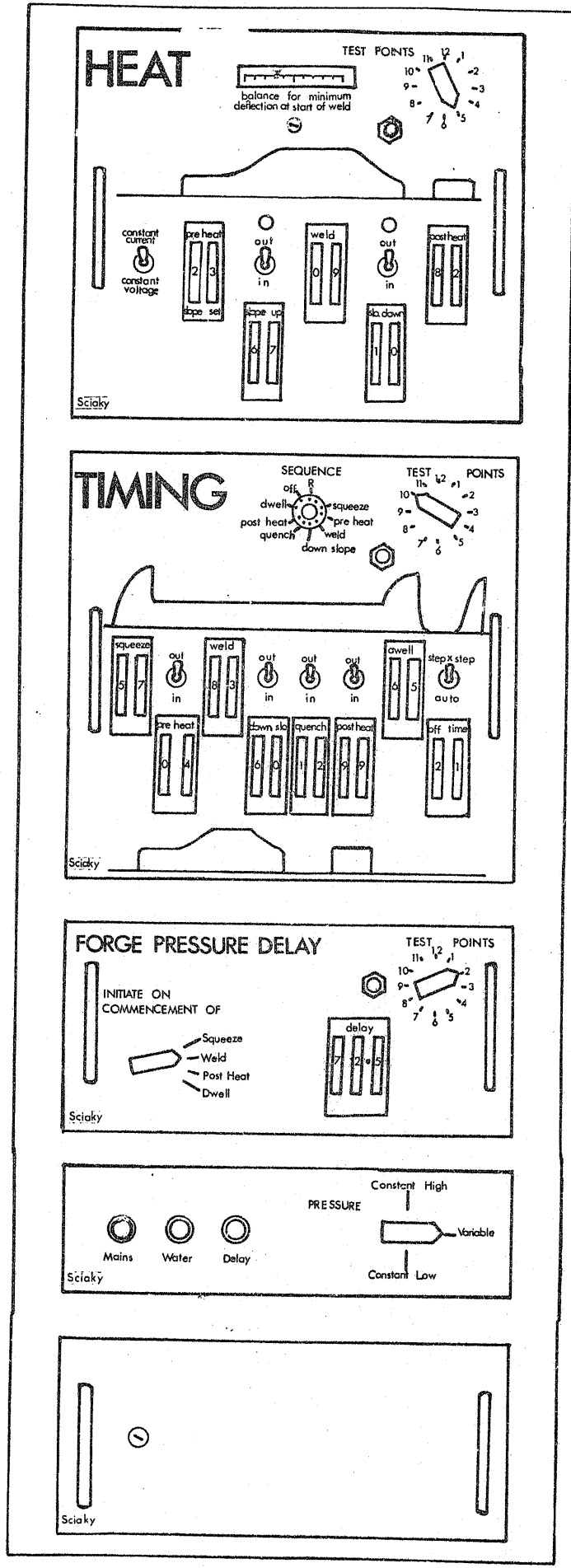
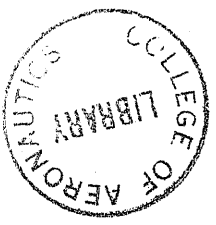
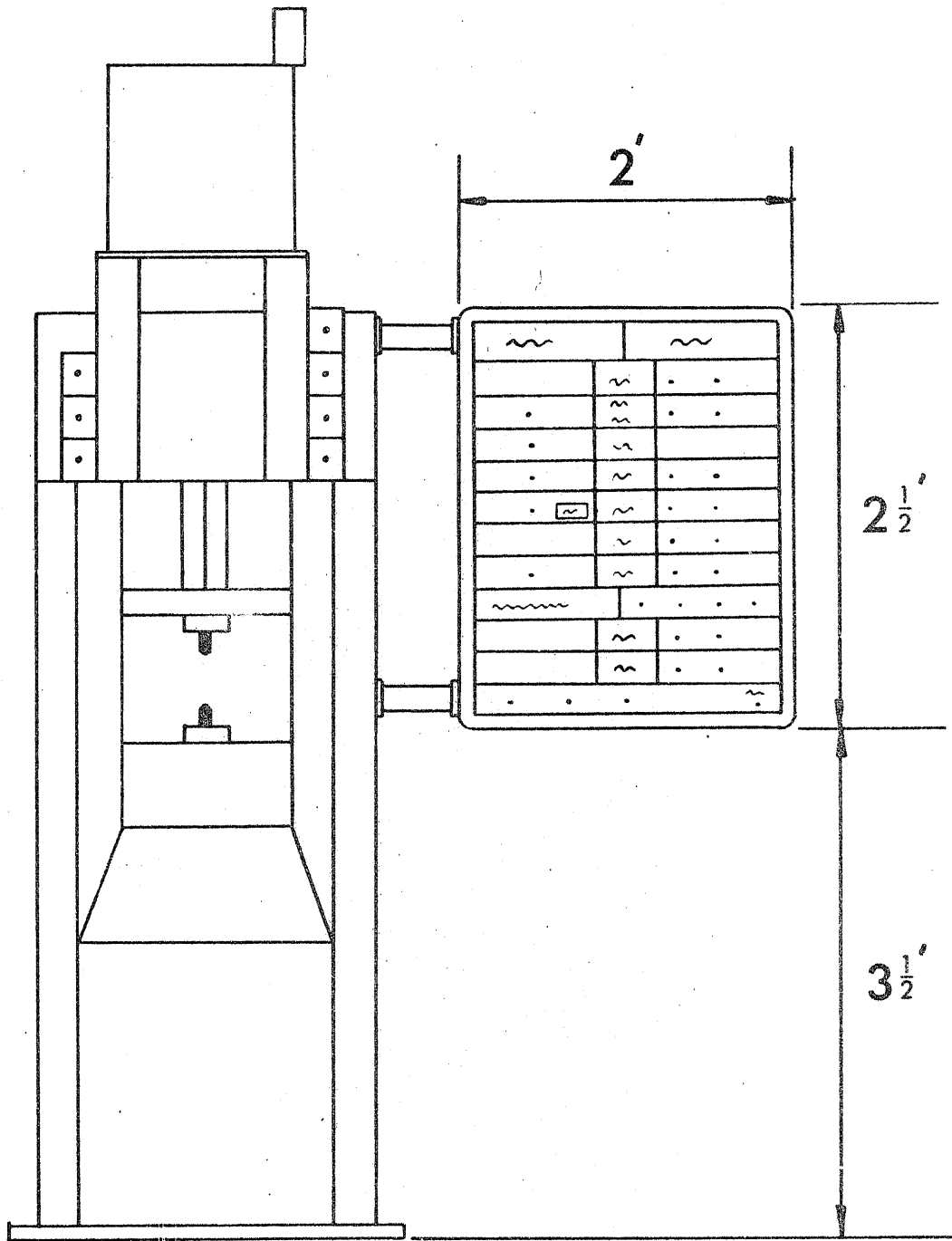


FIG 9

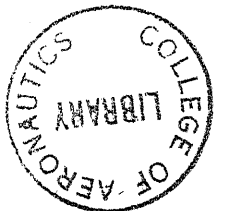


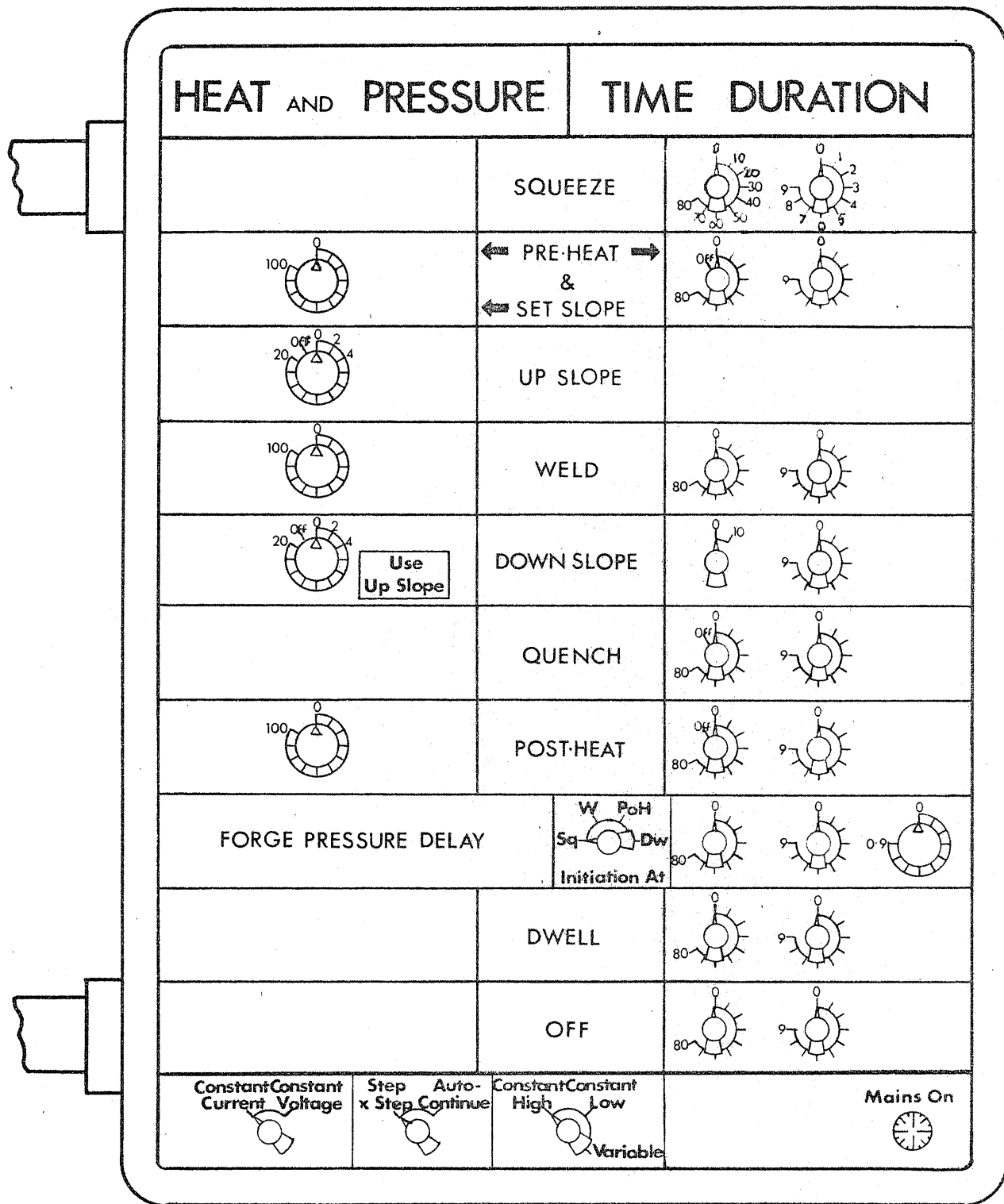


scale 1 : 12

PANEL POSITION ON MACHINE

FIG 10

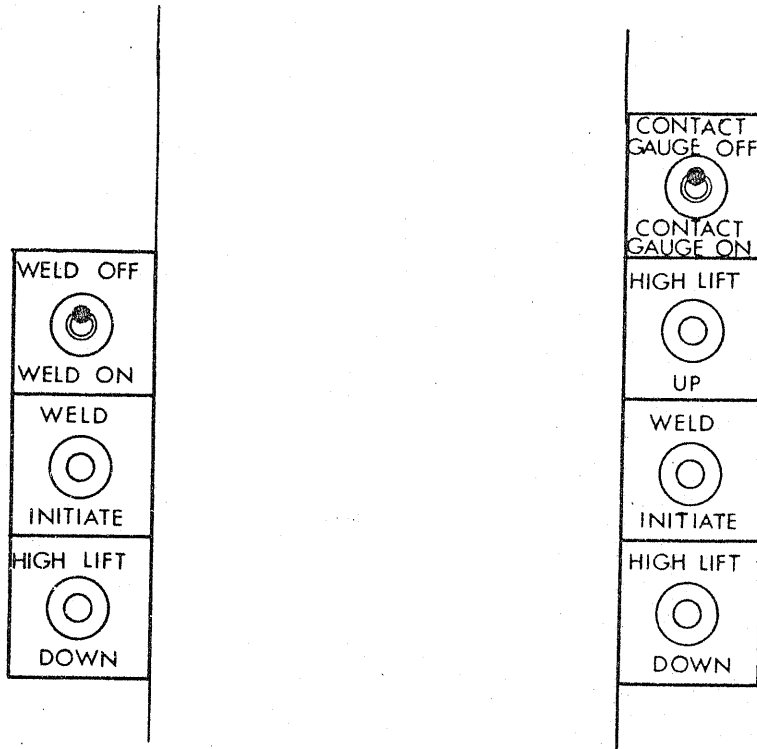




scale 1:4

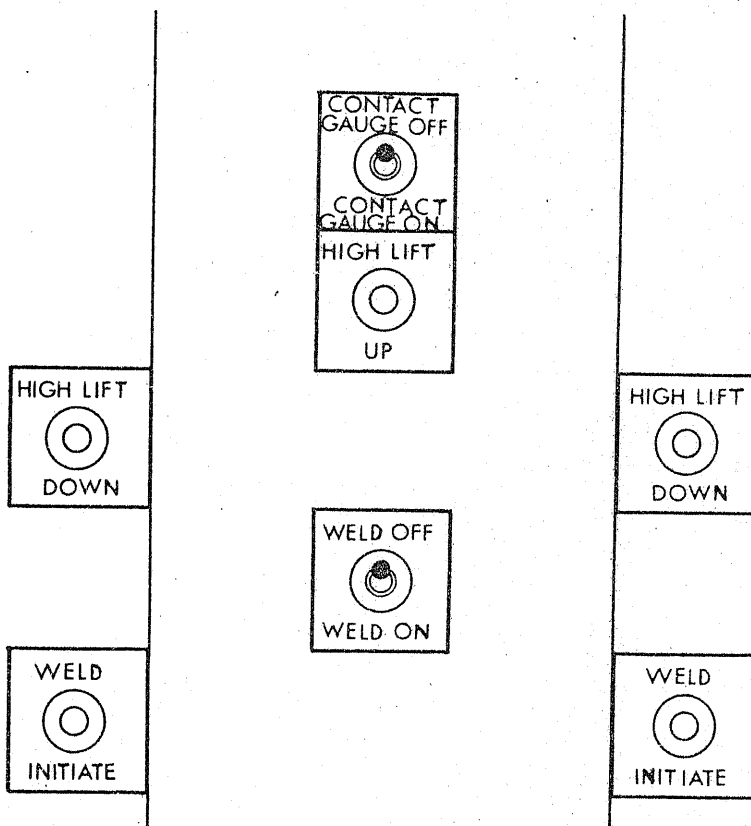
CONTROL LAYOUT

FIG 11



Existing Layout of Operating Controls.

FIG 12



Proposed Layout of Operating Controls.

FIG 13