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THE COLLEGE OF AERONAUTICS

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An investigation of the assembly of transistor cores

First Year Project 1964/65

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1. Introduction

This project was carried out for the Texas Instrument Company of Bedford, by members of the Ergonomics, Operational Research and Management sections at Cranfield. Texas Instruments wanted to increase production of double alloy transistors by 25%. The increase could not be achieved by hiring extra operators because the amount of floor space was limited. The problem facing the group therefore was one of expanding output by increasing the efficiency and productivity of the existing operators.

Description of the assembly line

The transistor assembly line employs 17 operators who work two shifts. Each operator assembles a batch of transistors as a unit. Each batch consists of 154 transistors and takes approximately 20 minutes to complete. The present system yields approximately 50,000 transistors a day.

Description of the assembly process

The general layout of the workbench used to assemble batches is shown in Fig. 5. Each operator's workbench measures 12" by 11". The transistors are constructed from five separate discs of material (as shown in Fig. 1). The discs are loaded one upon the other into a matrix of holes drilled into a graphite jig. Discs are stored separately in bottles at the top of the workbench and prior to loading they are transferred into a 'saddle' which is free to slide along the jig. The discs are then picked off the saddle one at a time by the operator using a suction pen and placed in the holes in the jig. The minimum size of the discs is approximately .030" diameter; the maximum .050". When all the material has been loaded into the holes in the jig a top plate is screwed onto the jig. The jig is then placed in a welding machine in which the particles are partially melted in order to bond the separate pieces together.

This report is divided into two main actions. In the first an analysis is made of the transistor assembly process. The following fields are covered:-

1. method study
2. technical
3. workspace

The second section comprises the recommendations made by the group on the basis of the foregoing analysis. Recommendations are made on:-

1. method at present used in the process
2. technical aspects of the process
3. the workspace
4. a suggested system of training and selection.

2. Method Study Analysis

Man material flow chart

Working from a film and tape recorded commentary made by Mr. T. Gardiner at the Texas Instruments factory, a detailed man-material flow process chart was drawn up. This is shown in Fig. 9. It shows in detail the sequence of operations in the assembly process and reveals the basic structure of assembly as consisting of the building up of first a gold, then an aluminium, then silicon, then aluminium and finally a gold lamination.

Two handed process chart

From the man-material flow chart a detailed two handed process chart was made. The chart showed that the left hand is inactive for a considerable proportion of the assembly time.

Methods-time measurement chart

A methods time measurement chart was made from the two handed process chart. The MTM chart enabled a detailed time scale to be given the assembly process.

Simo chart

A simo chart was constructed from the two handed process chart and the MTM chart. The simo chart showed graphically the relationship between the useful work done by each hand and the amount of time each hand was idle. The chart is shown in Fig. 10.

Detailed analysis of the time sequence revealed the following facts on the basic motions:-

MOTION	TIME (MINS.)	% PROCESS
Release	8.100	6.12
Move	0.980	50.5
Reach	0.250	1.62
Grasp	1.940	12.0
Position	2.640	16.5
Turn	0.130	0.81
Inspect	2.00	12.5

Total time/cycle = 16.04 minutes.

Allowances

After a detailed examination of the whole process the following relaxation allowances were made.

Energy output	1		6
Posture	1		0
Motions	1		0
Eye attention	4	fluctuating?	5
Personal needs	2		4
Special clothing	1		0
Thermal conditions	3	excessive air moving	2
Atmospheric conditions	1	normal	0
General environment	2		1
Monotory	3	absent	5
Concentration	2		4
Loneliness	1		0
			27%

It should be noted that the relaxation times tend to be generous to the operator. Overall cycle time therefore is 20.365 minutes.

The calculation of the total cycle time was made before visiting the factory. Upon visiting the factory it was subsequently found that the cycle time was 22.8 minutes. The difference represents a working efficiency of 89%.

3. Technical analysis

The transistor core

The transistor core assembly is in the form of a double sandwich consisting of a series of flat discs. Fig. 1 shows an exploded view of the assembly. In order of assembly the series comprises:-

1. bottom gold disc 0.030" diameter molybdenum plated on its upper surface
2. aluminium alloy disc .030" diameter
3. silicon disc .050" diameter
4. aluminium alloy disc 0.040" diameter
5. top gold disc 0.040" diameter molybdenum plated on lower surface.

It is essential that the discs are assembled in the correct sequence and that the gold surfaces are on the outside.

The Jig

The discs are assembled in a jig which consists of three sections:

1. the bottom section of the jig consists of a flat plate with a 9 x 18 matrix of concentric double recesses. The centre recess is designed to accommodate the two 0.030" discs. The other larger diameter recess receives the silicon disc. The bottom section of the jig also has a vertical counterbored hole at each end to accommodate the bolts which keep the three sections of the jig together during later processes. At the ends of the bottom section are two holes which mate with spigots on a fixture at the workplace.

2. the second section of the jig is flat on both top and bottom surfaces. It is pierced by a 9 x 18 matrix of holes which match the recesses on the bottom section. These holes receive the two .040" discs. The second section has bolt holes to match those on the bottom section.

3. The top section is similar to the other two in that it has two bolt holes and a 9 x 18 matrix of holes. The holes in this layer accommodate studs which are used to apply pressure to the discs during the fusing process. For a drawing see Fig. 2.

End pieces

The jig is held steady at the workplace by two end pieces one of which is fixed to the bench the other being moveable. The fixed end piece has two spigots which locate in the hole in the bottom section of the jig preventing movement of the jig away from or towards the operator. The moveable end piece has two spigots which locate in the holes in the bench preventing any lateral movement of the jig.

Saddle

Discs are placed in the jig from a saddle. The saddle straddles the jig and has a recess in its top to hold the discs. A drawing of the saddle can be seen in Fig. 3.

Pen

Discs are transferred from the saddle to the jig by a suction pen (See Fig. 4) which is operated by closing a bleed hole with the fore finger.

Bottle

The layout of the workplace is shown in Fig. 5. Bottles containing the discs are retained in recesses at the back of the workplace. They are stored in their order of usage.

Booth

The workplace is enclosed in a clean booth which is internally lit. The top half of the front of the bench is glass and the bottom half is left open to allow the operator to insert her fore arms when working.

4. Workspace analysis

Analysis of the layout of the workspace was made on the basis of a film taken at the factory by Mr. T. Gardiner. The major components in the layout are shown in Fig. 5. On the basis of the initial analysis the following proposals were made on chair design, table design, jig positioning and general illumination.

Chair design

A chair suitable for the operation is shown in Fig. 11. The figures should cover the 95% percental range. The seat and back should be of fairly soft material and about 1" thick. Depending upon the amount of money available to this section of job redesign, provision could be made for an adjustable back.

Table design

The table shown in Fig. 12 has been designed in relation to the chair. The minimum width is 16" but this could be extended to accommodate any associated equipment. Provision should be made in the table top to locate the base board holding the jig.

Jig position

The jig should be repositioned on the base board to ensure that there is ample room for the hand to be supported without interference from the gutter or board edge. To avoid interference with the right hand end of the jig it might be necessary to provide an arm rest or raise the angle of the base board.

General illumination

The workplace area should be illuminated to around 80 foot candles. The general illumination level will need to be supplemented by additional lighting from, for example, a table lamp. The flexible type of lamp is useful in avoiding shadows. Direct glare should be avoided by providing light shades and shields. Reflected light can be avoided by correct jig colouring but contrast between jig and components should be maintained.

5. Method study recommendations

General

Analysis of the assembly process revealed it to be essentially a one-handed process. To change this basic characteristic of the process would be impossible. For example it is extremely unlikely that most operators would have the necessary eye-hand co-ordination to use two suction pens at the same time. The fact that this is a one-handed process has to be accepted.

Method study recommendations deal with two main possibilities:

1. streamlining non-filling actions in the existing process, e.g. assembling the jig,
2. filling the matrix by a completely new method.

1. Streamlining non-filling actions in the existing process

α $2\frac{1}{2}\%$ of the existing total cycle time is spent in filling and emptying the saddle. A method of by-passing this obstacle is suggested further on in the recommendations.

β When assembling the jig operators were observed screwing down the two securing nuts separately. Time could be saved on the existing jig by screwing down each nut at the same time.

γ Pen, saddle and funnel have no precise location when not in use. Precise location would save the operator the slight amount of time and energy needed to find these objects.

It is estimated by Mr. Done that these three recommendations would give a saving equal to 11% of the total cycle time.

2. Matrix-filling by a new method

A. The main possibility which occurred to members of the group was the design of a jig which would enable the loading process to be automated.

B. It is recommended that the possibility of bonding gold and aluminium sheets together should be investigated fully. The discs could then be stamped out. Bonding before stamping out would reduce the assembly process to one of three elements and cut the cycle time by 50%. The possibility of bonding gold and aluminium sheets was suggested to metallurgical engineers during the visit to the factory. They questioned its feasibility mainly on the grounds of contamination. It is suggested that the possibility of bonding be examined and the problem of contamination be investigated.

6. Technical recommendations

The technical recommendations fall into two categories:-

1. a suggestion that the possibility of bonding alloy to gold be investigated,

2. a suggested method of automating the loading process.

Both are aimed at reducing what the group considered to be the most important time saving area - the loading process. At present nearly 90% of batch assembly time is taken up by transferring discs from saddle to jig. Not only is the loading process time consuming, it also involves identical operations. Each batch requires 770 identical operations since each of the 154 holes in the jig have to be filled with five different types of discs. Clearly any reduction of time achieved in the loading process will help considerably in reducing the overall process time.

1. Bonding alloy to gold

The possibility of bonding alloy to gold should be investigated since the two upper as well as the two lower discs have the same diameter. Bonding the two surfaces of the upper and lower discs would reduce the loading operation to filling each hole in the matrix with three discs and cut the total loading time by 3/5.

The difficulties involved in bonding however are considerable - the main problem being that of contamination. What is required is a method of bonding which during the furnace heating involved in the bonding process will leave no deposits. Since molybdenum gives a very volatile oxide it will be necessary to prevent any decomposition occurring which gives oxygen. Carboniferous bonding materials are impracticable since it would be impossible to achieve the complete elimination of the carbon.

The most likely method of bonding would seem to be that of surface tension. Water might be used provided that the heating temperature in the furnace was not great enough to cause the decomposition of the water. This danger would have to be especially guarded against in the case of aluminium oxide which has such a large free energy change of formation that it would easily decompose water.

Bonding would also yield considerable financial savings as well as reducing the loading time. It is recommended that a feasibility study on bonding be carried out by personnel qualified in this field.

2. Automatic loading

The key problem in loading the jig by machine is presenting the discs to the loading machine in an ordered manner. Machine loading would in fact entail long storage tubes in which large numbers of discs are stacked. Particular care would have to be taken in storing the gold-backed molybdenum discs the correct way up.

An automatic loading process would involve two main stages:

A. sorting the discs prior to loading
B. loading the discs.

A. Sorting the discs

Discs could best be sorted at the stamping out process. It is assumed that the discs are stamped out using a circular, hollow die from a sheet of material. Discs could be collected in tubes at the instant of stamping out (see Fig. 6). The ideal would be to use a matrix of long tubes which correspond with the loading jig (see Fig. 7). Since accuracy of position is essential in the final loading process it is recommended that the single storage tubes should be enclosed in a square block. The external dimensions could then be relatively easily machined to the required accuracy. A matrix similar to the loading jig could then be made by slotting the storage tubes into a convenient tray. Once sorted it is possible that problems may be encountered in cleaning and smoothing the discs prior to dispatching them to the assembly line. The use of ultrasonic vibration could well provide a solution to such problems.

Discs could also be sorted by allowing them to flow over a matrix of holes under high frequency vibration. If suction were applied at the bottom of the tubes it would be possible to collect the discs into stacked piles. This method suffers from the disadvantage that the gold/molybdenum discs are not sorted with the gold faces the correct way up. This method is inferior to the first.

B. Loading the discs

If the discs can be sorted into storage tubes and presented to the loading machine in a matrix form, it should be possible to design a pick up head which will transfer the discs to the jig.

The proposed pick up head (see Fig. 8) consists of a matrix of suction tubes in which suction is controlled by a simple ON-OFF valve. The head is lowered onto the storage matrix and the suction is turned on. The head is then lifted up carrying with it the discs and swung over and lowered onto the loading jig so that the discs are sealed in the jig. The suction is then turned off. It might be necessary to apply a small amount of air pressure to detach the discs from the tubes. The partially loaded jig can then be transferred to a similar machine which will then load it with the next type of material.

The most important problem in the process is the degree of accuracy required in positioning the jig and store matrix. Since the diameter of the smallest disc is .030″ the order of accuracy required for each part is probably in the region of .001″. It would be probably necessary in view of this to have a human operator to provide an overall control of the process.

---oOo---

More information is needed on the present process as well as the capital outlay and the approximate reduction in time and cost per unit of assembly should the process be automated, before detailed plans can be made.

Given the repetitive nature of the process, the relative scarcity of labour in the district and the growing demand for semi conductor components in industry we feel that money would be well spent in a further investigation of the possibilities of automatic loading. Any investigation should fully cover the following important areas:-

1. the feasibility of sorting discs at the stamping out stage
2. the feasibility of positioning the jig and the storage matrix with the required degree of accuracy.

7. Work space recommendations

The factory visited showed that a number of the work space suggestions originally made by the group and included in the analysis section had already been adopted.

The following recommendations on work space fall into two categories:

1. general environmental conditions
2. workplace layout.

1. General environmental conditions

A. Air temperature and humidity

Although no measurements were made it was agreed by the group that the combination of high temperature and low humidity that is necessary to reduce contamination, was uncomfortable. Fans were provided but these were few in number and only gave localised air movement. Conditions such as those that provailed at the factory are likely to cause some absenteeism. In an area with a considerable shortage of labour any means of reducing absenteeism must be investigated.

B. Lighting

It was agreed that the general level of lighting was sufficient. Most of the light was provided in the closed booths.

2. Workplace layout

A. Seating

It was evident that seating and in particular the seat/table combination had been reasonably well designed. Most of the recommendations made before the factory visit had already been adopted.

It was noticed however that some operators were leaning forward and resting their heads on the glass screen. If the operator is more comfortable in this position then some sort of simple headrest should be provided. It is doubtful whether this modification should be encouraged since there is a possibility of encouraging incorrect spinal posture.

B. Supplementary lighting

Certain modifications to the lighting within the booths can be made with the object of increasing the contrast when the operator decides which surface of the gold pieces is uppermost. Tests were carried out and it was found that a Northlight (6500°K) tube gave the best combination of contrast and general illumination. The tube should be placed above the operator's head in order to reduce glare. Additional lighting could be placed around the top edge of the booth but direct glare should be avoided.

C. Jig and workplace colouring

Glare from the jig and fixture surface could be reduce if these were finished in matt colours. The colours used however should provide sufficient contrast.

D Position of the boat on jig

It was decided after a number of positions of the boat on the jig had been suggested, that the operators themselves should be allowed to choose the most comfortable boat-to-hand position. Whether this would result in an improvement can only be found by controlled experiments or production comparisons. The expenses involved in this however might be hard to justify.

It was also proposed that a simple form of handrest should be provided. This would reduce fatigue when the hand is resting on the sharp edge of the jig.

E. Pen position

A fixed position should be provided for the suction pen in order to reduce delay to a minimum. The pen could be laid in a gutter attached to the side of the fixture.

F. Funnel

In order to reduce errors and delay involved in emptying the contents of the saddle back into the bottles at the end of each filling operation, it is recommended that the funnel be fixed and that the bottles be arranged in an easily accessible manner under it. The arrangement is shown in Fig. 13.

Construction

The channel section provides a fixed location for the bottles and enables them to be moved along by means of pushing bottle A. The possibility of tipping is reduced to a minimum. The channel section should be about seven bottle diameters long so as to ensure that bottle E is not pushed off the end.

The risk of contamination is reduced by placing a permanent cover over the bottles. The cover is supported from the rear of the channel section. The marker is placed at the left hand side to act as a bottle position indicator.

The funnel is also clamped to the rear of the channel directly over bottle A.

If the bottle codes are:

A Gold 2
B Alloy 2
C Silicon
D Alloy 1
E Gold 1

then at the beginning of the operation bottle E will be:

1. slid out of the channel
2. taken to the saddle
3. emptied (partly)
4. returned to the left hand end
5. pushed along until the left hand side of the bottle is just not visible behind the marker.

When the matrix filling operation is completed the saddle is:-

1. taken to the funnel
2. emptied into the funnel
3. replaced on the jig

The process can then be repeated.

Advantages

There are three distinct advantages to be gained from using this innovation:

1. Since the bottles are in a fixed location the operator has only to go to one end of the channel to pick up the next bottle and to the other end to replace the bottle.

2. Complete cover is provided during the whole operation. Under the old method bottles are frequently left uncovered all day.

3. Handling times are reduced during the filling and emptying operations.

8. Recommendations on training and selection

A Selection

The labour shortage at present existing in the Bedford area would make any elaborate selection technique unpracticable. Analysis of the job reveals the following attributes to be necessary and useful:

1. manual dexterity
2. ability not to suffer from eye strain when working with closely-spaced fine objects.
3. ability to perform a repetitious task without any decrement in efficiency with time.
4. stability of personality.

The proposed system of selection would involve:

1. a simple test along the lines of the actual matrix filling operation. Both the expense and the extent of the test can only be justified by the number of applicants and vacancies.
2. an examination of past history and/or a medical examination
3. further tests developed and used in the training programme.

B. Training

Any training scheme should be set up off-line. The advantages of off-line training are:-

1. less expense
2. objectives are more definite. It is possible to obtain 100% feedback of information, or results and progress to the trainee
3. the most necessary skill - filling the matrix rapidly and efficiently - can be emphasised at the expense of the easy operations.

Method of training

A block diagram of the training scheme is shown in fig. 14.

Films could be made of skilled operators performing the task and these could be used to compare with and improve the technique of the trainee. Trainees could also be usefully shown films dealing with the organisation and structure of Texas Instruments.

Such an off-line training scheme can be run for any number of trainees. It is estimated that it will achieve in a maximum of two weeks what the present on-line system achieves in eight weeks.

The times to be allocated to each stage of the training scheme can be calculated after a few trainees have progressed through the scheem. Emphasis can be given to the important parts of the process such as filling the jig matrix. As each element is mastered it can be combined with its predecessors until the complete job is mastered.

9. Acknowledgements

Mr. W.T. Singleton, M.A., Lecturer in Ergonomics, Department of Production and Industrial Administration, The College of Aeronautics, Cranfield - for his guidance and advice.

Mr. T. Gardiner, Ergonomics Laboratory, The College of Aeronautics - for his assistance on many aspects of the project.

Mrs. S. Mills, Ergonomics Laboratory - for her help in preparing the minutes of each meeting and also for helping to prepare this report.

Texas Instruments - for their co-operation in this project.

10. Conclusion

This project has helped its members to learn the basic techniques of method study and how they are applied so that the members have a fuller appreciation of these problems involved in method study.

It has also given the members considerable practice in the clear writing of reports for industrial applications.

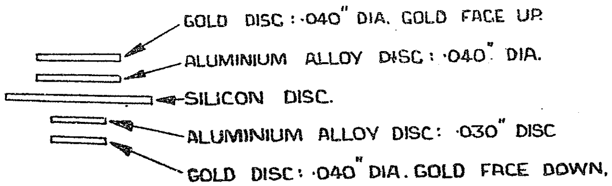


FIG. 1. EXPLODED VIEW OF TRANSISTOR CORE ASSY.

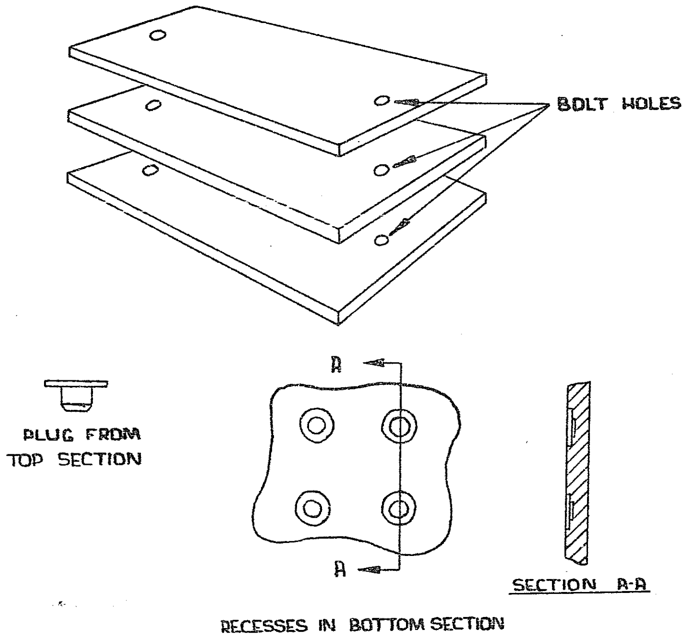
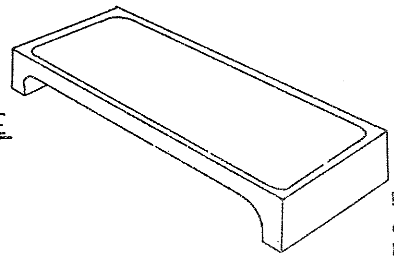


FIG 2. JIG

FIG 3. SADDLE



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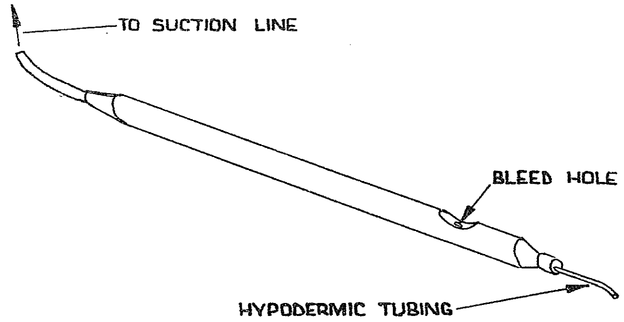

FIG. 4. SUCTION PEN

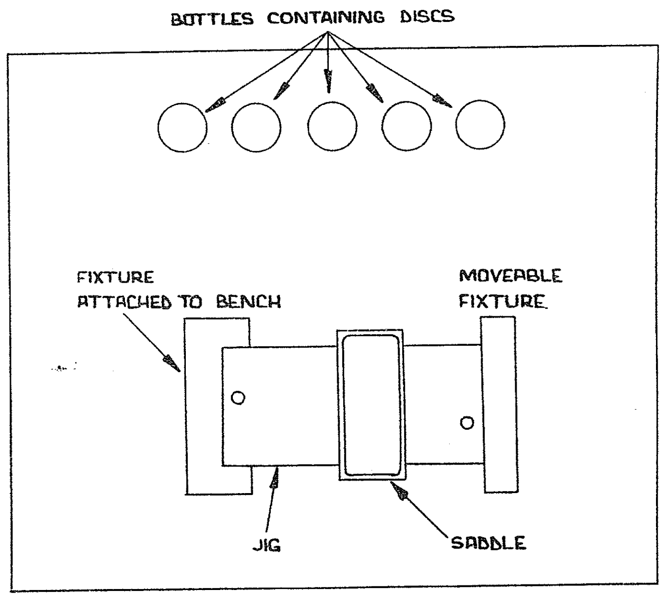

FIG. 5. WORKPLACE LAYOUT

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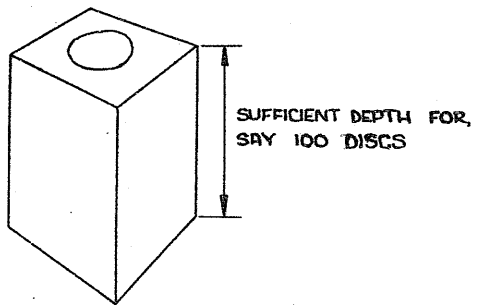

FIG 6. STORAGE TUBES.

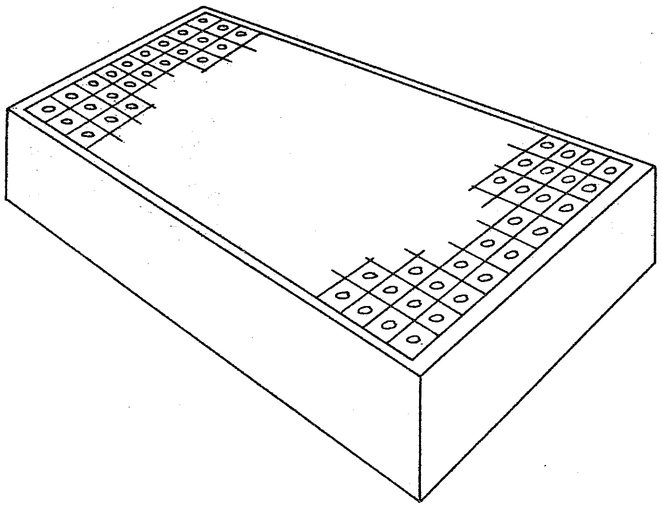

FIG 7. STORAGE TUBES ASSEMBLED IN MATRIX.

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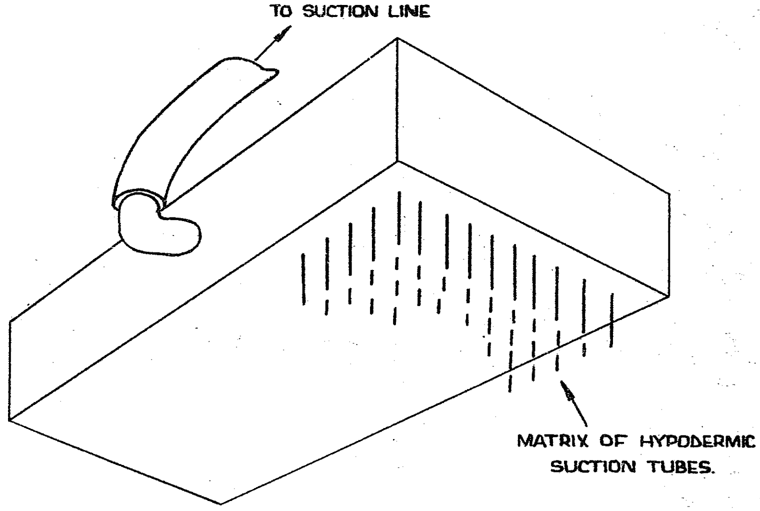

FIG 8 SUCTION HEAD

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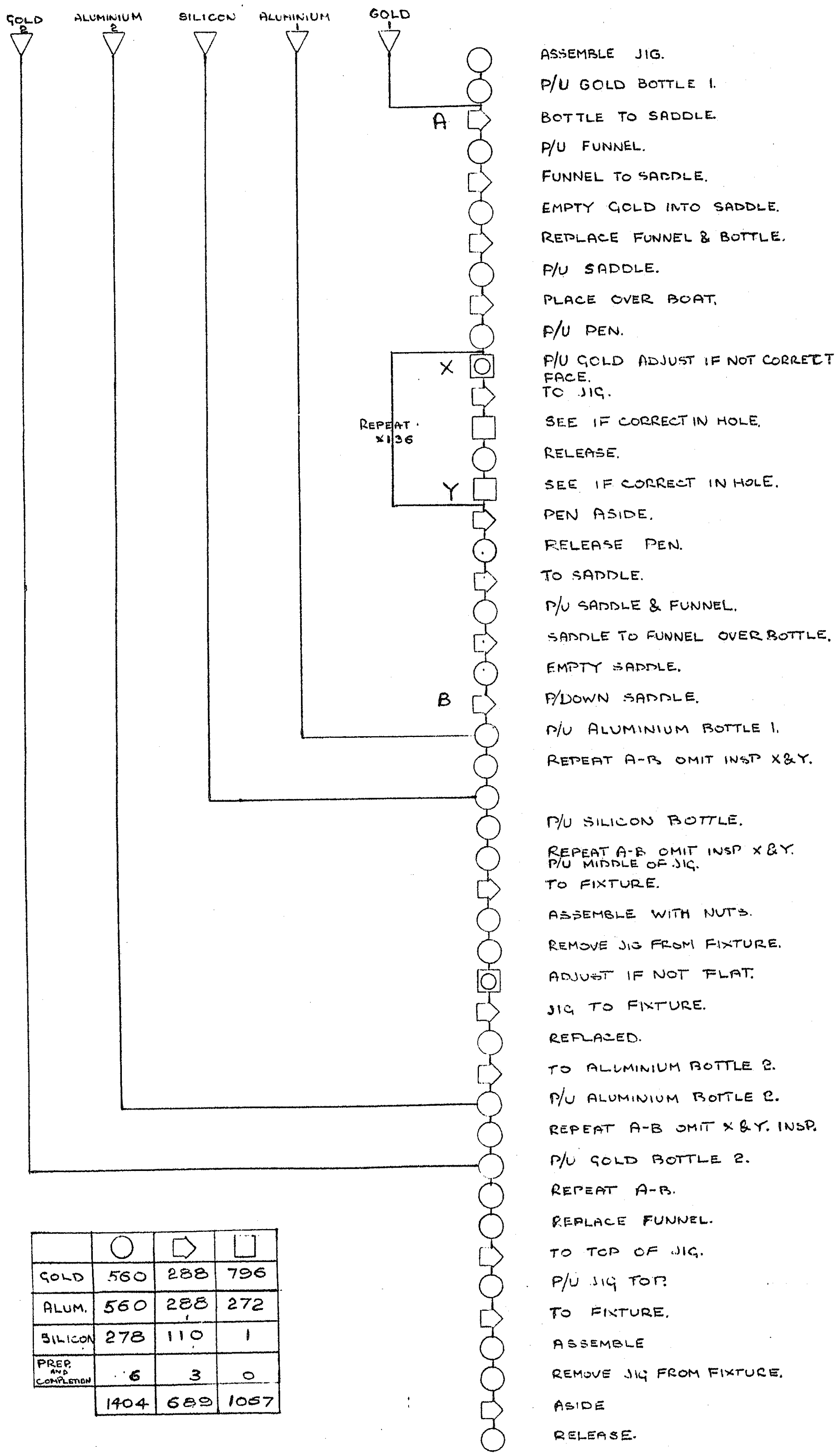
MAN - MATERIAL FLOW PROCESS CHART.



	○ (operation)	⇨ (transport)	□ (inspection)
GOLD	560	288	796
ALUM.	560	288	272
SILICON	278	110	1
PREP AND COMPLETION	6	3	0
	1404	689	1057

FIG 9

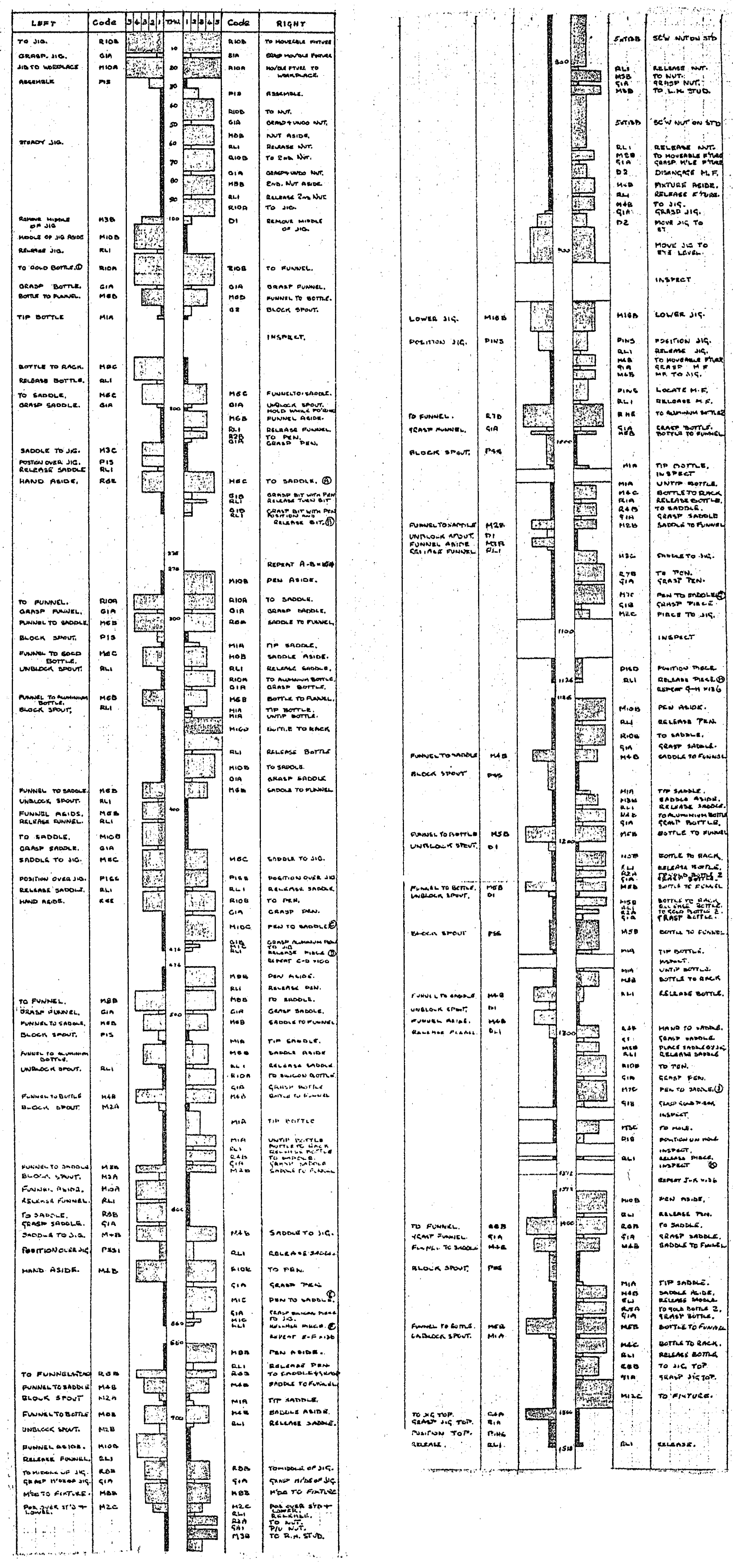


FIG 10

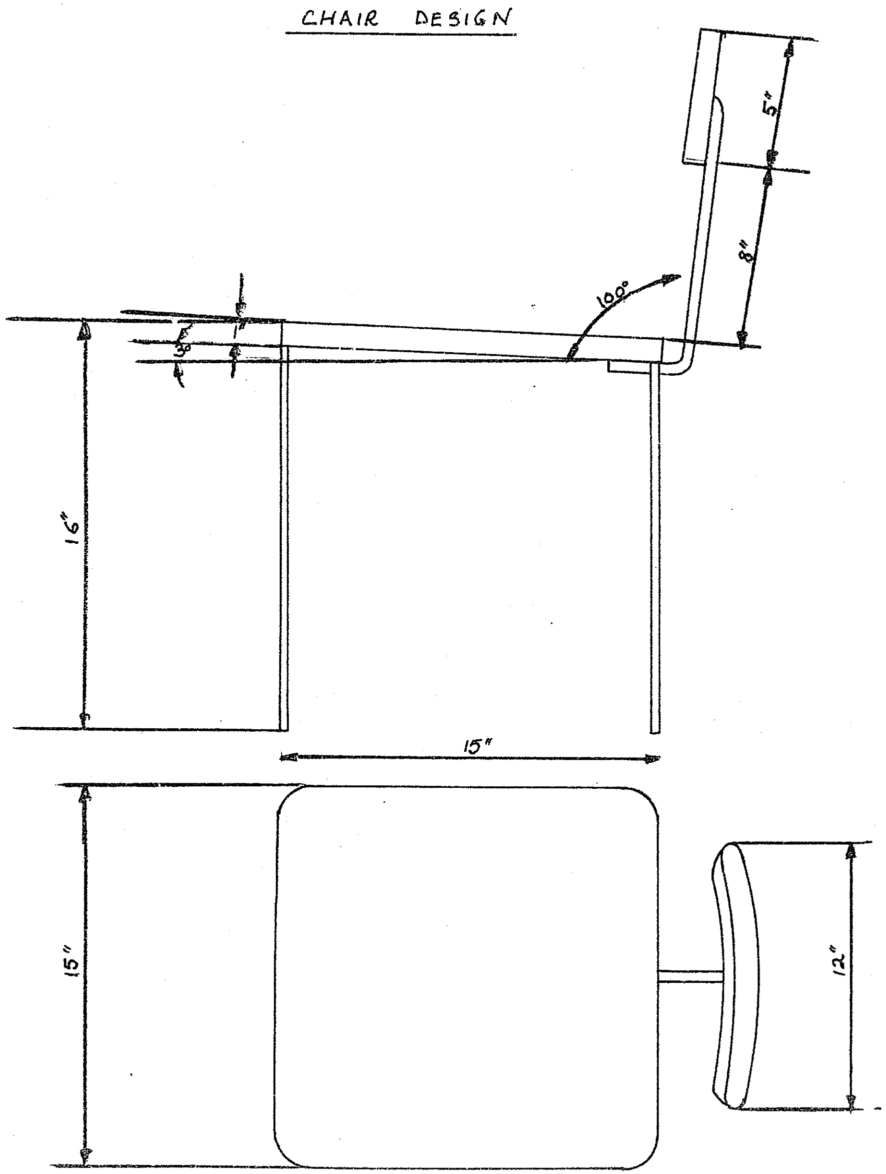


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FIG. 11.

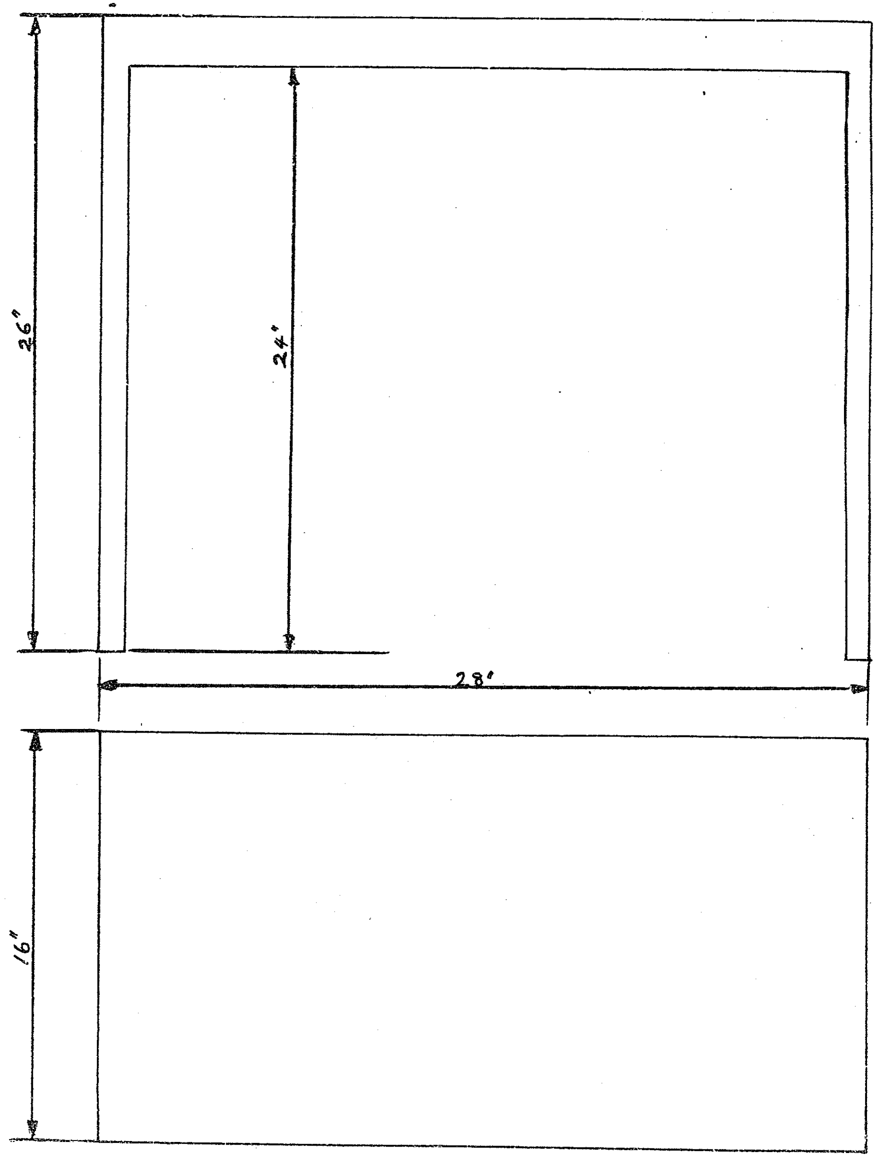

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FIG. 12.

LAYOUT OF BOTTLE REFILLING-BAY.

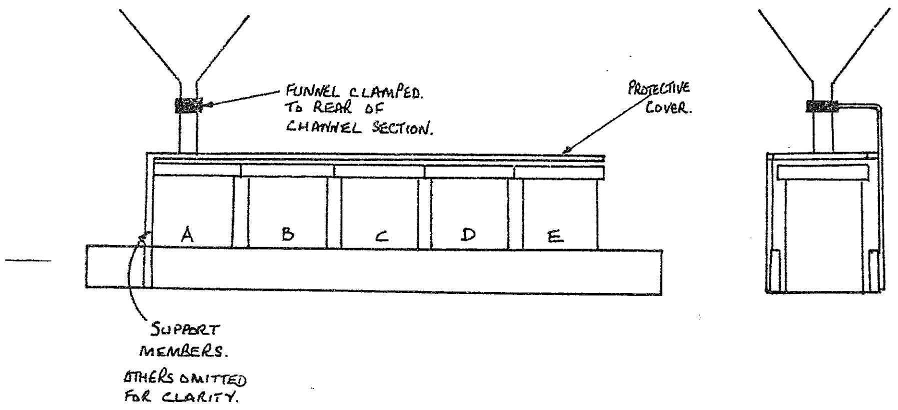

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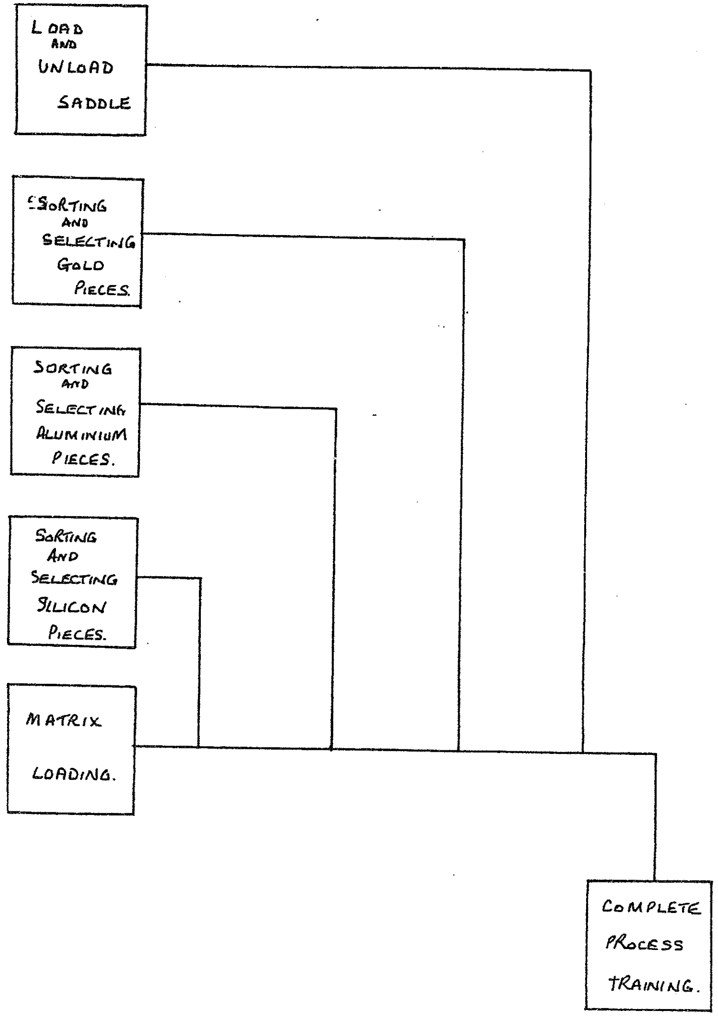
FIG. 13.



TRAINING SCHEME.

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FIG. 14.