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PROCESS DEVELOPMENT FOR AUTOMATED SOLAR CELL AND MODULE PRODUCTION

TASK 4: AUTOMATED ARRAY ASSEMBLY

Final Report

In Reference To:

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Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, California 91103

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PREPARED BY

MBAssociates
Bollinger Canyon Road, San Ramon, California 94583

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TASK 4: AUTOMATED ARRAY ASSEMBLY

Final Report

JPL Contract No. 954882

PREPARED BY: JOHN J. HAGERTY

30 June 1980

The JPL Low-Cost Silicon Solar Array Project is sponsored by the U. S. Department of Energy and forms a part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology by agreement between NASA and DoE.

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PREPARED BY
MBA MBAssociates
Bollinger Canyon Road, San Ramon, California 94583

TABLE OF CONTENTS

Section	Title	Page
1.0	INTRODUCTION	1
2.0	BASELINE PROCESS SEQUENCE DESCRIPTION AND CRITICAL REVIEW	4
2.1	Process Step Descriptions	5
2.1.1	Incoming Inspection	6
2.1.2	Etch, Clean and Dry	8
2.1.3	Diffusion	11
2.1.4	Edge Etch	14
2.1.5	Back Contacting	16
2.1.6	Front Contacting	17
2.1.7	Test and Sort	18
2.1.8	Circuit Fab	20
2.1.9	Pottant Application	23
2.1.10	Panel Layup, Wiring and Testing	26
2.1.11	Encapsulation	31
2.1.12	Trimming and Edge Sealing	33
2.1.13	Edge Sealing and Framing	34
2.1.14	Final Test	38
2.1.15	Packing and Shipping	39
3.0	ECONOMIC ANALYSIS OF BASELINE PROCESS SEQUENCE	40
4.0	VERIFICATION STUDIES OF PROCESS SEQUENCE STEPS	41
4.1	Etch and Clean	41
4.1.1	Damage and Texture Etch	41
4.1.2	Pre-Diffusion Cleaning	42
4.2	Edge Etch	44
4.3	Aluminum Back Contacts and Back Surface Field Formation	45
4.3.1	Background	45
4.3.2	Prior Techniques Utilized in Formation of Aluminum Back Surface Field	46
4.3.3	Mass Production Technology	48
4.4	Edge Sealing and Framing	51
4.4.1	Material Analysis	51
4.4.1.1	Cold Butyl	53
4.4.1.2	Heat Cured	55
4.4.1.3	Conclusion	55
4.4.2	Testing	56

TABLE OF CONTENTS (continued)

Section	Title	Page
5.0	HARDWARE DEVELOPMENT OF AN AUTOMATED LAYUP AND INTERCONNECT SYSTEM PROTOTYPE	61
5.1	Options	61
5.1.1	Bond Methods	62
5.1.1.1	Resistance Heating	62
5.1.1.2	Ultrasonic Bonding	63
5.1.1.3	Laser Bonding	63
5.1.1.4	Induction Heating	64
5.1.2	Metallization Pattern Recognition and Cell Orientation Techniques	64
5.1.3	End Effector Design Criteria	65
5.1.4	Conclusions and Selected System	66
5.2	Hardware Description and Development	68
5.2.1	Mechanical Systems	68
5.2.1.1	Preparation Station	68
5.2.1.1.1	Cassette Unloader	70
5.2.1.1.2	Vacuum Orientation Chuck	70
5.2.1.1.3	Ribbon Feed	72
5.2.1.1.3.1	Drive Rollers	72
5.2.1.1.3.2	Crimp and Cut Mechanism	72
5.2.1.1.3.3	Hold Down	74
5.2.1.1.4	Solder Paste Dispensing	74
5.2.1.1.5	Optical Orientation	79
5.2.1.2	End Effector Development	81
5.2.1.2.1	Resistance Heating End Effector	81
5.2.1.2.2	Induction Heating End Effector	83
5.2.1.2.2.1	Design	83
5.2.1.2.2.2	Testing and Modifications	83
5.2.2	Electrical and Control Systems	87
5.2.2.1	Electronics Package	89
5.2.2.1.1	Mechanical Equipment Interface	89
5.2.2.1.2	Optical Orientation Sensor Interface	91
5.2.2.1.3	Robot Interface	91
5.2.2.2	Computer Program	92
5.3	Operation Sequence	92
5.3.1	Command and Feedback Data Flow	92
5.3.2	Sequence Steps	94
6.0	CONCLUSIONS AND RECOMMENDATIONS	99
	APPENDIX A	
	APPENDIX B	
	APPENDIX C	
	APPENDIX D	
	APPENDIX E	
	APPENDIX F	

LIST OF ILLUSTRATIONS

Figure No.	Title	Page
2-1	Proposed Automated Solar Cell Fabrication Process	5
2-2	Ribbon Fabrication Machine	24
2-3	Ribbon Fabrication Method	25
2-4	Panel Layup Machine	29
2-5	Module Edge Sealing Station	36
2-6	Module Framing Operation	37
4-1	Reflectance From Texturized Surface of 1-0-0 Silicon	43
4-2	Al Paste P+ Back Surface Vs. Control	50
4-3	V_{oc} Loss as a Function of Annular Margin on a 4" Cell	52
4-4	Application of Edge Sealant	59
5-1	Preparation Station and Panel Layup	67
5-2	General View	69
5-3	Vacuum Chuck With Extended Pins	71
5-4	Ribbon Feed and Forming Mechanism	73
5-5	Ribbon Hold Down	75
5-6	Solder Paste Dispensing Bridge	76
5-7	Cell Solder Paste Dispenser	77
5-8	Optical Orientation Sensor	80
5-9	Resistance Heating End Effector	82
5-10	End Effector Coil	84
5-11	End Effector On Robot	85
5-12	TRS-80 Micro Computer	88
5-13	Electronics Package Components	90
5-14	Preparation Station Data Flow	93
5-15	Cell Preparation and Placement Cycle	95

LIST OF TABLES

Table No.	Title	Page
4-1	Edge Sealants	54
4-2	Sealants Tested	58

1.0 INTRODUCTION

The scope of work under this contract involves specifying a process sequence which can be used in conjunction with automated equipment for the mass production of solar cell modules for terrestrial use. This process sequence is then critically analyzed from a technical and economic standpoint to determine the technological readiness of each process step for implementation. The process steps are ranked according to the degree of development effort required and according to their significance to the overall process. Under this contract the steps receiving analysis were: back contact metallization, automated cell array layup/interconnect, and module edge sealing. For automated layup/interconnect both hard automation and programmable automation (using an industrial robot) were studied. The programmable automation system was then selected for actual hardware development.

This work has been done to improve the performance of solar modules and to lower the cost through process development and large scale automation. The guidelines used in this effort has been to work toward a process sequence which will provide a 500 megawatt/year production capacity in the industry by the year 1986. The baseline factory design used within this industry has a capacity for 200 megawatt/year production. The price goal guiding the effort has been to provide photovoltaic power at $.70/watt(1980 dollars) by 1986. These photovoltaic cells must be encapsulated for protection against the environment to allow an operating life of 20 years.

Contact metallization is an area of current (and future) cell production which represents a large percentage of the added cost to a wafer during cell making. Metallization also represents an area which can have an effect upon the useful life of an array through contact corrosion characteristics.

The efforts of ARCO Solar Inc. (ASI) under subcontract to this work have largely been directed at using thick film aluminum in back contact metallization scheme to improve cell performance through back surface field formation, and reduce materials costs. Work was directed at performing this aluminum p+ metallization in an automated fashion using a belt furnace.

Panel edge sealing (though a relatively low cost item) shows some possibilities for cost reduction and improved performance. The improved performance involves a vapor tight seal which can improve the life of the panel by protecting against vapor migration from panel edge to interior, and it can also guard against delamination of the panel assembly at its edges and corners.

Efforts have been directed at finding low cost sealants which could be applied in an automated, high throughput environment. This has led to the development of hot melt sealing techniques for application to the edges of encapsulated solar modules.

Array layup and cell interconnection has been seen to be one of the most labor intensive processes of current production facilities. Efforts with this process have therefore been directed toward short range benefits as well as development of long range technologies. To provide a transferrable technology which would be applicable to various module configurations, programmable automation has been studied and a prototype cell layup and interconnect system has been developed. The system uses a Unimate 2000 B industrial robot and an automated cell preparation station. It was developed as a feasibility demonstration of a process adaptable to industry.

In order to meet the production quantities desired, processes which are currently being used within the photovoltaic cell industry will have to be scaled up. Many process throughput rates are dependent on the number of wafers or cells handled. For example, in a cell layup and interconnect operation, the time to place and interconnect a four-inch diameter cell (one-watt each) is approximately the same as that to place and interconnect a two-inch diameter cell (1/4-watt each). This indicates that a desirable trend from an automation standpoint is to increase the size of cells, thereby reducing the number to be handled. Some process parameter variation is expected when using larger cell sizes, and therefore these variations have been the subject of some study.

Scale-up studies are also necessary in some batch processes due to the variations of process parameters which come about through the use of larger batch sizes. To this end, some of the work performed at ASI has been in the area of higher throughput rates in etching and cleaning operations, diffusion furnace junction formation, and plasma etching for the removal of front-to-back current shunts present after a furnace diffusion.

Economic analysis using the SAMICS system has been performed during these studies to assure that development efforts have been directed towards the ultimate goal of price reduction.

2.0 BASELINE PROCESS SEQUENCE DESCRIPTION AND CRITICAL REVIEW

The following sequence has been proposed for a process with an input of four-inch Czochralski wafers (as sawn) and an output of encapsulated solar arrays. The proposed sequence is shown in Figure 2-1. This production technique is capable of producing 200 megawatts per year (SAMICS baseline company size). A target volume throughput per production line has been set by MBA at 3,000-3,600 cells per hour for the cell manufacturing line, and 88 panels per hour for the module manufacturing line. This dictates a plant working three shifts per day, seven days per week, with six to eight parallel cell lines and one module line.

There is a trade-off in any production line of this nature between batch and continuous process. For some processes where individual processing time is large in comparison to the desired production rates, wafers or materials must be handled in a parallel or batch mode. When processing times are shorter, continuous processes can be used. For the proposed cell fabrication sequence an automated batch process is used in Figure 2-1 to the point in fabrication prior to contact printing. This batch mode is chosen because of the nature of the proven process steps currently being used by the cell manufacturing industry. Contact printing to final panel test and shipment is proposed to be a continuous process because of the nature of the steps involved.

In the proposed process it will be assumed that the wafers are purchased in such quantities that the containers they are received in are factory-specified and factory- or vendor-supplied. This will aid in simple materials input and handling at the start of the line.

Most of the cell making processes have had significant background work performed in the area of manufacturing equipment.

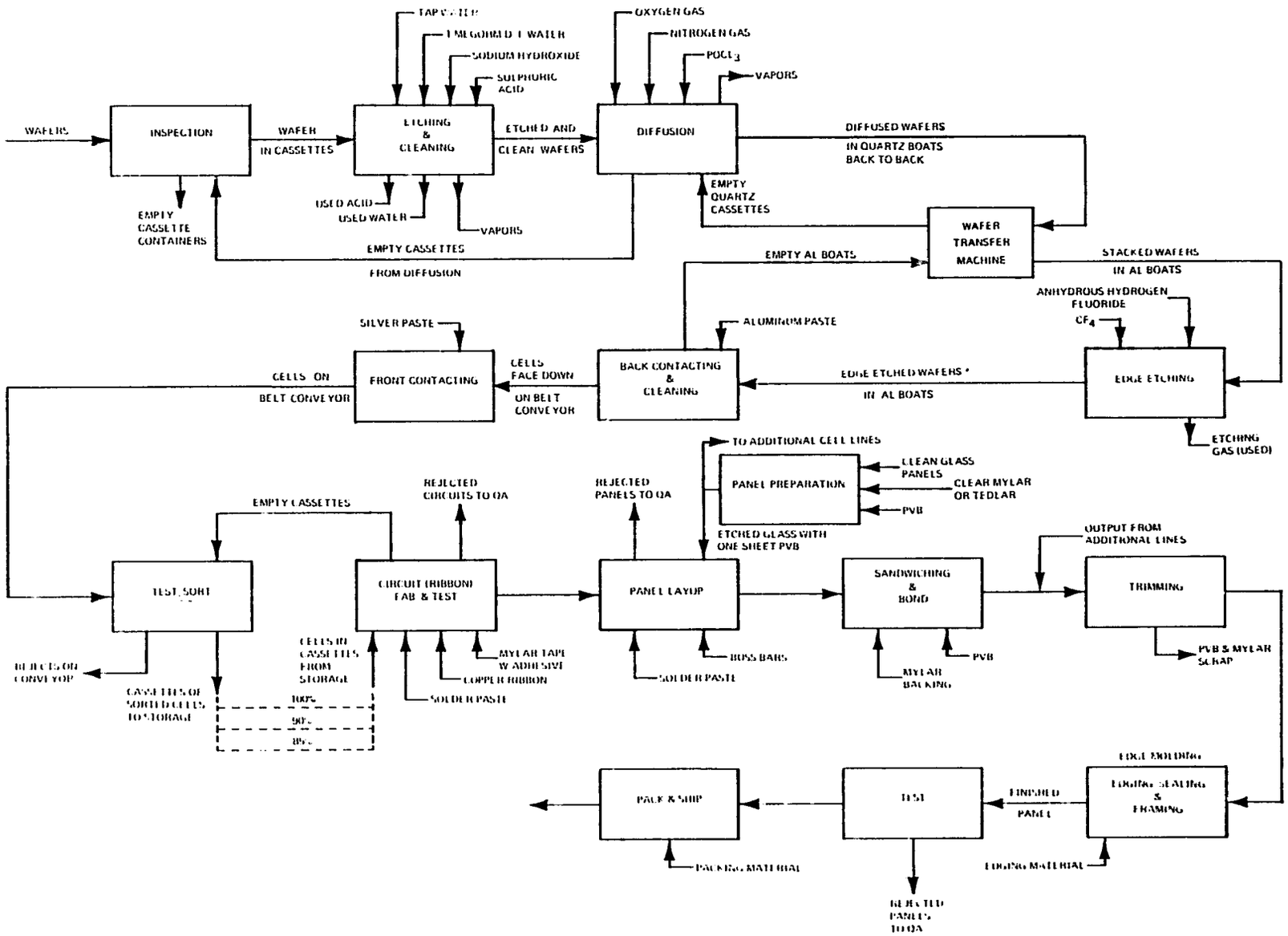


FIGURE 2-1
PROPOSED AUTOMATED SOLAR CELL FABRICATION PROCESS

Some of this comes from a technology transfer from the semiconductor industry. Most of the currently designed and currently available equipment requires scaling and/or modification to reach program goals.

The throughput rates for the semiconductor industry are much lower than that required for solar cell production and therefore special high speed techniques must be found to reach production cost and volume goals.

2.1 Process Step Descriptions

The process sequence will be taken one step at a time with a description given and problems discussed.

2.1.1 Incoming Inspection

Description

To standardize and control wafers which may be received from many vendors, incoming inspection (QA) will measure thickness, resistivity, and wafer shape/diameter. This station will measure the thickness and resistivity of all wafers and will measure wafer diameter on a sample basis.

Operation of this station will be as follows: Prior to measurement, a specially adapted machine will unpackage the wafers and send them via conveyor to the inspection plant. Assuming that the wafers are contained in a special cassette (possible 50 to 100 wafers closely spaced) a handling machine will feed the wafers to the in-line measuring locations where the thickness and resistivity will be determined using non-contacting probes. Thickness will be measured by two capacitive transducers which separately measure distance to the wafer surface. The resistivity measurement employs two special purpose transducers which create, in a wafer inserted into the gap between them, eddy currents whose magnitude depends on the wafers resistivity and thickness. Thickness information is received from the preceding tester. The wafer will probably be in the machine for longer than one second (including wafer handling)

but if the indexing cycle for serial events is one second, a production rate of one per second can be achieved. Testing equipment currently available could be modified and designed to reach this one second cycle time.

Each lot of cells will be characterized by prediction of expected efficiency based on variations in thickness, area, resistivity and diffusion length of the input material. Information from this station will be input for a central processor which will keep track of the data and enable simplified process control.

Input Requirements/Characteristics

- Wafers and incoming carriers.

The incoming wafers are to be in plant supplied and/or specified containers to allow automated handling. Wafers from in-plant slicing stations will be loaded into the specified containers after cutting and purchased wafers will be supplied in large enough numbers to make container specification practical. Empty cassettes will return from the diffusion station where the wafers will be transferred from plastic cassettes to quartz cassettes.

Output Requirements/Characteristics

- Wafers in plastic cassettes on conveyor to etch station.

The outgoing tested wafers are to be in standard 25 slot polypropylene cassettes. Empty receiving containers will be discarded, returned to plant receiving or cutting station, or shipped to wafer suppliers, depending on final specification.

Materials and Supplies Used

- Silicon wafers (four-inch diameter, .015-inch thick).
- Standard 25 slot cassettes.

Equipment Used

- Siltec 2600 series tester/sorter.
- Conveyor to etch station.
- Unpacking machine.

Critical Review

This step is presently performed manually. An operator unloads wafers from shipping containers, visually inspects and loads them into cassettes. At the required 3,000 wafers/hour production rate, such manual operation becomes prohibitive. It has already been assumed that volume purchase of sawn wafers will make it economically feasible for LSA facilities to procure the wafers in ready-to-process cassettes. These cassettes can then be automatically introduced into an off-the-shelf thickness/resistivity inspection station. Technology presently exists which will facilitate the development of a totally automated station to perform all the required incoming inspections.

Critical parameters are size, thickness and resistivity for the material and a 3,000 wafer/hour throughput. Automated technology in general, and the semiconductor industry specifically, will allow the required 3,000 units an hour rate required for incoming inspection procedures. Development of a special high speed machine will be required, but this can be done from proven technology. Thus, no specific verification should be required.

2.1.2 Etch, Clean and Dry

Description

The silicon used for this process sequence is in the form of as sawn Czochralski wafers. This station will etch the saw damaged surfaces from the wafer and then, by means of an automated materials handling system, transfer the wafers to a rinse and then to a texture etch bath. (The texture etch will eliminate the need for AR coating of the cells.) The wafers will then be transferred

to a cleaning and drying station in preparation for diffusion. This process will be performed in a batch mode due to the time required in the etch solutions, with etching and rinsing times regulated by the microprocessor controlled handling system. A system monitoring and controlling conditions in the etch tanks will assure constant etch rates.

Input Requirements/Characteristics

- Inspected wafers in plastic cassettes.

Output Requirements/Characteristics

- Etched wafers in plastic cassettes.

The outgoing wafers will be within specified thickness limits, damaged etched, black texture etched, clean and dry.

Materials and Supplies Used

- Sodium Hydroxide
- De-ionized Water
- City Rinse Water
- Isopropyl Alcohol
- Sulphuric Acid

Equipment Used

- Programmable hoist system such as SEL-REX PCB-2000 from Oxymetal Industries.
- Control system for etching tanks.
- Rinsing tanks.
- Etching tanks.
- Cleaning tanks.
- Basket loading/unloading device.
- Feed conveyor to diffusion.
- Linear blow-drier.

Critical Review

At a production rate of 3,000 wafers/hour this step is not a problem, even though it is a batch process, because the rates are higher than the most limiting step -- diffusion. At present ASI successfully etches 300 four-inch wafers per cycle in twelve cassettes. Current batch size increases indicate that the etching characteristics do not change drastically by increasing the lot size and stacking configuration.

It is anticipated, therefore, that 3,000 four-inch wafers can be etched per hour in essentially the same manner but in larger containers, using automated transfer equipment, larger etch tanks and control systems for monitoring and maintaining temperature, solute concentration and solution level. Computer controlled equipment (similar to what is used in the semiconductor and plating industries) with excellent programming flexibility is available to handle the wafer lot transfer duties, controlling the etch time accurately and automatically. Precise control of the solution properties (pH, temperature) will produce constant etch rates allowing high product reproducibility with the required throughput.

The process could also be handled in a semi-continuous processing mode by using long etch bath tanks and moving quantities of cells down the etch line. Very simple overhead carriers and transfer machanisms could be used to transfer cells from one bath to another at preset times. This type of equipment is readily available and has been used in commercial plating plants.

For those solutions which must be totally replaced after processing a given number of cells, speed of solution mixing and heating to process temperature becomes important. A possible solution to this problem is to include a set of tanks located adjacent to the etching and cleaning line. These tanks would be used for preparing a replacement solution and heating it to process temperature during wafer processing operations on the line. The only time required for replacement

of solutions would be the time required to pump out the old solution and pump in the previously prepared solution from the adjacent tank. Wafer etching operations could then continue with only this small interruption time.

The basic materials handling equipment for this station already exists. Verification should take the form of studies performed concerning etch rates and their dependence on temperature, concentration, agitation and other variables. An optimal control system should be determined including pH monitoring, NaOH addition and concentration selection. This system would be simplified by selection of a concentration such that the value of the derivative

$$d(\text{etch rate})/d(\text{concentration}) = 0$$

A convenient tank size will have to be determined in conjunction with control systems, etch rate, heater capacity, etc., and compatible rinsing techniques need to be established to ensure sufficient cleanliness. A cassette stacking machine will be required to assemble the cassettes coming from inspection into the proper batch configuration if this type of batching is used.

Verification studies of batch size scale-up were performed at ASI. No significant problems were encountered during the transition to etch tanks containing 10 times the volume of solution used previously. While existing capacity is now several mw/year, good results are projected for even larger tanks and higher throughputs.

2.1.3 Diffusion

Description

This station will diffuse batches of wafers to provide a uniform junction on one side of the wafer. The system will minimize the amount of diffusant deposited on the back side of the wafers. In order to do this the station will be designed to load two plastic cassettes worth of wafers (50 wafers) into 25 slots in a quartz cassette for back-to-back diffusion. The quartz boats will automatically be inserted into a diffusion furnace for $POCl_3$ diffusion and

automatically withdrawn at the end of the cycle. The equipment for this chemical vapor deposition reaction is well-developed and very reliable. The systems which are currently available provide automated diffusion atmosphere control as well as automated quartz boat pulling into and out of the furnace tubes. Interface machinery will be required to load the full quartz cassettes into the boat pulling mechanisms. The transfer tasks will be done in the diffusion room so that the quartz cassettes and other items going into the diffusion furnace do not leave the diffusion room. This room has the highest level of cleanliness in the cell fabrication area.

A furnace with multiple eight-inch diffusion tubes (with time, temperature and gas flows optimized) will be required to meet a target of 3,600 cells per hour with a uniform sheet resistance of approximately 40 ohms per square.

An alternative approach to junction formation may be to ion-implant the wafers. It should be noted that this process requires relatively high cost equipment, and equipment to operate at the target volumes requires some development. The diffusion furnace was chosen as a baseline here because of its current availability and performance.

Input Requirements/Characteristics

- Clean etched wafers in plastic cassettes.

Output Requirements/Characteristics

- Diffused wafers in cassettes or on conveyor.

Materials and Supplies Used

- Nitrogen
- Oxygen
- PCl_3 source

Equipment Used

- Automatic cassette dump load/unload transfer machine.
- Two diffusion furnaces with four eight-inch tubes each, automatic boat pullers, and automatic diffusion control.
- Automatic sled loader/unloader.
- Two feed conveyors.

Critical Review

It is proposed to use off-the-shelf type diffusion furnaces with already developed pusher/puller and microprocessor systems. Such a furnace including all safety and production control alarms to handle 3,200 four-inch wafers per hour is available. The major work here will be to adapt the dump transfer equipment and cassette loader and unloader to automatically put the boats in a sled lined up with the furnace tube.

This step is inherently a batch process in each tube and it is planned to use batches as they come from the etching station.

The equipment for this chemical vapor desposition reaction of $POCl_3$ on silicon is well developed and very reliable. ARCO Solar has already performed the initial experiments with diffusion of two wafers per slot back-to-back, and feels this wll be very successful. A minimum amount of diffusion source material will remain in the wafer back.

$POCl_3$ diffusion techniques are well established in the semiconductor industry. ARCO Solar currently diffuses 400 four-inch wafers per run in four tubes. The diffusion system proposed would meet the volume goal.

An important wafer transport function is included in this step. Wafers coming from the etching station must be transferred two to a slot into quartz boats for diffusion. This should be feasible in an automated fashion using a specially designed machine.

Detailed verification studies were not performed on this step as the diffusion is currently being done at close to the single diffusion tube rate. This scale-up therefore does not pose a significant problem. The wafer handling equipment conceived is within the state-of-the-art of manufacturing equipment, but will require special design efforts.

2.1.4 Edge Etch

Description

This station will take the wafers from the diffusion station in plastic cassettes and coin stack them in preparation for plasma etching of the edges. This will eliminate the front-to-back contact formed during diffusion. The wafer stacking and loading/unloading of the reactor will be mechanized and control of the process will be automatic. The etching cycle should last approximately 15-20 minutes, depending upon the batch size.

This process step can also be performed after front and back metallization processes have been completed. Edge etching in this manner only affects the edges themselves. One advantage to performing this process in this sequence is to keep all of the batch processes in one zone, and then process continuously thereafter.

Input Requirements/Characteristics

- Diffused wafers.

Output Requirements/Characteristics

- Edge etched wafers on a conveyor.

Materials and Supplies Used

- CF_4
- O_2

Equipment Used

- Etching chamber with automatic load/unload.
- Vacuum pump for etching chamber.
- Wafer stacking equipment.
- Process programmer.
- In-feed, out-feed conveyor.

Critical Review

Plasma etching is new, but ARCO Solar has had parts etched by three different manufacturers of such equipment, LFE, International Plasma Corporation and Tegal Corporation and had good results. It does work, but the current machines are small and have been optimized for use in manufacturing IC's and other fine electronic devices. We feel this process will significantly help LSA achieve its goal of $0.70 per watt (1980 dollars) selling price. The etching rates and throughput of upgraded machines can handle the required 3,000 - 3,600 wafers per hour without problem.

ARCO Solar is currently using this technique in production with excellent results. Plasma etch equipment developed for the semiconductor industry has been applied to batches of 100 four-inch wafers. The desired rate of 3,000 - 3,600 wafers per hour would, therefore, require eight such tubes assuming a 15-minute cycle.

The equipment used in low-temperature plasma processing is reliable and accomodates a high degree of automation. Special plasma etch equipment may become available from manufacturers for this large volume application. The basic principles involved do not constrain system geometry to the small sizes presently available. Larger and an overall reduction of equipment cost.

2.1.5 Back Contacting

Description

This station will receive diffused and edge etched wafers on a conveyor, feed them into an automatic screen printer, and print aluminum ink on the back. The wafers will then be dried and fired for back surface field formation. The aluminum which has not alloyed with the silicon will then be etched from the wafer using hydrochloric acid. The wafers are then rinsed and dried and sent on by conveyor to a printer which prints a gridded silver contact on the back.

Input Requirements/Characteristics

- Edge etched wafers on a conveyor.

Output Requirements/Characteristics

- Silver printed wafers on a conveyor (with aluminum back surface field).

Material and Supplies Used

- Aluminum Paste
- Silver Paste
- Hydrochloric Acid
- Rinse Water

Equipment Used

- Automatic screen printer.
- Drying and firing furnace.
- Etch tanks.
- Input and output conveyors.

Critical Review

Silkscreen-printed aluminum paste works quite well for back contact metallization. When fired, the aluminum paste fuses with silicon to form a low resistance back contact layer. Cell performance can be enhanced by the formation of a back surface field. Aluminum paste is very inexpensive and silkscreening is a proven, high volume, low cost method for applying such paste.

ASI currently prints aluminum paste back contacts on four-inch wafers at a rate of 500 per hour using a manually loaded printer. An industry survey has been conducted, and automatic printers are available which are capable of meeting the 3,000-3,600 four-inch wafer per hour goal. Therefore no printing demonstration has been performed. It has been found that etching off the aluminum back contact and applying a silver contact allows uniform interconnect metal systems and techniques. The extra cost for the silver is not as high as a solid back contact, as a gridded silver pattern can be used. This is due to the low resistance created by the alloyed aluminum. Back surface field formation depends on proper drying relationships. Verification work which was done on this process is detailed in Section 4.0.

2.1.6 Front Contacting

Description

This station will receive wafers on a conveyor from the back contact station. It will etch the oxide from the front of the cell which has purposely been left on through the back contact step. It will print the front contact on the cell, dry the print, and fire the cell (front and back silver contacts) under the proper conditions for the front contact optimization. Following this step the cells will be transferred to test and sort.

Input Requirements/Characteristics

- Wafers face down on a conveyor.

Output Requirements/Characteristics

- Completed cells on a conveyor.

Materials and Supplies Used

- Silver Paste
- Silk Screens
- CF_4
- O_2

Equipment Used

- Automatic loader for printer.
- Automatic screen printing machine.
- Drying and firing furnace.
- Cell flipping mechanism.
- Input/output conveyors.

Critical Review

The front surface oxide (glass layers) deposited during diffusion is left on up to this point to protect the front junction. This layer is etched away in a Dryox-etcher with a cycle time of approximately 15 minutes. Printing, drying and firing equipment is similar to that used in back contacting and available for high speed throughout. No problems are foreseen with this step.

It appears feasible to perform the necessary printing, drying and firing for this step at the desired rates using specially designed equipment.

2.1.7 Test and Sort

Description

This step is for quality control and process monitoring. The station receives the finished cells with exposed ohmic contact pads, ready for lead bonding.

The station will isolate each cell and individually measure its performance. Based on performance the cell is sorted by class or rejected. Each class is separated, marked and loaded into a "class" cassette. This data is reported through the central process controller to provide process parameter adjustments.

The cells, after they are sorted into relative efficiency classes, can be put into buffer storage. This allows enough cells of the same performance ratings to be accumulated so that they can be put into the same module. This is required to gain maximum efficiency from each module system. The buffer storage is inherently a batch process since the cells are accumulated into a sorted batch.

It is expected that after the production system has been experimented with in a high volume production environment, that overall process control will yield more uniform results. This is a desirable feature to seek in order to remove the requirement for a batch storage. In this case, the test station would merely be an accept/reject decision station as far as the mechanics of the product flow are concerned.

The output of this station is therefore working solar cells, and these could be either packaged for shipment to a module manufacturing company, or they could be input directly to a cell encapsulating line located within the same facility.

Input Requirements/Characteristics

- Completed cells on a conveyor.

Output Requirements/Characteristics

- Sorted and tested cells in cassettes.

Materials and Supplies Used

- Containers for classified cells.

Equipment Used

- Test and sort station.

Critical Review

This step possess few problems for meeting the throughput of 3,000-3,600/hour. Testing equipment is currently available for this station, it remains to interface with a sorting mechanism. Cell orientation should not be a problem as the probes can be designed to contact the metallization on the front regardless of orientation and the back contact is totally symetrical. Contacts must be exposed and cell handling will be fully automatic.

This process is presently used for essentially the same application, but on a smaller scale. Current methods of wafer handling and cassette loading need to be speeded up and automatic cassette feed and release developed. Currently existing equipment should be surveyed and existing designs selected which best lend themselves to rate increase. System/equipment specification and detailed conceptual designs should be developed for automatic loading and unloading of several cassettes within the machinery.

2.1.8 Circuit Fab

Description

There are a few viable techniques which can be used to connect cells into an array in an automated fashion. These basically break into two groups, hard automation and soft automation. There are distinct advantages to either group. The soft automation (or programmable automation) techniques allow a variability in the manufacturing environment. The concept is to use a programmable handling device (industrial robot) with specially designed tooling (end effectors) to handle, place and interconnect cells. Using this technique, different models of a module can be easily accommodated with the same piece of manufacturing equipment. This type of handling is also applicable to various cell types, sizes, shapes and manufacturers.

The hard automation techniques consist of providing a piece of handling and processing equipment specifically designed and dedicated to a limited task. This type of equipment is generally much faster, and can therefore reduce production and equipment costs, however, it lacks the variability of application available with the soft approach.

A programmable assembly station should accept standard poly cassettes of randomly oriented cells, unload the cells and rotate them to a standard orientation. It should also prepare the interconnect leads by cutting them to length from roll storage and forming a stress-relief crimp in the correct place in the lead. The industrial robot can then take this indexed and prepared cell and place it anywhere at any orientation in an array of variable configuration. Having all of the orientation and preparation machinery in a fixed station this way reduces the weight and complexity of the robot's "end effector" which requires only pickup and interconnect devices.

The soft automation technique is slower than the dedicated machinery approach and would probably require several parallel stations to reach the desired throughput rates.

This type of preparation station has been selected for actual hardware development and is discussed in detail in Section 5.0.

Concepts for a high speed hard automation station consist of two stage operations wherein a ribbon of series connected cells is manufactured, and at a later process, these ribbons are laid in place in a modular array and connected in parallel. The following description is for the first step of ribbon manufacture.

The station will produce a series-connected ribbon of photocells consisting of a continuous, non-conductive, dimensionally stable carrier tape under the cells and two parallel lead wires between the cells. This method of interconnection was chosen for three reasons:

1) Redundancy of contact points and leads.

2) Ease of handling downstream.

3) Ease of automation at the panel layup step.

By omitting one cell and snipping the tape, leads are provided to connect to a buss bar at the panel wiring station.

Input Requirements/Characteristics

- Test and sorted cells in cassettes

Output Requirements/Characteristics

- Ribbons of series connected cells.

Materials and Supplies Used

- Mylar tape 1-1/2" x .001" with acrylic adhesive.
- Copper ribbon .002" x .080".
- Solder paste.

Equipment Used

- Ribbon circuit fabrication machine.

This piece of equipment must be a specially designed piece of equipment. This will allow the high speed operations necessary to meet goals.

Critical Review

The pacing operating for this process is forming bonds between the cells' contact points and the load wire. While many forms of bonding are used in the semiconductor industry, ASI and MBA feel the solder-paste method currently used by ASI should be used in this process. This method is the most reliable found to date. While other bonding methods (ultrasonic, welding, etc.) are faster and eliminate solder paste dispensing, they are not as reliable. The automatic cell unload device will be an off-the-shelf automatic wafer unloader.

An infeed conveyor is incorporated into the station and allows the cell to be oriented if required. This can be done using a pattern recognition technique that searches for a reference point in the metallization pattern. This orientation station provides a convenient station for application of solder paste to junction points. Making the conveyor narrower than the cell allows application to both the top and bottom junction points simultaneously. It also provides a method of positioning the cell under the soldering heads prior to the automatic cell transfer device. Lead wires (or flat copper ribbon) will be fed from large rolls. Two wires will be fed simultaneously into position between the cell and the soldering tips. Sketches of these concepts are shown in Figures 2-2 and 2-3.

As no similar process or handling equipment exists for this process step, detailed concepts must be developed and detailed design specifications defined. No detailed verification of this hard automation process has been undertaken by MBA.

2.1.9 Pottant Application

Description

This station will receive clean, dry glass panels and prepare the module by laying a sheet of pottant (PVB or EVA) on the top surface. This appears to be a straight-forward operation and no technical problems are foreseen in its implementation.

Input Requirements/Characteristics

- Clean dry glass panels (consistent orientation).
- Pottant in sheets or on a roll (PVB or EVA).

Output Requirements/Characteristics

- Glass panel and pottant on a conveyor.

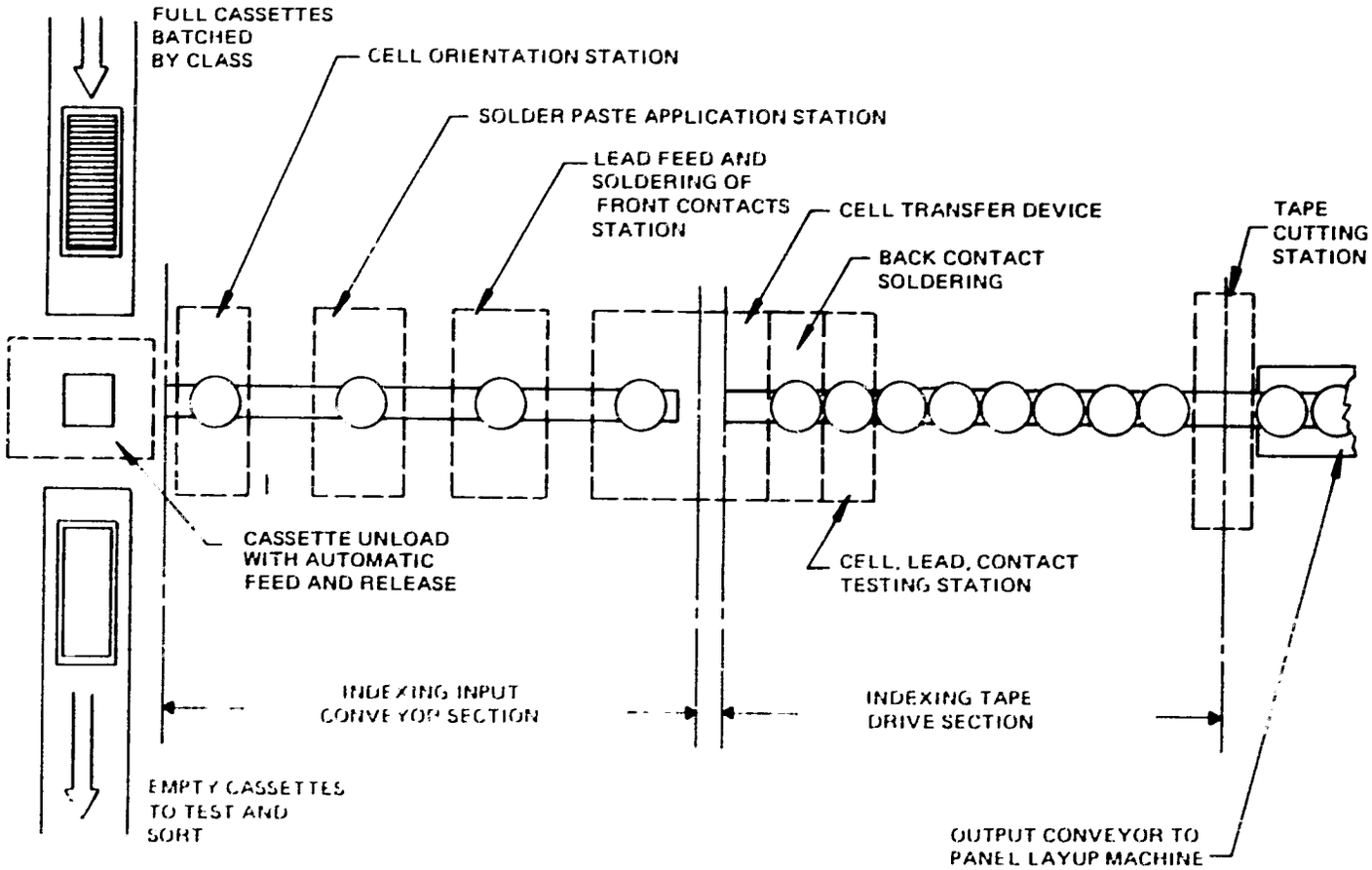


FIGURE 2-2
RIBBON FABRICATION MACHINE

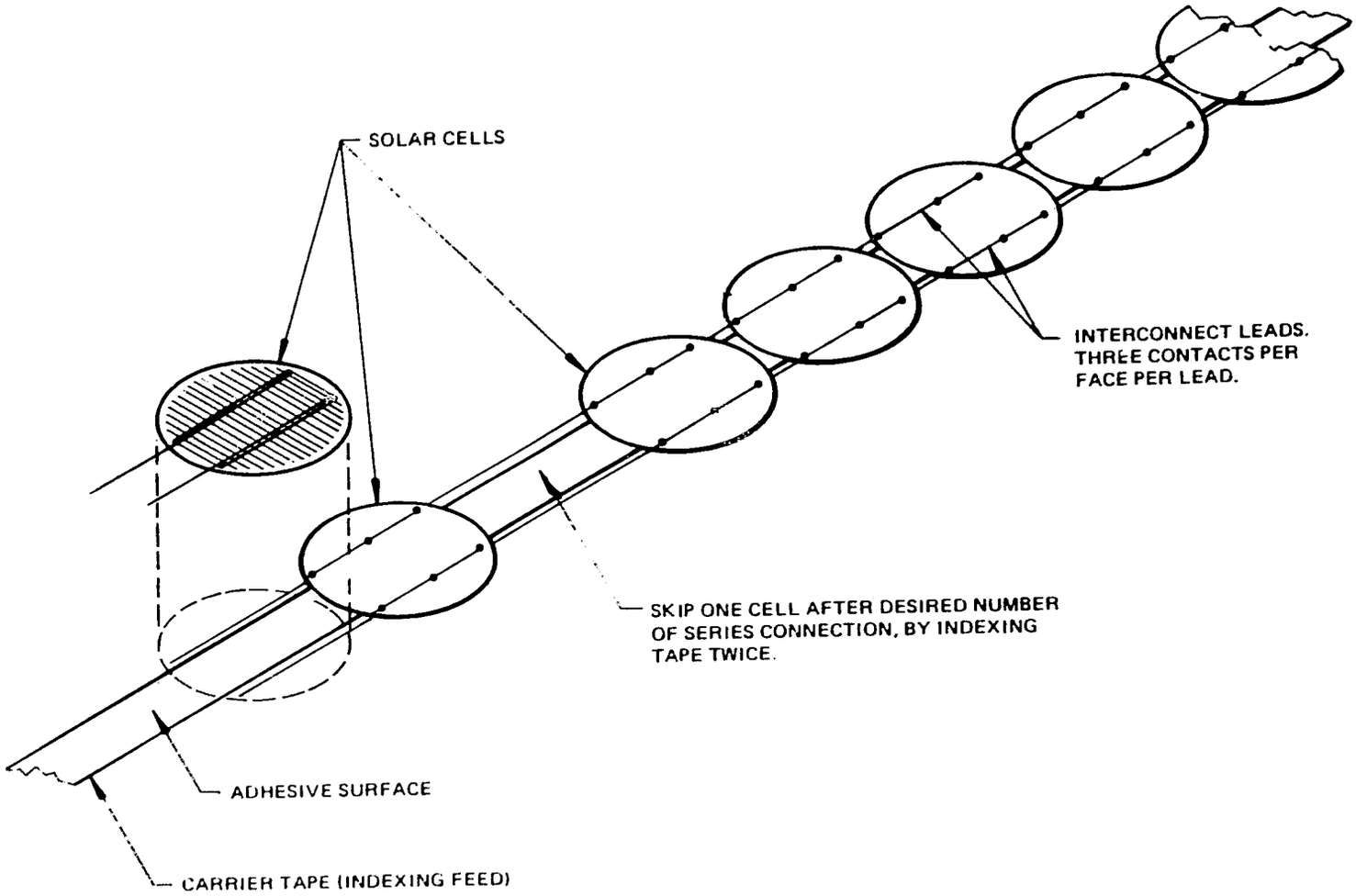


FIGURE 2-3
RIBBON FABRICATION METHOD

Materials and Supplies Used

- PVB or EVA on rolls or precut sheets.
- Glass panels.

Equipment Used

- One panel preparation machine designed and built for this task.

Critical Review

At a production rate of 3,000 - 3,600 four-inch cells per hour and a glass usage of approximately 16 square inches per cell, approximately 375 square feet of glass will be processed per hour.

To receive, depalletize and clean 1/8-inch thick, 48-inch wide panels at this rate will require automation currently used in industry. It is possible that doubling the rate and operating only half-time may be the most cost-effective manner in which to treat this process.

ASI has shown that by etching the front surface of the glass, reflectivity can be reduced by three-percent, thereby increasing panel efficiency. This process can easily be done at a rate far in excess of that required by one cell production line.

This step consists of only a familiar material-handling concept which is currently utilized throughout several other industries. Therefore, detailed verification experiments were not performed in this effort.

2.1.10 Panel Layup, Wiring and Testing

This station accepts pre-wired circuit ribbons and buss bars, assembles them on the front glass panel and completes the circuit wiring.

It will be built up around an indexing belt which moves each panel stepwise to a specific point where each assembly or test operation is affected. Many automated manufacturing processes employ

this technique, so its implementation should pose no inherent problems. The major assembly operation (buss bars and circuit ribbons) occurs at the first stop, and since these items (particularly the ribbons) must be positioned fairly accurately, a holding fixture for the panel will be required. This fixture could be a set of movable stops which align and hold the panel during the assembly operation and then automatically release at its completion.

The buss bars will be transferred via an infeed conveyor and positioned on the panel by a vacuum-pickup on a walking beam transfer conveyor. The simplest setup would have the buss bar conveyor perpendicular to the main indexing belt and wide enough to deliver buss bars, two at a time, to either end of the panel. The transfer conveyor would be required to move the buss bars in only one direction; rotation or multi-axis motions would not be required. If the panels are sufficiently long, it would be cost effective to split this procedure, that is, provide a pair of infeed conveyors and transfer conveyors for each end of the panel.

The circuit ribbon infeed conveyor will run parallel to the main indexing belt with the ribbons aligned in the direction of motion. The ribbons will arrive oriented parallel to their final location on the panel so that they can be transferred to the panel without rotating them. This conveyor need only be wide enough to carry a single row of ribbons since there will be sufficient time, while one is being transferred, to bring up the next. The ribbon transfer machine will be more complicated and accurate than the buss bar transfer machine. It must index laterally so that each ribbon is positioned directly adjacent to the previous one. If the cells are circular instead of square, the transfer machine will also be required to index longitudinally to provide optimum packing of the circular cells on the panel. The most critical positioning tolerances will be between the ribbons, hence the inherent indexing accuracy of the ribbon transfer machine is more important than the positioning relative to the panel. The ribbon infeed conveyor/transfer machine setup will be located opposite the main indexing belt from the buss bar transfer machine so that both processes can make use of the same holding fixture.

Circuit ribbon leads will be bonded to the buss bars using the same solder-paste technique employed to bond the leads to the cells. For panels of the size currently envisioned, the lead bonding machine could easity solder all of the leads at the same time by providing a set of soldering heads (one for each lead) for both ends of the panel. The individual soldering heads would have to be large enough to compensate for lateral variations in lead positions from panel to panel. A simplier but more wasteful method would be to solder a continuous strip down the entire length of the buss bar. Lead bonding could also be accomplished using a single row of soldering heads, but this would require indexing each panel two times, (once for each buss bar).

Lead to buss bar bonds will be tested for electrical conductivity by the automatic bond test machine. A set of probes will be placed across each bond, a voltage will be applied and the resulting current measured. The current will be checked at operational levels to prevent false indications. Present estimates indicate that there would be sufficient time to test each bond separately by indexing the test probes form one lead to the next. If this does not prove to be the case, multiple test sets could be incorporated with a minimal increase in complexity.

An engineering sketch of this concept is shown in Figure 2-4.

Other techniques are available for panel layup and interconnect. Another technique which shows some promise is to lay up the cells into an array possibly in an interconnect fixture. This would allow the cells to be laid up in conjunction with array interconnect pieces. The connections between elements could then be made all at once, possibly in a solder reflow arrangement with atmospheric control. This could reduce electrical connection time by doing them all simultaneously. However, it should be noted that cell and interconnect positioning time may be larger due to the larger distances which must be traversed by an automated positioning tool.

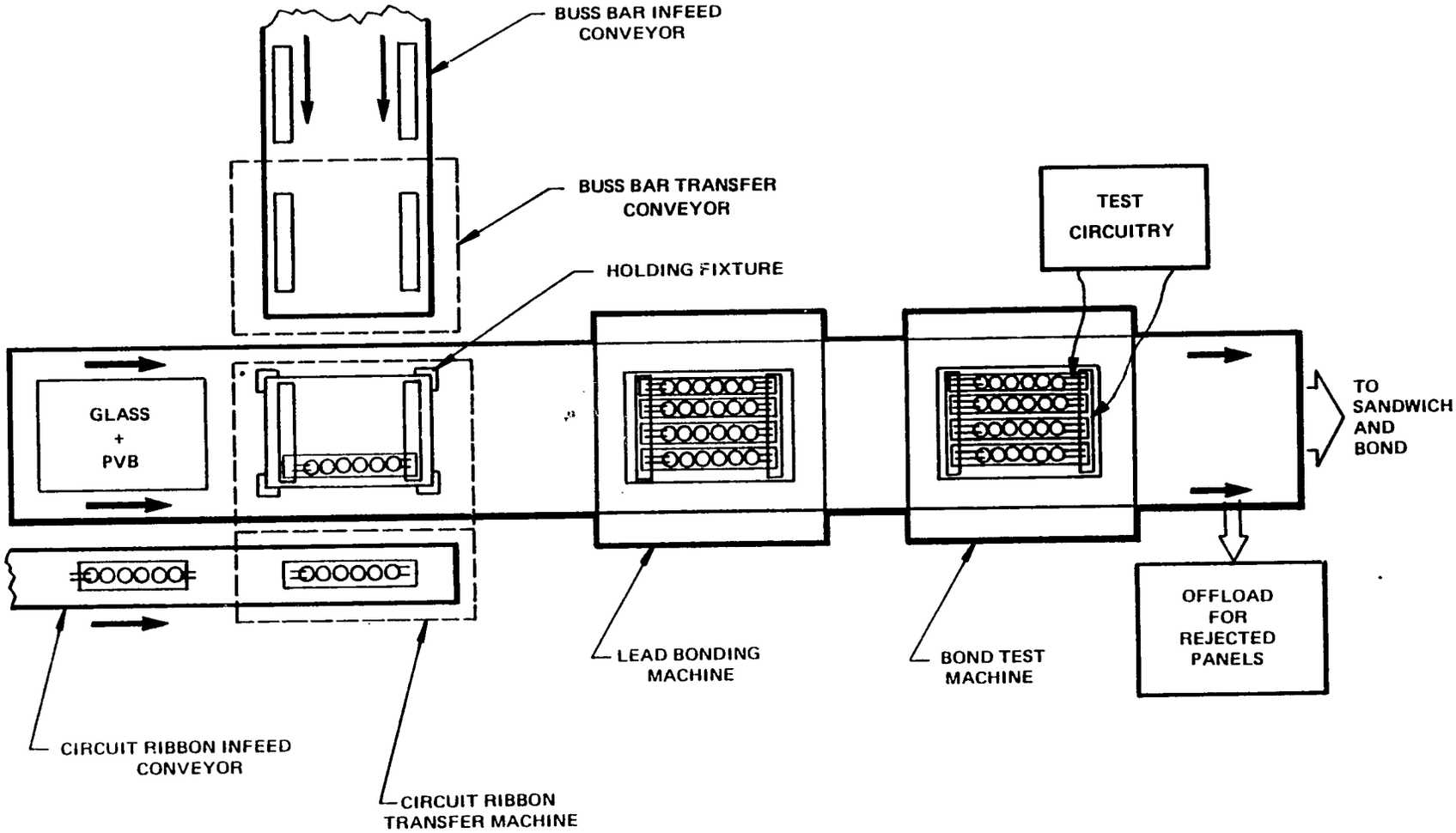


FIGURE 2-4
PANEL LAYUP MACHINE

Input Requirements/Characteristics

- Glass panels with pottant on conveyor.
- Solar cell circuit ribbons.

Output Requirements/Characteristics

- Subassemblies prepared for final encapsulation process. (This consists of a tested and operating module).
- Rejected panels removed from process.

Materials and Supplies Used

- Glass panels with pottant.
- Series connected ribbons of solar cells.
- Copper buss bars.
- Solder paste in bulk containers/tubes.

Equipment Used

- Specially designed handling and soldering machine.
- Indexing belt.
- Test station.

Critical Review

Although no equipment presently exists for the automated performance of this step, the soldering technique is similar to that of a ribbon fabrication step. In addition, this step requires a relatively simple x-y ribbon-handling assembly.

Panel layup and cell interconnect processes have had the least amount of work directed to them. This is because wafer handling and processing has been studied in the past for other semiconductor applications. Continued work and design is needed in this area in order to meet LSA goals.

2.1.11 Encapsulation

Description

Encapsulation process techniques vary according to the encapsulating system used. Many types of encapsulating materials are feasible, being traded off by performance and cost features. For the purposes of the process sequence and step descriptions, the encapsulating system chosen is a glass superstrate with a pottant of polyvinyl buturayl (PVB) or ethylene vinyl acetate (EVA). A protective plastic back cover of mylar or tedlar is added. This process station would receive interconnected panels, laying on a glass superstrate, transported to this station on a conveyor. The process step here would include adding sheets of PVB and protective plastic preparatory to bonding the panel elements together.

The bond is made by heating the sandwich to approximately 350°F while pulling a moderate vacuum on the system to eliminate trapped air. The heating and vacuum application require a relatively long time, so to reach a target production rate of 190 panels per hour, special measures must be taken. This may involve a carousel arrangement where the panels are in the encapsulating machine for a longer period, but the input-output rate matches the 190 panels per hour. Another technique is to do the bonding in a batch mode, heating and pulling a vacuum on several panels simultaneously. This technique requires a buffer storage for panels coming from the layup and test phase and generally increases the process complexity.

Using the carousel arrangement, the module assembly is transferred to the equipment which has receptacles arrayed radially around a common center, and the carousel rotates slowly while the processing progresses. An incoming panel is placed in one of the receptacles, which is simply a depression in the surface, slightly larger and deeper than the panel. A cover plate is pressed over the receptacle, capturing the perimeter of the plastic sheet between itself and the upper surface of the receptacle. A vacuum is pulled through a port in the cover plate,

pulling the plastic sheet firmly against the plate. A vacuum is then pulled through a port in the bottom of the receptacle, which evacuates the air in the panel assembly. The port in the cover plate is vented to atmosphere while the vacuum to the port in the receptacle is maintained. The protective plastic sheet is thus draped over the entire back surface of the panel, sandwiching all the layers (glass, pottant, cell array, pottant, protective plastic) and eliminating air bubbles. The receptacle is heated to 350°F, causing the two layers of PVB to soften and flow to fill the gaps and voids between the glass, cell, and plastic sheet layers and bond them. After the bonding process is completed, heating is stopped, the vacuum is released and the cover plate is pulled away from the receptacle surface. At this point the rotating table has completed one full cycle and the panel is removed and passed on to the next processing station.

Input Requirements/Characteristics

- Partially fabricated solar panel, with entire array properly oriented and electrically connected.

Output Requirements/Characteristics

- Panels with protective back cover installed.
- All internal components bonded into a rigid, self contained unit. Entire unit ready for trimming process.

Materials and Supplies Used

- PVB or EVA on rolls or in sheets.
- Protective plastic sheeting on rolls for back of panel (Mylar or Tedlar).
- Size of rolls to be determined by panel dimensions.

Equipment Used

- Pottant cutoff/transfer machine.
- Protective plastic cutoff/transfer machine.
- Vacuum/thermal bonding machine (specifically designed for this process).
- Conveyor and positioning assemblies as required.

Critical Review

This process is presently used on a smaller scale in the present production of solar modules. Up-scaling and automation design should be undertaken in order to verify volume throughput rates desired.

This verification of high speed techniques was not undertaken as part of this work.

2.1.12 Trimming and Edge Sealing

Description

This step receives panels from the encapsulation step and trims any flash remaining from the encapsulant system. Trimming is required to prepare the edge surfaces for application of an edge sealant and/or a framing element. Attaining process speeds for trimming to reach the target of 190 panels/hour does not appear difficult, however, no off-the-shelf equipment has been found.

A specially designed machine will accept panels from the encapsulation step off a conveyor and trim any flash remaining with a flying knife. It will then deposit the panel on an output conveyor. The only critical parameter would be that the panels in a given run be of consistent size.

Trimming may not be required when the encapsulation process is automated and uniform results provided. The plastic backing was supplied in a larger than module size in order for it

to act as a vacuum membrane. Special design of the encapsulating equipment could possibly eliminate this requirement.

Input Requirements/Characteristics

- Completed module as outputed from the encapsulating machine.

Output Requirements/Characteristics

- A trimmed panel with no flash ready for framing.

Materials and Supplies Used

- None.

Equipment Used

- One panel trimming machine.

Critical Review

MBA can see no technical problems associated with automating this task. Several nearly-identical processes are cur rently being utilized by various industries which will require only slight modification and up-scaling of the basic design concept. Verification demonstrations of trimming were not undertaken during this work.

2.1.13 Edge Sealing and Framing

Description

Edge seal is required to prevent moisture intrusion into the panel from the edge, as well as to prevent panel delamination at the edges. Edge sealing also could be used as an edge support depending upon the characteristics of sealant used. Edge sealing is especially important when used in conjunction with the baseline encapsulating system proposed here, as the pottants are moisture sensitive.

Edge sealing studies point toward the possible use of a hot melt adhesive application system. Several different types of sealants are available with varying properties, one of the most promising being a butyl sealant which is currently being used for thermopane window glass insulating systems. An advantage of melted sealant application is the short cure time required for the applied sealant bead. This appears to be on the order of 5 to 10 seconds, depending upon the material used. This type of application system also interfaces well with an automated production system as has been demonstrated by numerous can labeling, box gluing, and other packaging techniques being used in industry.

At this station, the encapsulated module comes down a conveyor and the leading edge triggers extrusion of a bead of hot melt adhesive onto the edge of the panel as it passes. Before the adhesive cures, the frames are applied. If edge frames are not required on the panels, the station will merely seal the edges. Figures 2-5 and 2-6 show an artist's conception of the process station.

Input Requirements/Characteristics

- Bonded solar cell modules.

Output Requirements/Characteristics

- Solar modules bonded and framed ready for final test.

Materials and Supplies Used

- Bulk form hot melt adhesive.
- Edge frames fed in with proper orientation.

Equipment Used

- Two hot melt extrusion machines.
- Frame hopper/application machine.
- Incoming conveyor.
- Outgoing conveyor.

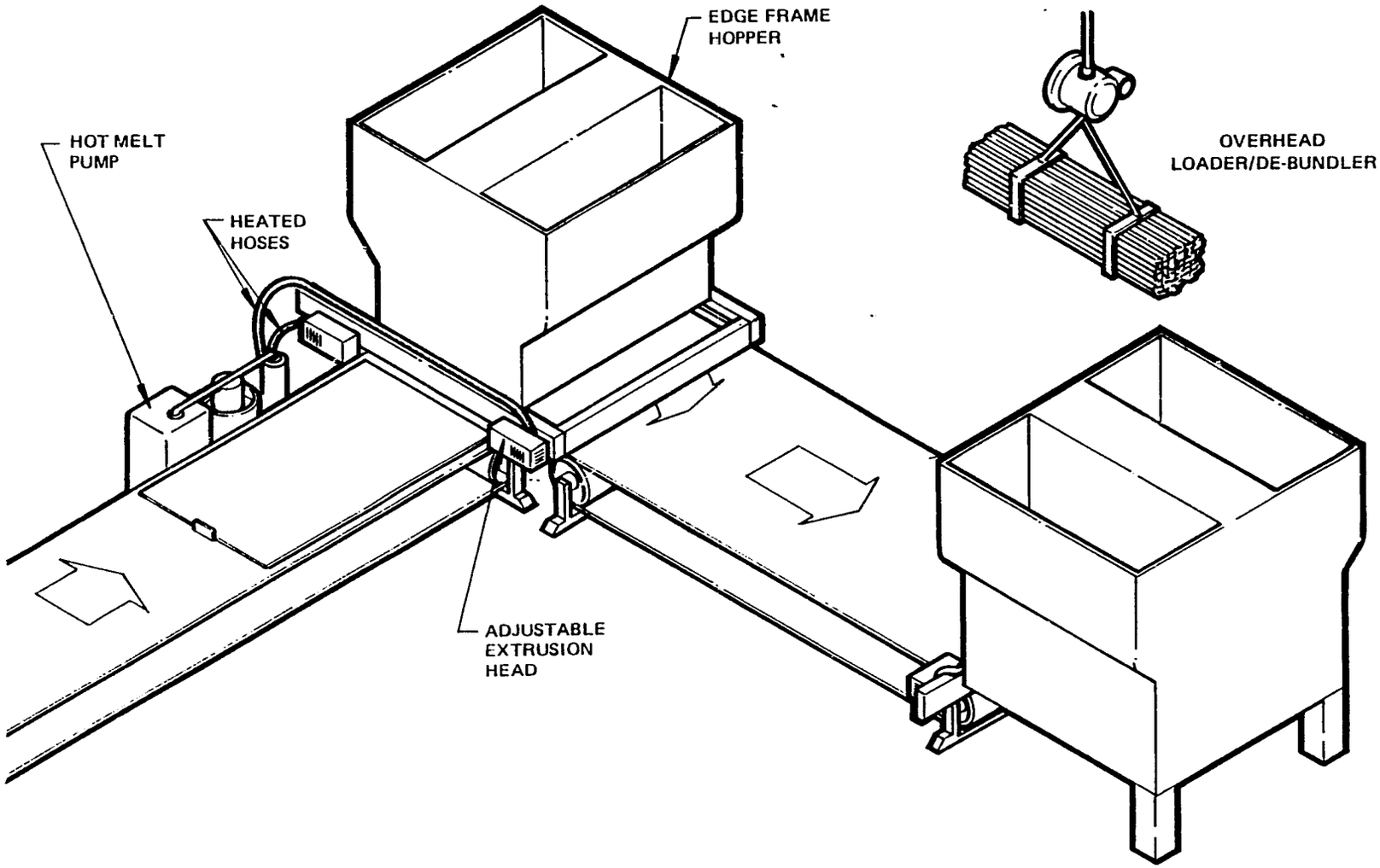
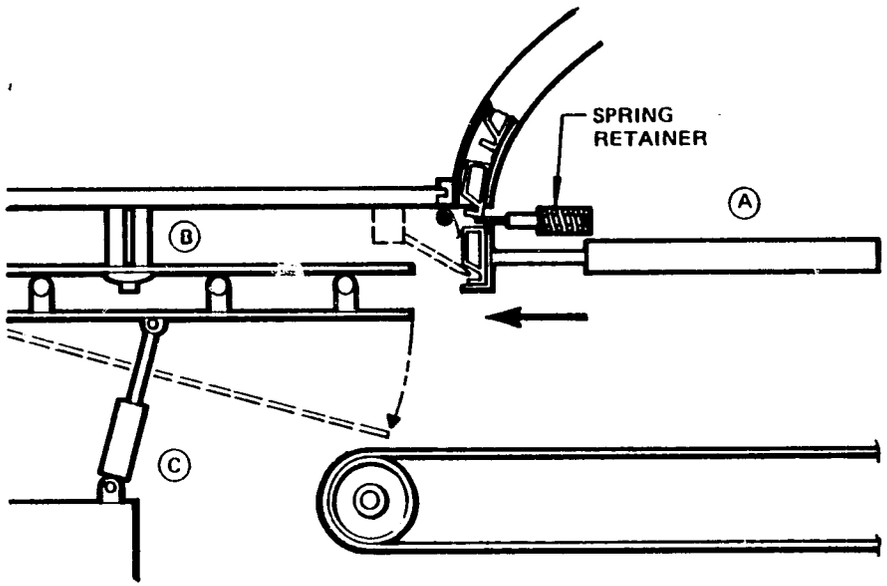


FIGURE 2-5
MODULE EDGE SEALING STATION



(A) PNEUMATIC RAM KEYED TO LOCATION OF EXTRUSION HEAD, INITIATED BY TRAVELING BEAM.

(B) TRAVELING BEAM WITH SUCTION GRIP POSITIONS PANEL (EXTRUSION HEAD POSSIBLY MOUNTED HERE TO APPLY ADHESIVE TO FRAME).

(C) PNEUMATIC RAM KEYED BY RETRACTION OF FRAME POSITIONING RAM LOWERS TABLE, ALLOWING THE PANEL TO SLIDE ONTO THE NEXT CONVEYOR.

FIGURE 2-6
MODULE FRAMING OPERATION

Critical Review

This step should be well suited for automation. Sealant types and properties for use must be determined prior to equipment design. An analysis of available sealants was done under this contract. Conclusions are given in Section 4.4.

2.1.14 Final Test

Description

With the module encapsulated and framed, it must have a final test to ensure its readiness for shipment. The timing is not too critical, as there are 19 seconds allocated per panel for test. A pulsed solar simulator should be used, and a performance label can be made and applied at this process station. The final performance data should be input into the central processing system to keep process controls updated.

Input Requirements/Characteristics

- Completed panels on a conveyor with contact points uncovered.

Output Requirements/Characteristics

- Tested and classified panels.

Materials and Supplied Used

- None

Equipment Used

- Solar simulator.
- Label printing and attachment machine.

Critical Review

This common process is presently utilized in the same application and will require little, if any, modification. No problems are anticipated in automating the existing procedure. Off-the-shelf components can be assembled for module handling and testing.

2.1.15 Packing and Shipping

Description

This step should be made as simple as possible to reduce time and materials. When optimizing final panel size and shape and panel edging and framing, the impact at this step must be considered. A special arrangement of materials handling equipment will be used to palletize the modules.

Input Requirements/Characteristics

- Finished, tested modules.

Output Requirements/Characteristics

- Packaged modules ready for shipping.

Materials and Supplies Used

- Packing crates and materials.

Equipment Used

- Crate wrapping, sealing machine.
- Conveyors.

Critical Review

Packaging does not pose too many problems, as long as the system handles the glass panels properly. Considerations for packaging and shipping should be taken into account when designing framing. The modules should probably be palletized, possibly with the same packing that the input glass comes in.

This is a common material-handling situation encountered and successfully accomplished in all manufacturing situations, and requires no verification.

3.0 ECONOMIC ANALYSIS OF BASELINE PROCESS SEQUENCE

The baseline process sequence has been modeled using the Solar Array Manufacturing Industry Costing Standard (SAMICS).

The SAMIS system takes all the process parameters and determines a selling price by modeling all direct and indirect costs, as well as modeling profits. Details of each process with associated direct and indirect requirements and costs are given.

The process sequence was modeled within a projected 1986 industry. Two companies were formed: CELLCO, which manufactures cells from as-sawn Czochralski wafers, and MODULECO, which manufactures solar modules which have been encapsulated and framed.

Initial industry simulations resulted in a production volume of 200 Mw/Yr at a 1986 selling price of $.82/watt (1980 dollars). Further simulations were performed with continual improvements being made to the processes. The most recent simulation (which is more accurate than previous simulations with respect to commodities used) provides a production of 500 Mw/Yr of completed modules which are 4-feet by 8-feet using cells which are 12.3% efficient. They are produced at a 1986 selling price of $.74/watt (1980 dollars).

This run was done in early 1979 using the then-current SAMICS mod; the output from this run is presented in Appendix A. However, there have been several SAMICS updates since this run was made making it somewhat dated (e.g. results are presented in 1975 dollars).

For this reason, the Format A, B and C data for the simulation are included in the Appendix. Should a more current simulation be desired (to take advantage of current SAMICS mods, updated database, etc.) one can be done using these data.

No SAMICS simulation was performed for an industry using programmable automation. However, data on a programmable automation process are presented in Format A form in Appendix B. These data are based on the prototype system developed by MBA under this contract. The system itself is described in Section 5.0.

This process (called ROBOTBOND) can be run either stand-alone or as part of the whole industry. When used as the latter, it replaces both the processes CELLAY and LAYUP.

4.0 VERIFICATION STUDIES OF PROCESS SEQUENCE STEPS

The major effort under this contract has been the development of a prototype automated layup and interconnect system using an industrial robot. This system is covered in detail in Section 5.0.

Other efforts have been directed toward process development and verification of a few steps within the process sequence. Most of the efforts have been in the area of aluminum back surface field formation, and module edge sealing and framing. Additional efforts have been spent in the areas of process scaleup of etching and cleaning processes and plasma edge etch of wafers. Details of these efforts are given below.

4.1 Etch and Clean

4.1.1 Damage and Texture Etch

The use of acid mixtures to remove saw cutting damage from the surface of a silicon slice is a costly and time-consuming process. Not only are acid etchants expensive, the N_2O_4 fumes generated require thorough scubber systems. In addition, the actual quantity of etchant utilized is typically greater than the stoichiometric quantity of required. For these reasons, sodium hydroxide has replaced acid. The etch rate is predictable (therefore controllable) and does not generate toxic fumes, although the hydrogen evolved in the reaction must be diluted with air to maintain an H_2 concentration of less than 4% (the minimum for flammability). It should be noted that the technique is not applicable to 1-1-1 orientation silicon.

A minimum of 1.5-mils must be removed from each side of a wafer if that wafer has been cut with an I.D. type saw. (Only 0.5-mils need be removed if the slices have been cut with a slurry saw.) Insufficient material removal is evidenced by low open circuit voltage and high leakage currents. When etching silicon wafers, the spent sodium hydroxide is replaced according to the following equation:

$$Si + 2NaOH + H_2O = Na_2 SiO_3 + 2H_2$$

For each 28 grams of silicon removed, 80 grams of sodium hydroxide is required and water is added to a fill line on the inside of the etch tank by a float control. The density of silicon may be taken as 2.23 gm/cm^3 except for the first mil of material which is spongy (due to cutting damage) and may be approximated as 1 gm/cm^3. After damage removal etching, the wafers are quickly removed to a cascade-rinser (to minimize air exposure and staining) in preparation for texture etching. Each basket of slices is then transferred sequentially to another tank containing a low concentration of sodium hydroxide, two to three percent in water, with a small quantity of isopropyl alcohol to precipitate the sodium silicate which forms. The tank is stagnant (except for the hydrogen percolation) and maintained at 80 $\pm$ 1°C. After 20 minutes in this tank, the 1-0-0 wafers have become texturized (tetrahedral pyramids cover the surface) and are transferred to another cascade-rinser. The reflectance as a function of wavelength is shown in Figure 4-1 for the typical slice produced by this process.

4.1.2 Pre-Diffusion Cleaning

The major contaminant in sodium hydroxide is iron. This tends to plate onto the silicon surface during etching and must be dissolved along with any residual sodium hydroxide, although the presence of sodium ions is not as deleterious to device performance as with other types of semiconductor processing. This function is accomplished through the use of sulphuric acid soak (3% in water for a time period of 10 minutes). A low concentration is used to permit complete iron solvolysis without re-deposition as an insoluble salt and it is neutralized by dumping with the sodium hydroxide contained in the texturization tank. Another cascade-rinse station follows the acid bath and the wafers are now spun dry in a commercially available spinner rinser.

ASI has etched 400 four-inch wafers per hour using the process described. The sodium hydroxide replacement technique was shown to be a satisfactory production procedure for 12 continuous

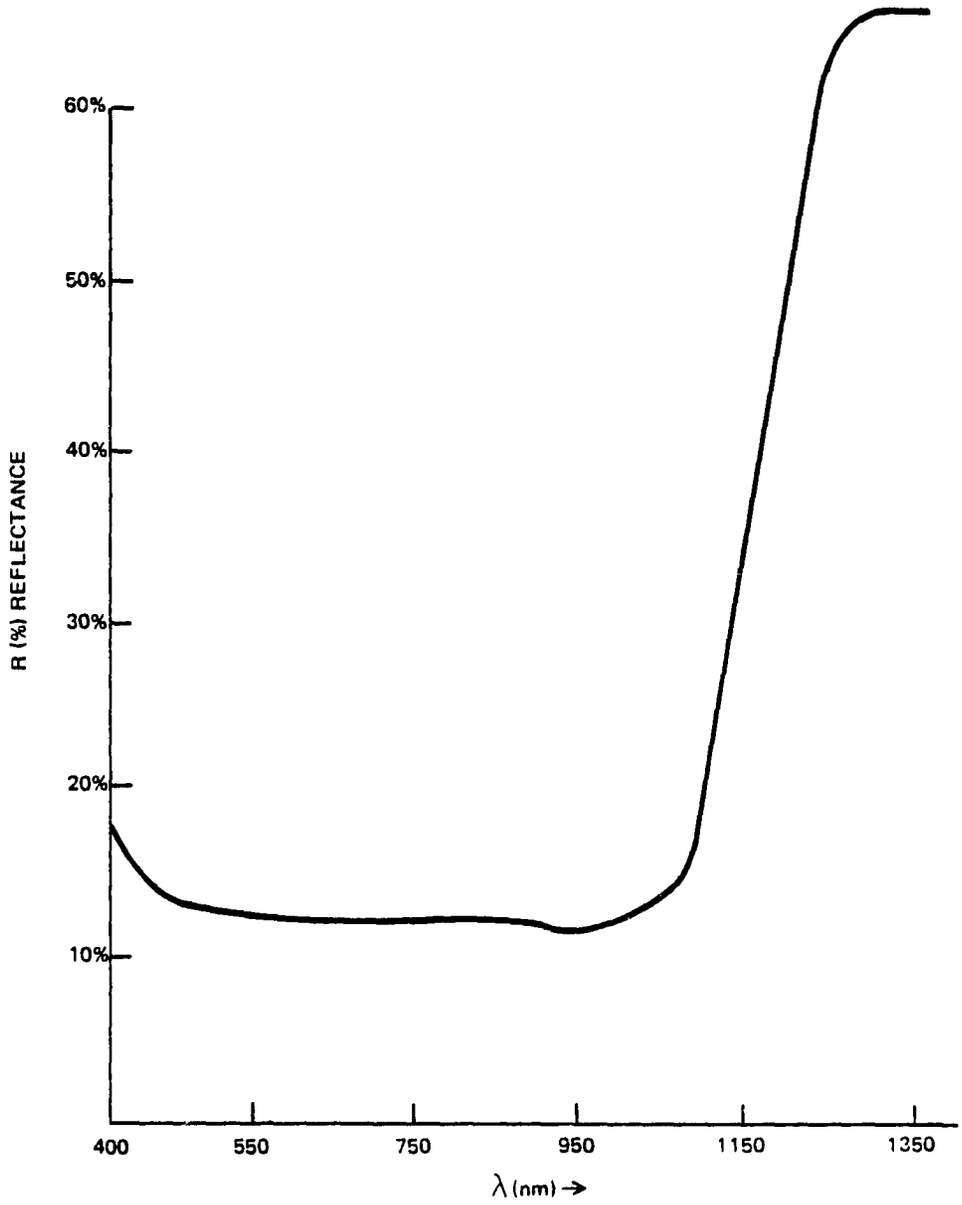


FIGURE 4-1
REFLECTANCE FROM TEXTURIZED SURFACE
OF 1-0-0 SILICON

300 wafer lots. The wafer-to-wafer and batch-to-batch uniformity being well within a production tolerance of $\pm$ 1 mil. Process control equipment will be specified for monitoring and maintaining the solution conditions by gradual addition of sodium hydroxide.

4.2 Edge Etch

The proposed cell making process sequence includes a chemical vapor deposition and diffusion step to provide junction formation. The technique used to mask the back of the wafer from receiving a large quantity of dopant is to diffuse the wafers with two inserted in each quartz cassette slot. In this manner, the wafers mask each other. The edges of the wafers receive a large quantity of dopant, and the backs of the wafers receive a varying dopant layer which falls off to zero at the center of the wafer back. This imperfect masking provides a current short of the cell front-to-back and must therefore be removed. Conventionally this has been removed through the use of wet acid back etch. The desire to remove the requirements for an intermediate wet etch step has led to investigations of other techniques. ARCO Solar originally proposed the substitution of plasma back etch for chemical wet etch. During experimentation with back etching, it was found that the desired performance could be arrived at by removing only the diffused edge of the wafer. This technique removes a back etch process, but adds a plasma edge etch.

Several techniques for materials handling through such a station could be used. Edge etching in a moderate size plasma etcher requires approximately a 15 minute sequence. Wafers are loaded into the reactor, on boats or fixtures made of aluminum, glass or plastic. Then the reactor is sealed, and evacuated by a mechanical pump. Gas flows into the reactor, passing between electrodes that supply electrical energy (from a RF generator) to convert the gas into plasma. Gas flow, electrical power input, processing time and other variables are governed by a control unit.

The gases used most frequently to generate plasmas for manufacturing process are oxygen, argon and freon 14. They are inexpensive and are readily available in cylinders from suppliers of industrial gases.

One technique which can be used to mask the front and back surfaces from being etched during the process is to design a carrier which holds a stack of wafers with the front and back surfaces of adjacent wafers in contact. Loading into and out of a plasma etcher could be done manually or with an automatic loader/unloader.

Cells are currently being edge etched by coin stacking and exposing them to a $CF_4 + O_2$ plasma for a period of about ten seconds per wafer. The plasma etching apparatus for accomplishing this task is similar to that disclosed in U. S. Patent 3795557.

4.3 Aluminum Back Contacts and Back Surface Field Formation

4.3.1 Background

The use of a back surface field to create an acceptor gradient at the back side of a solar cell has the following advantages:

1) An increase in open circuit voltage is observed for all resistivities greater than 0.8 ohm centimeter.

2) The short circuit current of the solar cell is enhanced, particularly for bulk resistivities in the range of 0.8 to 1.0 ohm-centimeter. This is a result of increased long wavelength response. This particular effect is of substantial significance in optimization of poly-crystalline device performance.

3) A back surface field provides a greatly reduced back contact sheet resistance. Sheet resistance

on the order of one to five ohms per square are typical. This low sheet resistance makes it feasible to utilize a gridded back contact pattern.

4) The curve fill factor obtained for high resistivity devices is substantially improved over that of a non-field solar cell.

Although any conventional acceptor materials such as boron, aluminum, gallium or indium may be utilized to form the back surface field, the greatest success has been achieved while utilizing aluminum. Aluminum is an ideal material because of its capability to dope silicon to high levels (10^{18}), and because it alloys with silicon at a relatively low temperature (557°C). This alloying action makes it possible to form the sharp junction which is essential for optimized back surface field performance.

The alloying action is also capable of gettering substantial quantities of impurities from the bulk of the silicon. This particular effect has not yet been optimized on a production basis but offers the possibility of manufacturing efficient solar cells from metallurgical grade silicon. The back surface field impacts crystal growing technology, both because it is effective with any silicon crystal orientation, and because the allowable resistivity spread for any given slice is quite large. The back surface field further opens options in sawing technology because it permits full efficiency devices to be manufactured from slices only five mils thick. Finally, aluminum is the ideal back surface field material because it provides a low cost back contact which is environmentally stable and because it segregates the unwanted parasitic diffusion normally removed by wet processing techniques from the back side of a solar cell.

4.3.2 Prior Techniques Utilized in Formation of Aluminum Back Surface Field

Since 1972 evaporated aluminum has been utilized as the primary method for obtaining a back surface. The technique

typically employs vacuum deposition of an aluminum layer between 5,000 angstroms to 8 microns thickness. Following this aluminum evaporation an alloy sequence is accomplished. The sequence typically consists of heating for periods of 10 to 30 minutes at a temperature of 750 to 900°C. Although the technique is often effective, it is quite erratic in formation of a fully enhanced back surface field, evidenced by a greatly improved open circuit voltage. The unpredictability of the evaporated aluminum method as well as the lack of a high yield of fully enhanced devices has made it a cost ineffective technique.

In 1975, experiments were begun to fully characterize the reason for this lack of process control. The most significant variable apparently is the interfacial layer between the aluminum and silicon. An alternative technique has been devised which involes utilization of aluminum powders as the source for the acceptor material. Upon heating an aluminum powder material in an oxidizing atmosphere, a highly exothermic reaction occurs. This reaction overcomes the initiation problems encountered with evaporated aluminum layers and has been demonstrated to provide nearly 10 millivolts more open circuit voltage in completed devices than was observed with the best of evaporated aluminum layers. The significant variables associated with the powder process are the thickness and temperature profile associated with field formation.

Initial work was performed by printing aluminum on wafers and firing them in a open tube. Silicon wafers of three-inch diameter were diffused and printed with both commercially available e.g. Englehard A 3484 and Plessy LP19-4662 and ARCO Solar aluminum paste. All paste materials were fired at 900°C in an air atmosphere for times periods of 40 to 60 seconds in an open tube. This type of procedure had been previously utilized successfully for two-inch diameter wafers but never for three-inch sizes. The major difference found in going to the large diameter slice was in the time necessary to achieve significant heat transfer for back surface field formation (20 to 50 seconds).

4.3.3 Mass Production Technology

ARCO Solar has purchased a radiant conveyor belt furnace, Model GS-800, from Radiant Technology in Cerritos. This furnace was used to demonstrate the feasibility of mass production techniques for back surface field formation on devices more than four times larger in area than any previously successful back surface field device. Initially difficulties were encountered in transferring the small scale tube firing technique to high throughput belt processing. The significant variables identified and characterized during the course of this work included heat up, soak and cool down time with the furnace. Each of these factors must be optimized in coordination. The first variable, heat up time, was found to be most important. During this period, it is necessary to drive off the volatile organic materials of the plasticizer binder and initiate the exothermic reaction which is a key to successful field formation. The lamps within the radiant heated furnace were adjusted so as to provide for this hot entrance zone requirement. The soak time was governed by the necessity to heat the wafer to a temperature between 700 and 900°C, but to maintain it at this temperature for a short period (approximately 60 seconds).

Three-inch cells with an aluminum paste back contact were successfully fired on this conveyor belt furnace to yield the current and voltage enhancement typical of back surface field formation. The aluminum paste was printed and dried at 200 degrees centigrade. Wafers were passed through the furnace at a rate of 2.08 feet per minute with the maximum power settings possible. The cells were above the aluminum silicon eutectic (557°C) for a period of 90 seconds. These tests were performed with material of a nominal resistivity of 5-25 ohm-cm. The starting lifetime of the material was questioned and high purity IC grade wafers were tried.

A number of three- and four-inch wafers were fired on the conveyor belt furnace. The aluminum paste utilized in these

experiments was Englehard A3484. The paste contained no frit materials and was printed and dried in automated continuous fashion. A substantial improvement was found in the substitution of low concentrations of high viscosity ethelcelulose for the standard grade plasticizer typically found in these paste materials. This improvement was not observed in field formation but in the ability to clean and interconnect to the back side of the slice. A wide range of belt speeds and peak furnace temperature was found to be suitable for optimum field formation and production of low resistance back contacts. Figure 4-2 shows field enhanced three-inch wafers.

After firing, the wafers were reloaded in cassettes and processed through a hydrochloric acid rinse which strips the aluminum dopant source leaving a P+ back. This allows the use of a gridded silver contact to be printed on the back. Less silver can be used because of the low resistance which exists because of the aluminum/silicon alloying. Future improvements in wafer processing should permit retaining the aluminum layer. This is dependent upon devising an interconnection technique for reliable connection to an aluminum contact. One technique may be to use an ultrasonic solder bath to tin the back side of the wafer with complete coverage. This tinning is necessary to seal the backside and prevent galvanic corrosion between the aluminum metallization and the interconnect material.

Since the back surface field as applied by screen printing does not extend to the wafer edge, a slight voltage drop occurs which is related to the area without BSF and the bulk resistivity of starting material. For a full BSF:

$$J = J_o e^{qv/kt}$$

For a device which is partially BSF (A') and partially non-BSF (A")

$$J' = J_o' e^{qv'/kt} \qquad J'' = J_o'' e^{qv''/kt}$$

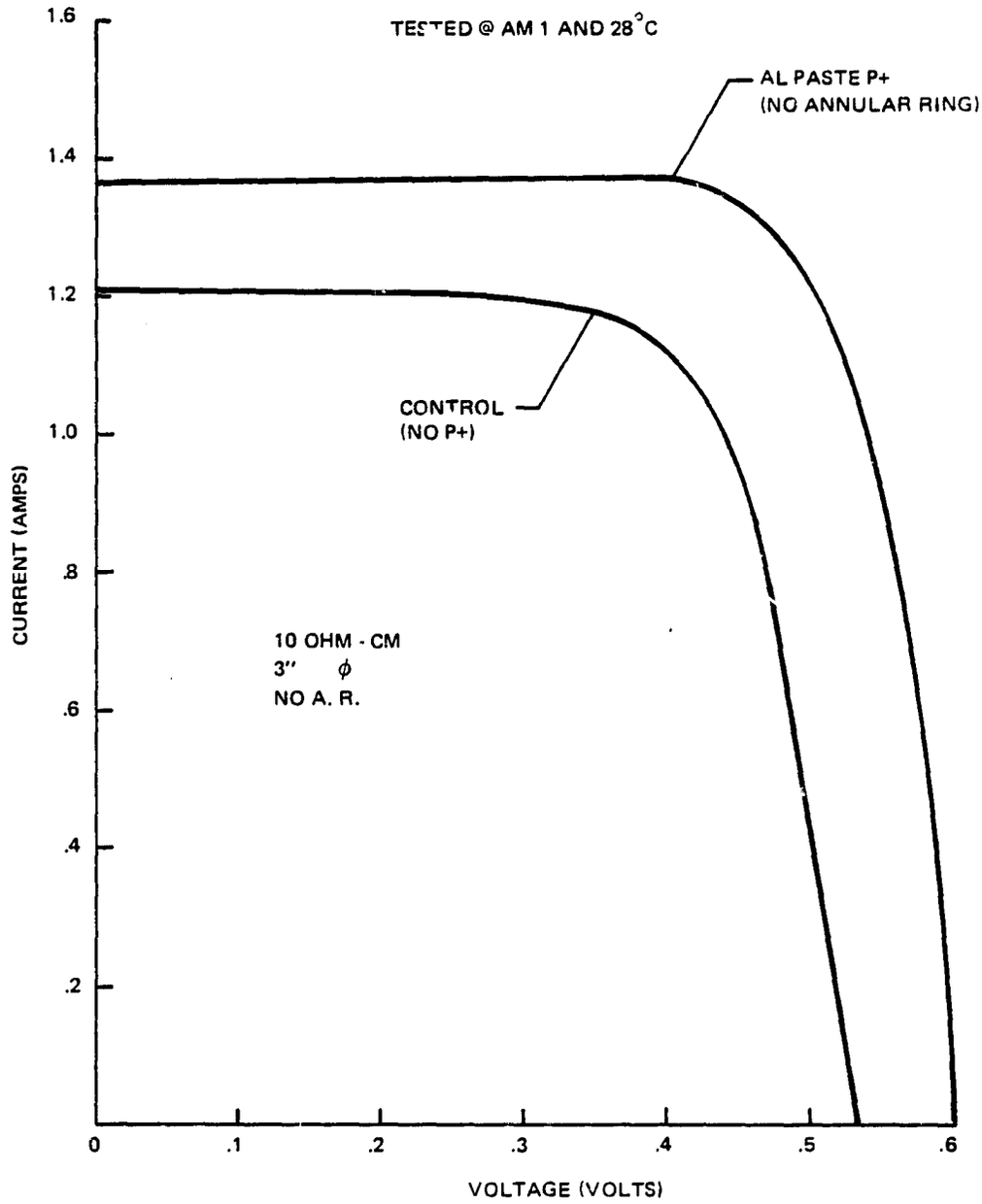


FIGURE 4-2
AL PASTE P+ BACK SURFACE VS. CONTROL

for Area = A' Area = A"

$I = J'A' + J''A''$ if the composite cell has the same I_{sc} as BSF.

$$J_o e^{qv/kt} A = (J_o'A' + J_o''A'')\, e^{qv'''/kt}$$

$$e^{qv/kt} = \frac{J_o'A' = J_o''A''}{J_o A} = e^{qv''/kt}$$

$$J_o' = J_o$$

$$v - v''' = \frac{kt}{q} \ln \left(\frac{A'}{A} + \frac{J_o''}{J_o} \frac{A''}{A}\right)$$

$$A' = A - A''$$

$$v - v''' = \frac{kt}{q} \ln \left(1 - \frac{A''}{A} + \frac{J_o''}{J_o} \frac{A''}{A}\right)$$

at short circuit, assume $J_{sc}' = J_{sc}''$, and at open circuit, assume

$V_{oc} = V_{oc'} \approx .595$ $V_{oc}'' = .520$

$$V - V''' = 0.0259 \ln \left(1 - \frac{A''}{A} + 18.1 \frac{A''}{A}\right)$$

This allows the plot shown in Figure 4-3 to be made for V_{oc} loss as a function of the annular margin on a four-inch cell.

4.4 Edge Sealing and Framing

4.4.1 Material Analysis

The panel edge seal, though a relatively simple element, has the potential for increasing the resistance of the array to environmental conditions, aid in prevention of de-lamination, and can bond an edge frame to the panel. Several types of sealants have been considered thus far, with the major driving factor being material cost. With satisfactory sealant performance, cost is the ultimate selector.

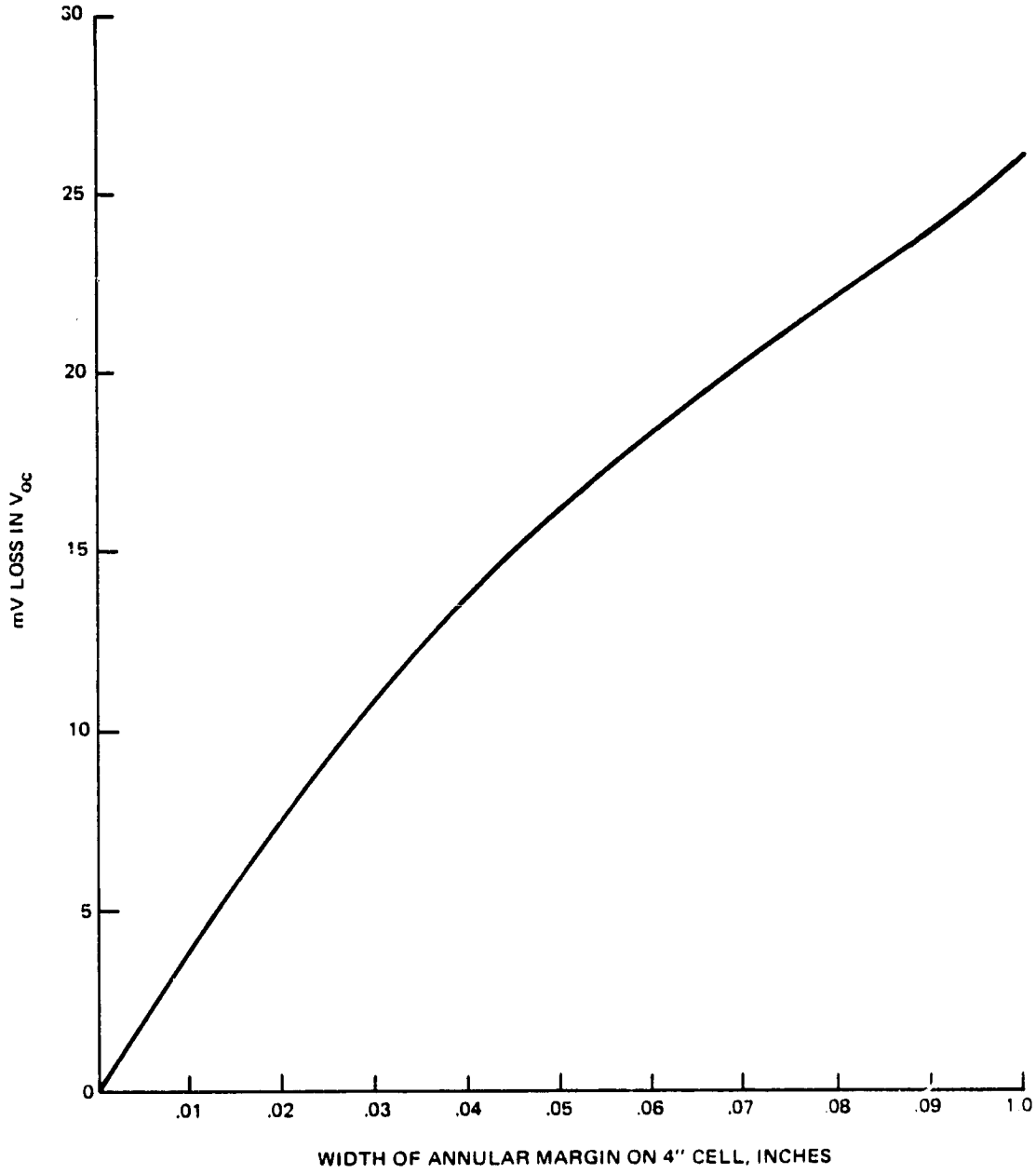


FIGURE 4-3.
V_{OC} LOSS AS A FUNCTION OF ANNULAR MARGIN ON A 4" CELL

The sealant industry was surveyed and potential materials were examined. The various types include two part polysulfides, gunnable sealants of various types, sealant tapes and hot melt adhesives. Table 4-1 details the sealants examined.

Polysulfides are currently being used in the insulated window industry with application similar to solar panels. However, the polysulfides are usually two part mixtures, slow curing (16 hours to 7 days) and fairly expensive, approximately 3.5 times as expensive as the hot melts. The gunnable sealants either remain a non-hardening putty or have long cure times (3-7 days). The need for rapid throughput of the line makes long cure time an undesirable characteristic. The hot melts typically have open times less than a minute and are inexpensive costing from $.36 to $.16 per 4 x 8 panel.

Final analysis of the data gathered during this survey pointed to two strong candidates for edge sealing materials: EPDM (hot melt) and Butyl rubber (both hot melt and cold setting). Summaries of these materials follow.

4.4.1.1 Cold Butyl

Cold setting (aka compression setting or non-setting) Butyl is used by automotive manufacturers to seal windshield and rear window glass. A long ribbon or tape is placed in the channel and the glass simply pressed into place. This arrangement must withstand 70 mph wind force @ 190°F (Ford Motor Company Test). This configuration is very similar to our laminated-panel-and-edge-frame concept.

Cold Butyl is very attractive from a time and cost standpoint. It adheres well to glass, requires no special application machinery and has a zero cure time. It is already mass produced in very large volumes (thousands of tons per year for the auto industry alone) so the price is very competitive.

The only drawback is that current JPL edge frame design requires a stand alone gasket. This is necessary to dimensionally stablize the panels and provide edge protection for frameless panels during shipping and handling (frameless panels allow much higher packing densities for

Sealant	Manufacturer	Type	Form	Application	Cost/4x8 Panel Cost/Watt	(a) Lifetime/ Weathering	Cure Time	(b) Automation Potential
EPCAR	B. F. Goodrich	EPDM	Depends on Application Method	Hot Melt or Pre-formed Extrusion	$ .20 $.00070	Excellent	< 1 Min.	Excellent
1081	H. B. Fuller	Hot Melt Butyl	Rope or 55/gal drum	Hot Melt Extrusion	$ .19 $.00068	Excellent	10 - 20 Secs.	Excellent
Duribbon 72-6417	National Adhesives	Hot Melt Butyl	55/gal	Hot Melt Extrusion	.20 .00070	Excellent	60 Sec.	Good
Versalon 1138	General Mills	Hot Melt Polyamide Resin	25 Lb. bag Pellets	Hot Melt Extrusion	.28 .00100	Poor	10 Sec.	Good
Versalon 1140	General Mills	Hot Melt Polyamide Resin	25 Lb. bag Pellets	Hot Melt Extrusion	.34 .00121	Poor	10 Sec.	Good
Z12-069	Swift Adhesives	Hot Melt	Billets	Hot Melt Extrusion	.16 .00057	Fair	32 Sec.	Good
Z12-355	Swift Adhesives	Hot Melt	Billets	Hot Melt Extrusion	.16 .00057	Fair	80 Secs.	Good
JM 3764	3M	Hot Melt	Cartridges	Hot Melt Extrusion	.36 .00128	Poor	45 Secs.	Fair
428	PRC	Polysulfide	Two Part 55/gal	Mix and Pump	.29 .00104	Excellent	16 Hours	Poor
438	PRC	Polysulfide	Two Part 55/gal	Mix and Pump	.25 .00089	Excellent	16 Hours	Poor
801	3M	Polysulfide	Two Part 55/gal	Mix and Pump	.69 .00246	Excellent	Tack Free - 20 Hrs. Cure - 7 Days	Poor
612	3M	Polysulfide	7 Lb. Package	Pressure Flow Gun	.68 .00246	Excellent	Non-Hardening Putty	Poor
5354	3M	Butyl Tape	50' Roll 3/8" x 1/8"	—	1.32 .00471	Excellent	Non-Hardening	Poor
404	3M	Synthetic Elastomer	55/gal drum	Pressure Flow Gun	.14 .00050	Good	Tack Free - 2 Hrs. Cure - 3 Days	Poor
5200	3M	Synthetic Elastomer	55/gal drum	Pressure Flow Gun	.32 .00114	Good	Tack Free - 48 Hrs. Cure - 7 Days	Poor
4050	National Adhesives	Butyl Sealant	Tape or 55/gal drum	Pressure Flow Gun	.20 .00078	Good	Tack Free - 3 Hrs. Cure - 3 Days	Poor

(a) Based on manufacturer supplied information.

(b) MBA opinion based on cure time, application, equipment needed.

TABLE 4-1
EDGE SEALANTS

shipping and warehousing). Unfortunately, cold Butyl cannot perform this function, but due to its other advantages it remains an attractive alternative should framing requirements change.

4.4.1.2 Heat Cured

Both Butyl rubber and EPDM are available in heat curing (hot melt) form. Both materials are comparible in cost and processing characteristics. Both require extended (up to half an hour) cure times at elevated temperatures. EPDM, however, appears to have the advantage over Butyl with regard to physical characteristics. EPDM is clearly superior in the areas of ozone and UV resistance. It also has a broader range of working temperatures (-60° to 300°F) than Butyl. There is even a precedent in the solar industry. Two of the elastomer manufactures are supplying EPDM to companies making thermal solar panels. Butyl had been tried early on as a panel sealant but has been unanimously rejected in favor of EPDM. Note: One should not base a decision on elastomers strictly on current availability. The ability to formulate properties into elastomers is quite extensive. One manufacturer (B. F. Goodrich) includes several "recepies" with its literature. The best approach is to select an elastomer family that has basic properties matching your basic requirements (i.e. temperature range or transparency). It is then possible to "customize" it with other, more specific requirements (i.e. UV and ozone resistance).

Some concern was expressed over the ability of either EPDM or hot melt butyl to adhere to glass. One suggested solution is to form the side pieces from extrusions and bond them to the glass with adhesives.

4.4.1.3 Conclusions

From the above analysis, EPDM appears to be the material best suited to solar panel edge sealing. Unfortunately, we were unable to obtain a sample in time to participate in the testing described in the next section. When reading the test results, it must be remembered that more work need be done to compare EPDM to the other materials tested.

There are still many options to be considered as to the manufacturing process to be used in forming the edge seal. The panels are far too large for conventional injection molding. The pressures required for an average panel would range into the hundreds of tons. Reaction Injection Molding (RIM), which uses a chemical cure rather than heat and pressure, is a possibility but requires more study. Transfer molding is, perhaps, the strongest candidate as it uses lower pressures than standard injection molding.

4.4.2 Testing

There is a wide variety of materials currently being used or considered for encapsulation of photovoltaic modules. After a survey which considered materials used in production at this time as well as promising candidates for the 1986 goals, the following materials were selected for compatibility testing:

- Glass
- Wood
- Acrylic
- Polyvinyl Butyral (PVB)
- Ethelene Vinyl Acetate (EVA)
- Tedlar
- Silicon
- Glass Reinforced Concrete (GRC)
- Aluminum

It is felt that testing of these materials will cover a broad range of encapsulation schemes. Three moduel designs wree decided upon as follows:

Module No.	Materials
1	Glass, PVB, Tedlar
3	Acrylic, EVA, GRC
3	Acrylic, Silicon, Wood

Applicability, adherence, and moisture resistance tests have been performed with a number of possible sealant types. These tests were performed by applying the sealant to strips of mylar (the more difficult element of the laminated assembly to adhere to) under various preparation conditions. Table 4-2 gives the sealants experimented with during this period along with results and performance judgements.

The hot melt systems appear to be the most applicable, with the butyl based type performing especially well. The 1081 Butyl manufactured by the HB Fuller Co., shows much promise. Appendix D gives some performance data for this type of sealant.

These sealants have also been used extensively for hermetic sealing of thermo-pane insulating windows. Performance requirements for insulated glass are similar to those for edge sealing of solar modules. SIGMA (Sealed Insulated Glass Manufacturers Association) has set up accelerated weathering tests for insulated glass. CE Glass, a manufacturer of insulated glass has performed extensive testing of HB Fuller 1081 butyl sealant comparing its performance to polysulfide. Appendix E gives the Sigma weathering test procedures as well as the CE Glass test procedures used for the butyl weathering tests. The less expensive butyl (approximately $1.25 per pound) was shown to perform better than the polysulfide in all cases.

HB Fuller 1081 hot melt was successfully used to apply the frames and edge seal to two 1' x 4' modules. The sealant was applied into the channel of the frame with a Hardman Polymeric Sealant Applicator (PSA) model 240, shown in Figure 4-4. A specially designed nozzle was used to get material distribution over the sides and bottom of the channel, leaving a slight space for the module to be inserted and reducing the need for the viscous material to flow out along the sides of the module. Open times were sufficient to allow good flow characteristics and adhesion, even though the sealant was applied with a hand held gun and consequently was slower than possible with automation. There appears to be no need to preheat the aluminum frames. Plexiglass frames were constructed and used in some of the framing experiments to verify that no bubbles were entrapped.

TABLE 4-2

SEALANTS TESTED

SEALANT	MANUFACTURER	TYPE	HOW APPLIED	RESULTS
Hydro-Seal	American Energy Group	Acrylk-Latex	Dipped	Did Not Adhere to Mylar
Acrylic Cement	Tap Plastic	Acrylic	Dipped	
12-355	Swift	Hot Melt	Heated, then Dipped	Good Adhesion Slow Cure
12-069	Swift	Hot Melt	Heated, then Dipped	Good Adhesion Rapid Cure
Sealer 5354	3M	Synthetic Rubber	By Hand	Good Adhesion Non-Hardening
Industrial Sealant #612	3M	Oil Resistant Elastomer	By Hand	Adheres After 30+ Minutes
Industrial Sealant #801	3M	2 Port Polysulfide	Spatula	Takes 7 Days to Cure
Thermo-Seal #1081	Distributed By H. B. Fuller	Butyl	By Hand	Excellent Adhesion Excellent Drying Time
Butyl Rubber Sealant	National Adhesives	Gunnable Butyl Rubber	Gun Applied	Good Adhesion Remains Flexible

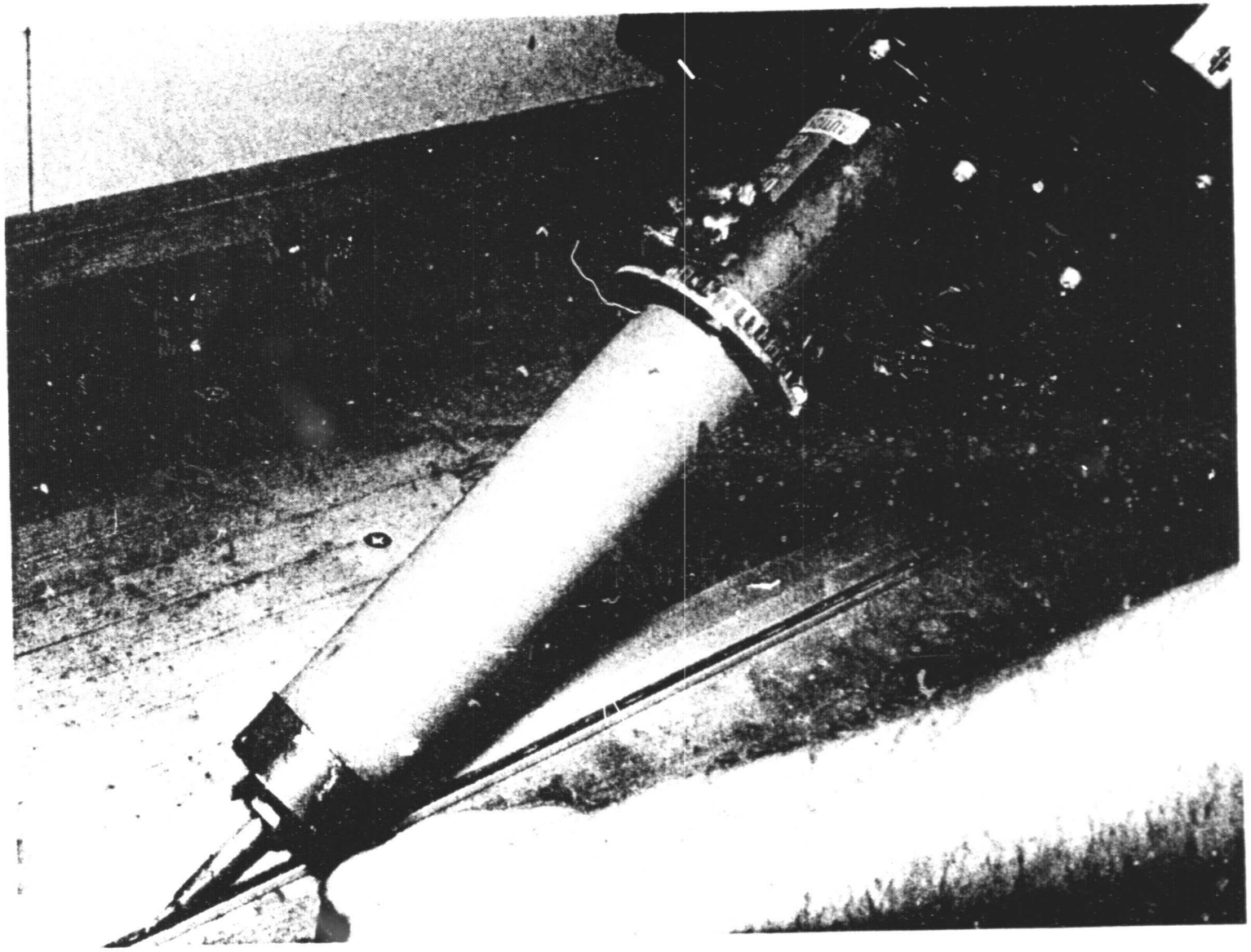


FIGURE 4-4
APPLICATION OF EDGE SEALANT

MBA
1999-1673

Appendix F contains information on several available hot melt sealant application systems available from various manufacturers.

Included is a very recent development that may impact edge sealing. This is the FoamMelt™ system developed by Nordson Corporation. In this system an inert gas is mechanically introduced into a hot melt adhesive and held in solution such that the adhesive can be applied in a foamed condition. This foaming action is a primary element that enhances hot melt's already desirable characteristics.

Some of the benefits claimed for this system by the manufacturer include:

- Increased open time
- Faster set time
- Improved Spreadability
- Volumetric Increase for greater filling capability
- Improved Wetting
- Lower Heat Density
- Reduced sagging or running
- Reduced adhesive consumption

5.0 HARDWARE DEVELOPMENT OF AN AUTOMATED LAYUP AND INTERCONNECT SYSTEM PROTOTYPE

The main effort under this contract was the design and fabrication of a prototype array layup and interconnect system using an industrial robot.

The robot general enough for this task, and one that could possibly be used for other handling tasks within the process sequence, is the Unimate 2000 series industrial robot. Some performance data for this robot is given in Appenidx C.

Before any design or construction began, a sizable analysis was done to determine an optimal system configuration. This analysis addressed such areas as workload distribution (how much to be done by the robot versus a piece of dedicated equipment), bonding methods, end effector (the robot's "hand") design, and alignment techniques (to put the randomly oriented cells in the correct alignment). The details of this analysis are presented below.

5.1 Options

There are several options for lay-up and interconnection. These include placement and interconnection of the cells into a ribbon or other convenient sub-unit. The sub-units would then be placed and connected into the module configuration (as a hexagonally close packed module for instance). Another option would be to place an interconnect, place a cell and iterate until the module was complete. Then a reflow scheme would finish the interconnection. A third alternative would place a cell and electrically bond it to the adjacent cell in one operation. The first option would be fast, as the robot would be placing more than one cell at a time. However, another robot (or piece of dedicated hard automation equipment) would be needed to form the sub-unit. The versatility would be severely restricted as the end effector would be designed to pick and place a specific sub-unit. Variations in size and shape of the cells would alter the relative position of the cell's center increasing the complexity of the tool or requiring a separate one for each shape variation.

Placement of the cells and interconnect hardware alternately gives greater versatility but would be slower and require a reflow step. The pick, place and interconnect configuration offers more speed than the placement of cells and interconnects separately.

Options in cell handling techniques include mechanical and vacuum pick-up. Vacuum handling offers versatility, using a suction cup which can pick up any size and shape cell. A mechanical gripper would be complex if it were to accomodate the range of cell types. A vacuum cup is easy to control through the use of the robot memory and controls. It can be compliant to cushion the cell and reduce damage during handling and placement. Air eductors can also be used to create the vacuum from compressed air.

An important trade-off to consider is the amount of work to be performed by the robot itself versus a preparation station or another robot. A preparation station could orient the cell and attach interconnect hardware in preparation for the robot whose job becomes only to pick and place and final connection. Another approach would be to have the robot pick up the cell, orient it, attach hardware, place it, and complete the interconnection. This would involve a rather elaborate end effector and probably a longer cycle time. However, end effector design is restricted by the limited maximum load of the robot (25 lbs. at maximum speed, 75 lbs. maximum at reduced speed) which precludes very elaborate designs.

5.1.1 Bond Methods

Several Bonding methods were investigated. The following sections discuss the trade-offs with each method.

5.1.1.1 Resistance Heating

Conventional resistance heating (e.g. soldering iron) has the advantages of being both inexpensive and fully developed. It requires no bulky power supplies or signal generators and is easily adapted to an end effector. However, it is far too slow (5-10 sec. per connection) for production line assembly. A different type of resistance heating was used

with a prototype end effector. This technique used a low voltage, high current pulse that passed through the cell and generated heat due to the cell's own internal resistance. This end effector is described in Section 5.2.1.2.1.

5.1.1.2 Ultrasonic Bonding

This method shows great promise for interconnection of solar cells. It uses a signal generator which can be remotely located and only the ligthweight transducer need be mounted on the end effector. Another advantage is that the bond is a direct metal-to-metal weld which requires no solder or flux and effectively bonds both aluminum and silver; two metallization systems used. The bond time is very fast (<0.5 sec.) and energy consumption is low since the materials to be jointed are bonded directly and surrounding areas remain cool. Unfortunately, our investigation shows that near optical-bench stability is required to assure reproducible bonds. Vibrations from roof-mounted air conditioners and closing doors were sufficient to degrade bond quality. Since these are several orders of magnitude lower than vibrations at the end of the robot arm, this method is unusable for our system. However, it still appears to be a good technique for a hard automation system where vibrations can be more rigidly controlled.

5.1.1.3 Laser Bonding

Laser cutting and welding are becoming quite popular in industry and there are many off-the-shelf units that would be directly applicable. Lasers have the advantages of being very fast and extremely versatile in terms of pulse duration and focusing. This allows the laser to be "tuned" for either welding or soldering. Although welding does away with both solder and flux, soldering is expected to be better for bonding leads to solar cells. Unfortunately, industrial lasers operate in the infared region and all of the materials presently under consideration for leads and metallization patterns (Al,Ag,Cu,Sn) are highly reflective to IR. The very high initial pulse necessary to overcome reflective effects and weld the lead material (≈100w) could simply vaporize the lead and damage the cell. Laser bonding holds great promise for industrial scale

production but has several drawbacks that made it unsuitable for prototype development with the Unimate robot. Although the beam can be positioned anywhere (through appropriate optics) once in place it must remain fixed and the array moved under the beam. An X-Y beam moving system is available, but is is very expensive (150K) and moves only 16" x 16".

5.1.1.4 Induction Heating

This fast bonding method has advantages similar to ultrasonic bonding in that the power supply can be remotely located with only the coil mounted on the robot. Additionally, since heat is produced by inducing eddy currents in the material rather than bonding by direct mechanical vibration, the coil need only be brought into close proximity to the material being bonded, rather than requiring a rigid, vibration free, accurately positioned contact. All that is required is a slight pressure on the lead to ensure contact during bonding.

Since it is a zone heating system, it does not have the precise area control of a laser or ultrasonics; hence it would be used to solder rather than weld, requiring the application of solder. Other than that, induction heating seems to have the advantages of ultrasonic bonding without the rigid requirements. We therefore decided to use induction heating as the bonding method of our prototype.

5.1.2 Metallization Pattern Recognition and Cell Orientation Techniques

The cheapest and fastest method of cell orientation would be a mechanical alignment on the flat. Many round wafers for solar cells are made on the same production lines as those for the micro-circuit industry. These have a flat machined onto the edge which the IC manufacturers use to align the crystalline structure of the wafer for their many precision operations. Solar cells do not require this precision and designing orienting machinery around the flat increases the production cost of the wafer through both the extra time and equipment required to machine the

flat and in material loss.* Many manufacturers produce square and hexagonal cells which have an inherent flat side and could use mechanical alignment. An orientation system, however, should be able to accept cells of any configuration. Barring the guarantee of a flat side, orientation can be achieved by optical methods.

One such method involves the use of a negative image of the metallization pattern to creat a moiré fringe pattern when placed over the cell. The object is to maximize the signal generated from the reflection of the cell through the negative screen.

This method gives good continuous feedback and can handle 1° orientation relatively well. This is a simple and inexpensive optical orientation method, but more flexible and accurate methods are possible.

Pattern recognition can be accomplished using a laser to scan the metallization pattern and detect the reflection from the grid lines with a photodiode, amplifier and comparator. Using beam splitting techniques to get 2 or 3 beams, the alignment can be determined and corrected by determining the period and phase difference between the scans of the grid lines. The system could easily be programmed to recognize and orient any type of cell or pattern.

The negative image method has been chosen as an adequate and inexpensive method to orient the cells for prototype purposes. Laser scanning techniques would probably be impelmented for production situations.

5.1.3 End Effector Design Criteria

The design and development of cell handling end effectors was preceded by an analysis of the constraints and design criteria for the end effector and the options available for the sequence of steps and techniques for layup and interconnection of a module.

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*This is more than just scrap loss since the machined-off portion is active cell area. Although it is only 0.8% of the total cell area, this is equivalent to 24 cells/hr. on a line producing 3000 cell/hr.

The constraints and design criteria considered were:

(1) Versatility

(2) Speed

(3) Accuracy

(4) Simplicity

(5) Light Weight

(6) Reliability

(7) Cost

The end effector should be able to handle the various sizes, shapes and metallization patterns of cells and be able to place and interconnect them into whatever module size and series/parallel configuration desired. Proposals for hard automation assembly machines are in the range of 5 seconds/cell. If the versatility of programmable off-the-shelf hardware is desired, a sacrafice in speed must be tolerated. A target rate was set at 6 - 12 seconds/cell for robot pick-and-place time and 20 seconds/cell for overall system cycle time. This 20 seconds includes all cell preparation and bonding. Cell placement tolerances requirements are expected to be different for square and round cells. Simplicity of the end effector will reduce the cost and increase reliability which should put the output in the 95% range with overall system cost directed towards the LSA goals. A lightweight end effector will reduce the inertial effects of the robot arm, and keep it moving at its maximum speed.

5.1.4 Conclusions and Selected System

Based on the criteria given in the above analysis, we arrived at a candidate system for prototype development. This system is shown as an artist's conception in Figure 5-1. For simplicity, only one of the ribbon feed and solder paste dispensing mechanisms are shown. In actuality, however, there are two of each of these since we are using an ARCO Solar cell which has a dual lead configuration.

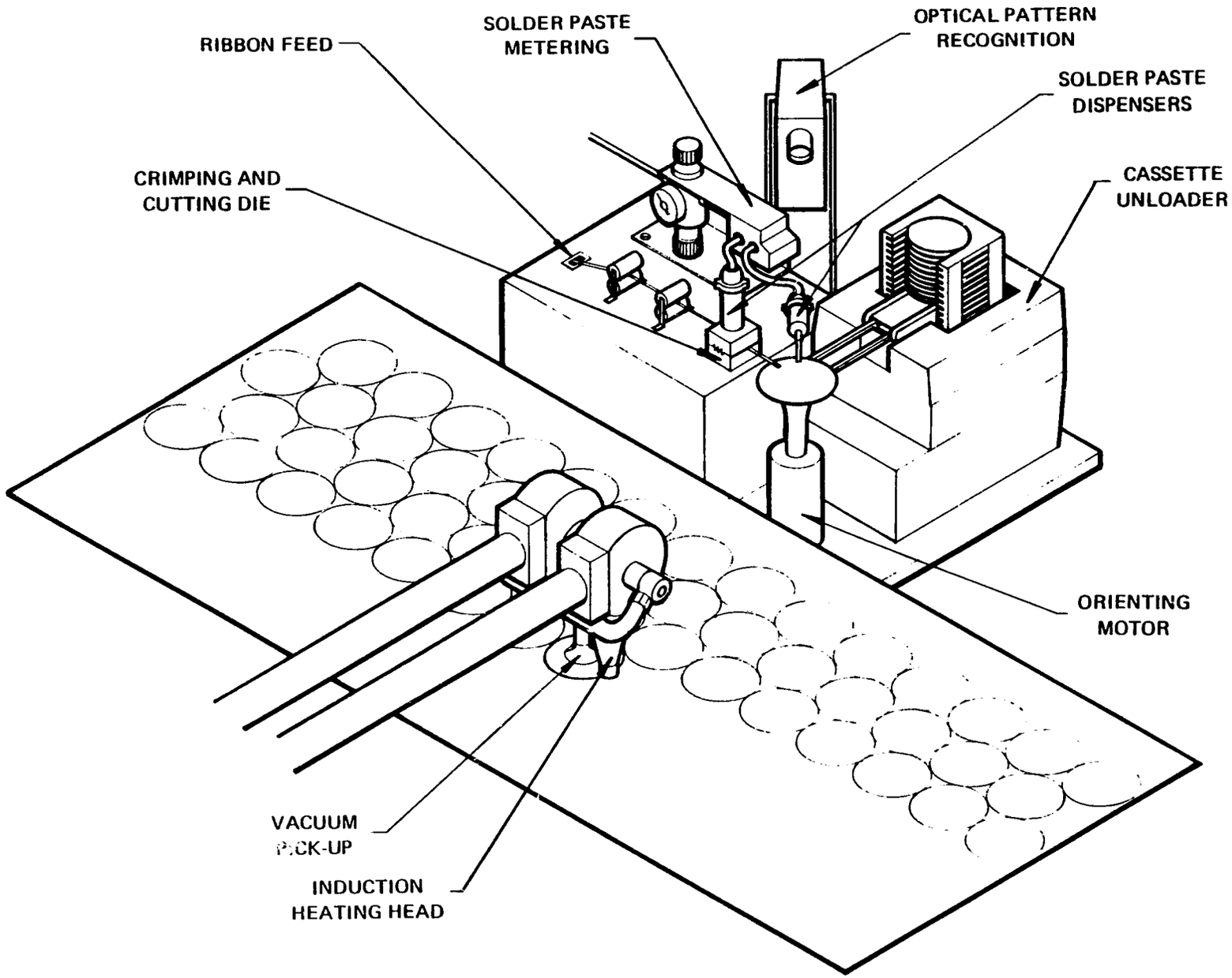

FIGURE 5-1
PREPARATION STATION AND PANEL LAY-UP

Our method, therefore, incorporates a robot end effector which combines an induction heating coil and a compliant vacuum pick up. This scheme of robot operation requires that it interface with a "smart" preparation station. This station must accept standard H bar cassettes of randomly oriented cells, unload the cells, rotate them to the orientation the robot is expecting, apply the proper amount of solder paste in the correct places, measure and cut lengths of interconnect lead, place a stress-relief crimp in the correct place in the lead and do it all with a cycle time less than or equal to that of the robot. The robot then picks up this fully-prepared cell, begins heating it while "in transit", and places the hot cell on top of the exposed, solder-coated leads from the previous cell completing the connection. A small micro-computer is being used to syncronize all of this activity.

5.2 Hardware Description and Development

Following is a description of all of the equipment incorporated into the system in its final form. This equipment is divided into mechanical and electrical systems as they were developed separately. Development histories are given only when it is helpful to understanding.

5.2.1 Mechanical Systems

The major mechanical system consists of the preparation station which is further broken down into its various subsystems. The robot end effector also comes under this heading.

5.2.1.1 Preparation Station

The cell preparation station is the major mechanical development of this contract. It consists of several individual components each of which will be discussed separately. Figure 5-2 is an overall view of the station.

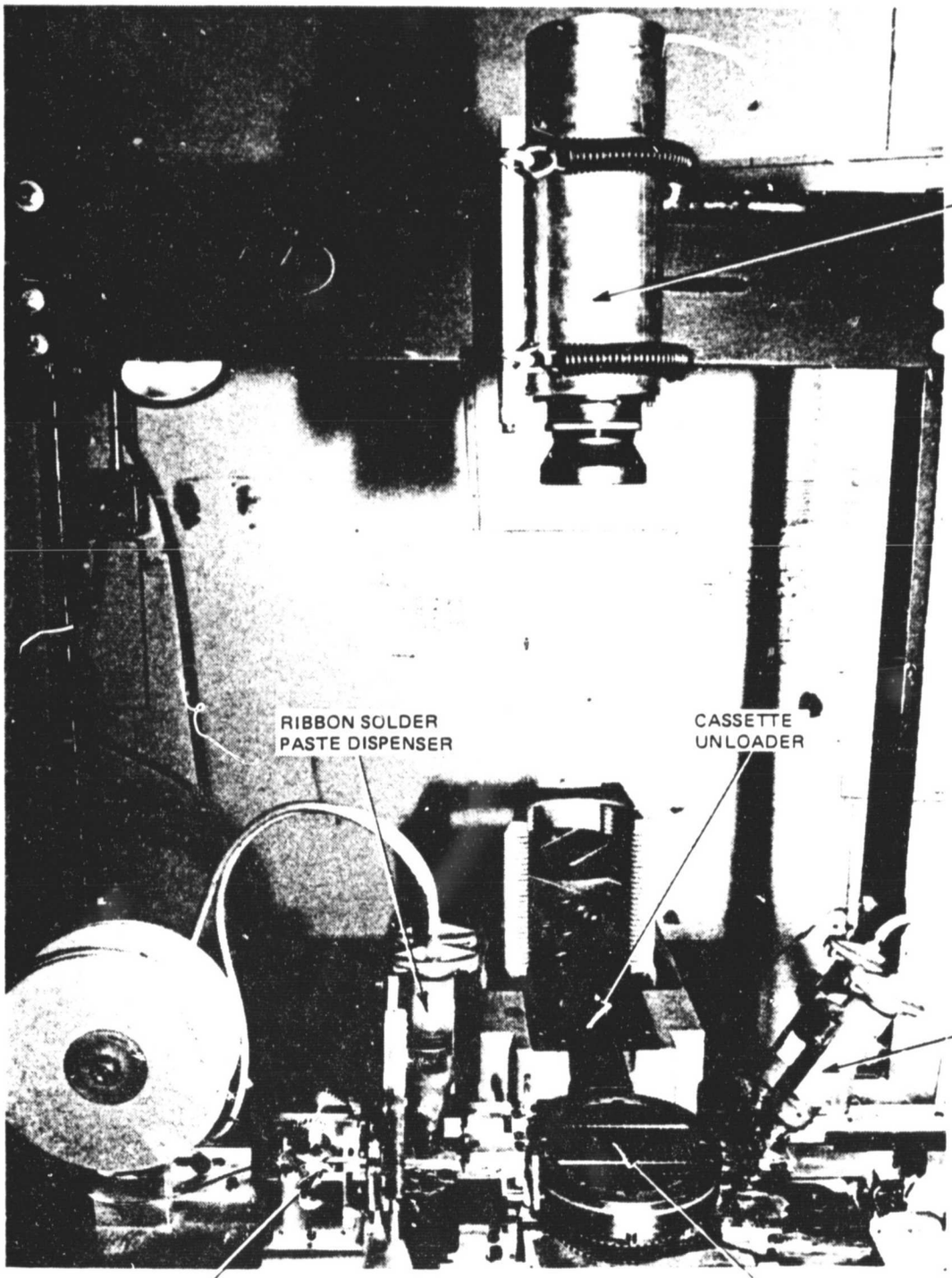

FIGURE 5-2
GENERAL VIEW

5.2.1.1.1 Cassette Unloader

To unload the cells from the standard H bar poly cassettes, we are using a Siltec model 2600A load/unload module. There was only one modification done to the Siltec. As delivered, the cells emerge from the cassette and stop at the edge of the unloader. The unloader was modified to extend the drive belts out approximately 2" to the edge of the vacuum chuck.

5.2.1.1.2 Vacuum Orientation Chuck

As originally conceived, this was simply a rotating vacuum cup that was attached to the underside of the cell after it was unloaded from the cassette; its sole purpose being to provide rotation for cell orientation. By the time the first prototype had been built, however, its role had been expanded. It was now seen as the platform upon which all of the cell preparation would be performed and it operated in two modes: pressure and vacuum.

The first mode (slight positive pressure) makes the chuck an air table allowing the cell glide off of the unloader without touching the chuck's surface. The pressure also extends the cell locating pins which correctly locate the cell on the chuck regardless of whether or not the cell has a flat (Figure 5-3). The chuck is tilted approximately 5° from the horizontal to allow the cell to glide "down hill" into the pins. The second mode, vacuum retracts the pins and clamps the cell to the chuck with a force of 50 - 70 lbs. It was found however, that reverting to the first mode (pressure) when releasing the cell caused slight dislocations in cell position as well as re-extending the locating pins which interfered with robot operation. It was decided to add a third mode, ambient pressure, which breaks the vacuum to release the cell, but does not cause cell motion or extend the pins.

The vacuum was originally supplied by a standard shop vacuum pump. A problem was encountered, however, with the high leakage rate around the retractable locating pins. This tended to overwhelm vacuum pump leading to aloss of hold down force. The solution to this

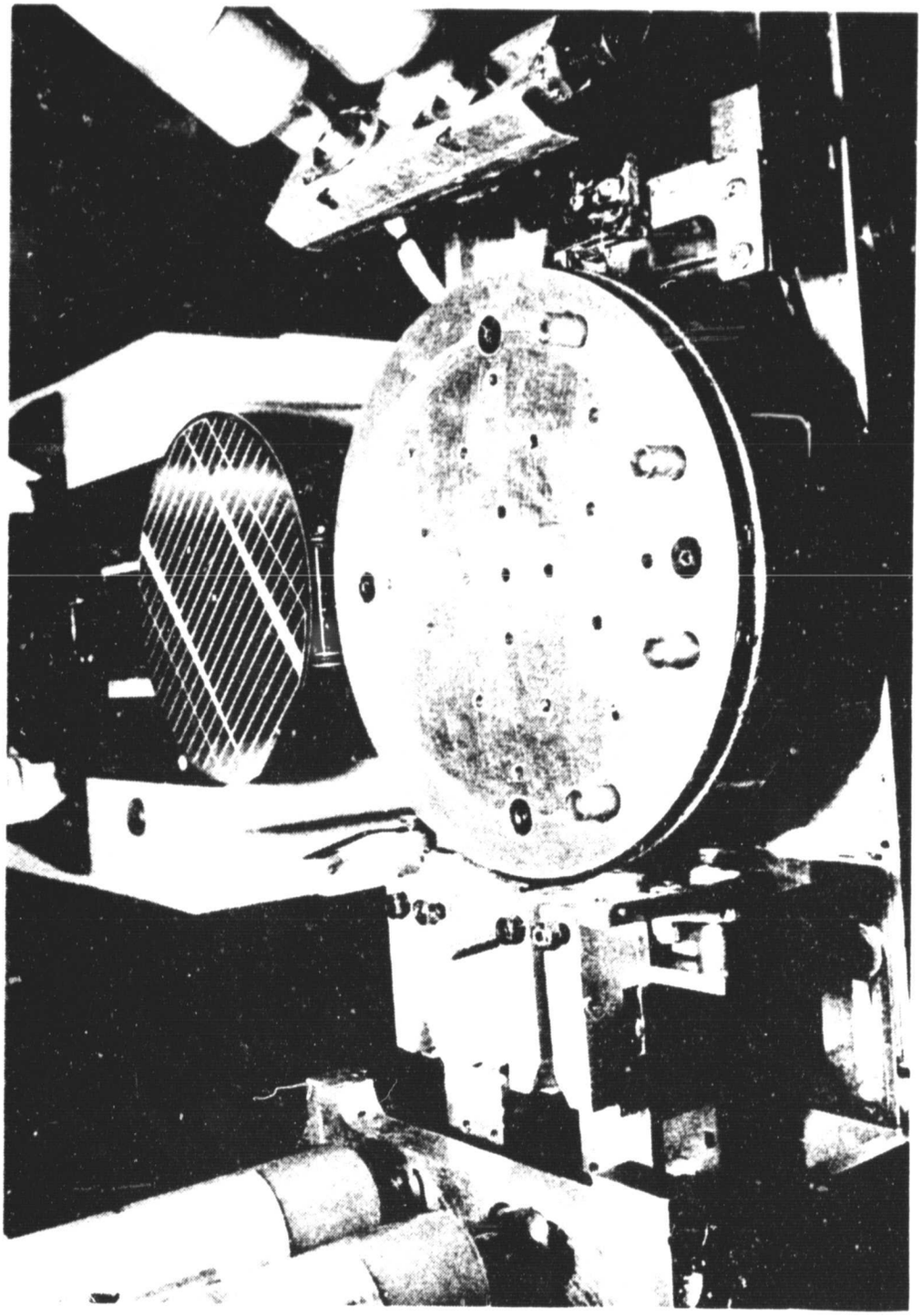

FIGURE 5-3
VACUUM CHUCK WITH EXTENDED PINS

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problem, was to replace the vacuum pump with a commercial eductor or venturi-type vacuum generator. This device uses a compressed air stream to "generate" a high flow-rate, low grade vacuum. This is precisely what is required in our high leakage rate situation. The main drawback is that the hold down force is reduced to 5-10 lbs., although this is sufficient for our purpose. As mentioned, early tests of the vacuum chuck showed hold down forces of approximately 70 lbs. but those tests were made before the locating pins were installed. The two big advantages to using the eductor are 1) the vacuum is constant (the vacuum pump would atart at very high vacuum levels, approximatley 28 inch Hg, but would leak to 0 long before the cell was prepared), and 2) it does away with the external vacuum source requirement simplifying the plumbing and making the station more self sufficient. The only external requirements are a single AC line plug and one shop air connection.

5.2.1.1.3 Ribbon Feed

The ribbon feed assembly (Figure 5-4) consists of several mechanisms, each of which will be discussed separately.

5.2.1.1.3.1 Drive Rollers

The original prep station design had two sets of drive rollers for each interconnect ribbon. It was determined, however, that a single set of rollers is sufficient to feed the ribbon across the entire length of the cell. The rollers have synchronizing gears which insure that the rollers turn without slipping, which would cause the ribbon to curl. The roller assemblies were narrowed from their original size to allow the close (1.625") spacing of two feeds side-by-side which is necessary for the simultaneous application of both leads. Both feeds are driven by a single pin tooth belt located between them.

5.2.1.1.3.2 Crimp and Cut Mechanisms

These were originally conceived as one device: a crimping die placed close to the cell with a cutting blade on its rear edge. This is sufficient for creating stub leads but in our system the crimp must be placed in the center of an 8" lead. It was determined that these

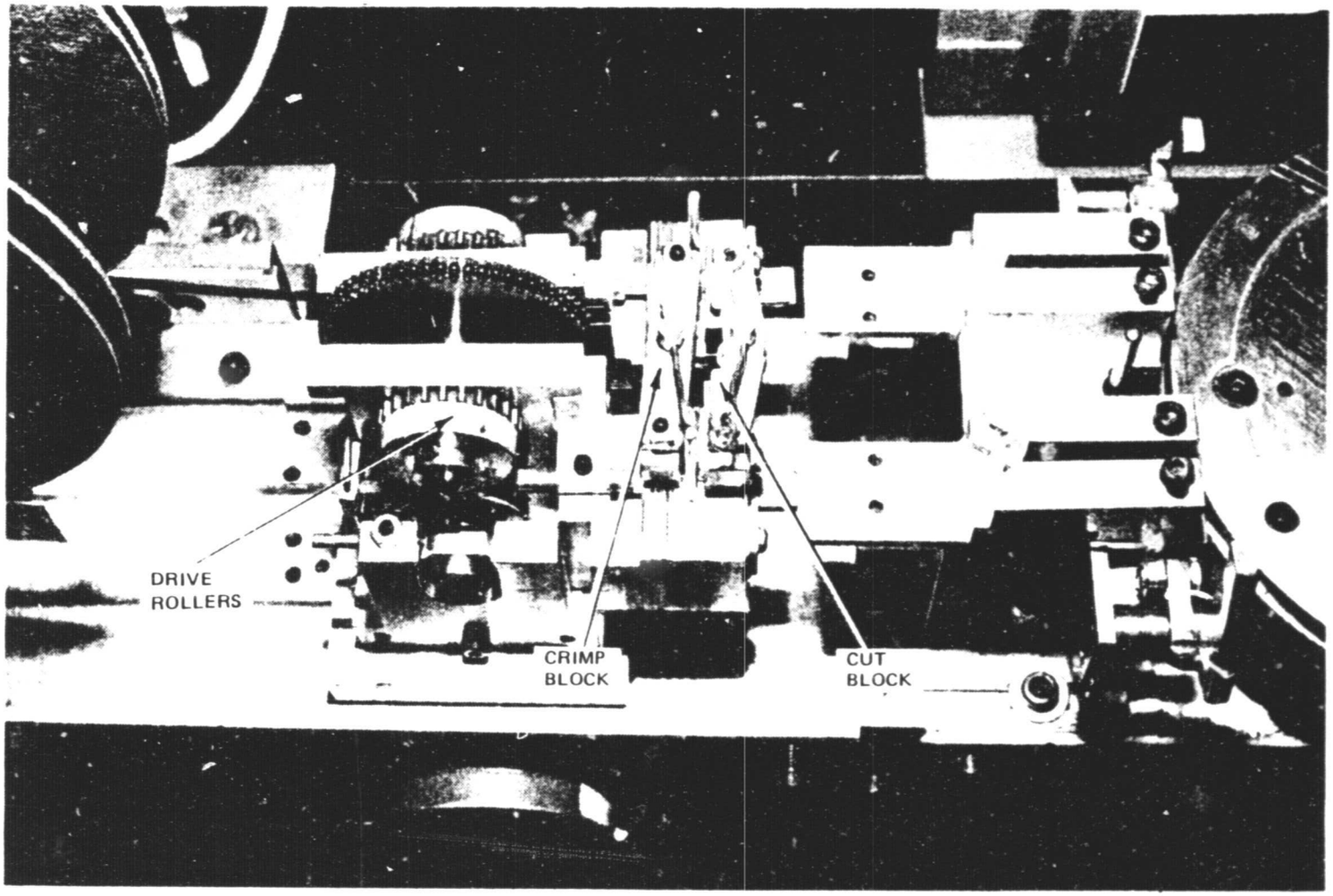

FIGURE 5-4
RIBBON FEED AND FORMING MECHANISM

functions would have to be separated. This could be done by leaving the crimp block near the cell and move the cutter back 4". However, with this configuration, when the robot lifted the cell, it would drag 4" of solder paste covered lead through the crimping die. Smearing of the paste and contamination of the die would be unavoidable. Therefore, in the final design we have also moved the crimp die back 4" and placed it behind the cutter. The lead preparation procedure now is to feed out half the lead (approximately 4"), crimp it, then feed the remaining lead while applying solder paste from a dispensing needle located just above the cutter. The cutter is the last device through which the lead must pass. In this way there are no verticle obstructions to the prepared lead when the robot lifts it.

Although each of the leads has its own crimp block, they are operated simultaneously by a single air cylinder through a "T" bar and bell crank linkage. An identical arrangement operates the cutter assemblies.

5.2.1.1.3.3 Hold Down

Interconnect lead hold downs (Figure 5-5) have been provided in the prototype to prevent lead motions during robot hovering and pickup maneuvers. There are two small, padded arms operated by a single cylinder on a common linkage which clamp the leads to the vacuum chuck's surface. The arms are articulated to swing out as well as up to be completely clear of the lead during lifting by the robot.

5.2.1.1.4 Solder Paste Dispensing

There are two sets of solder paste dispensers on the preparation station. One pair is mounted on a bridge over the cutter assembly and dispenses paste on the lead as it emerges from the feed assembly (Figure 5-6). The other pair is mounted on a motor driven ball slide which first extends out over the cell then lays down a bead of solder while retracting (Figure 5-7).

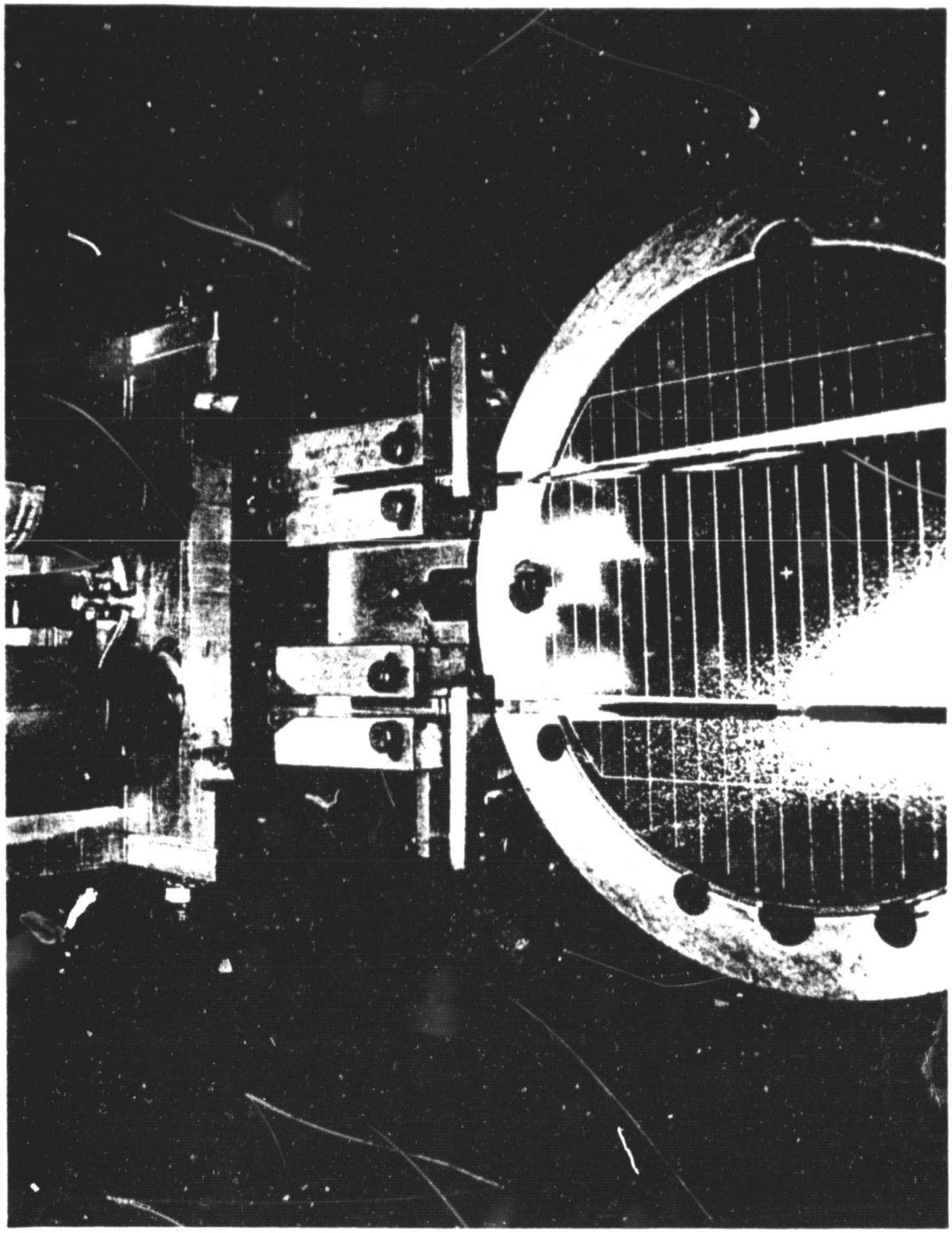

FIGURE 5-5
RIBBON HOLD-DOWN

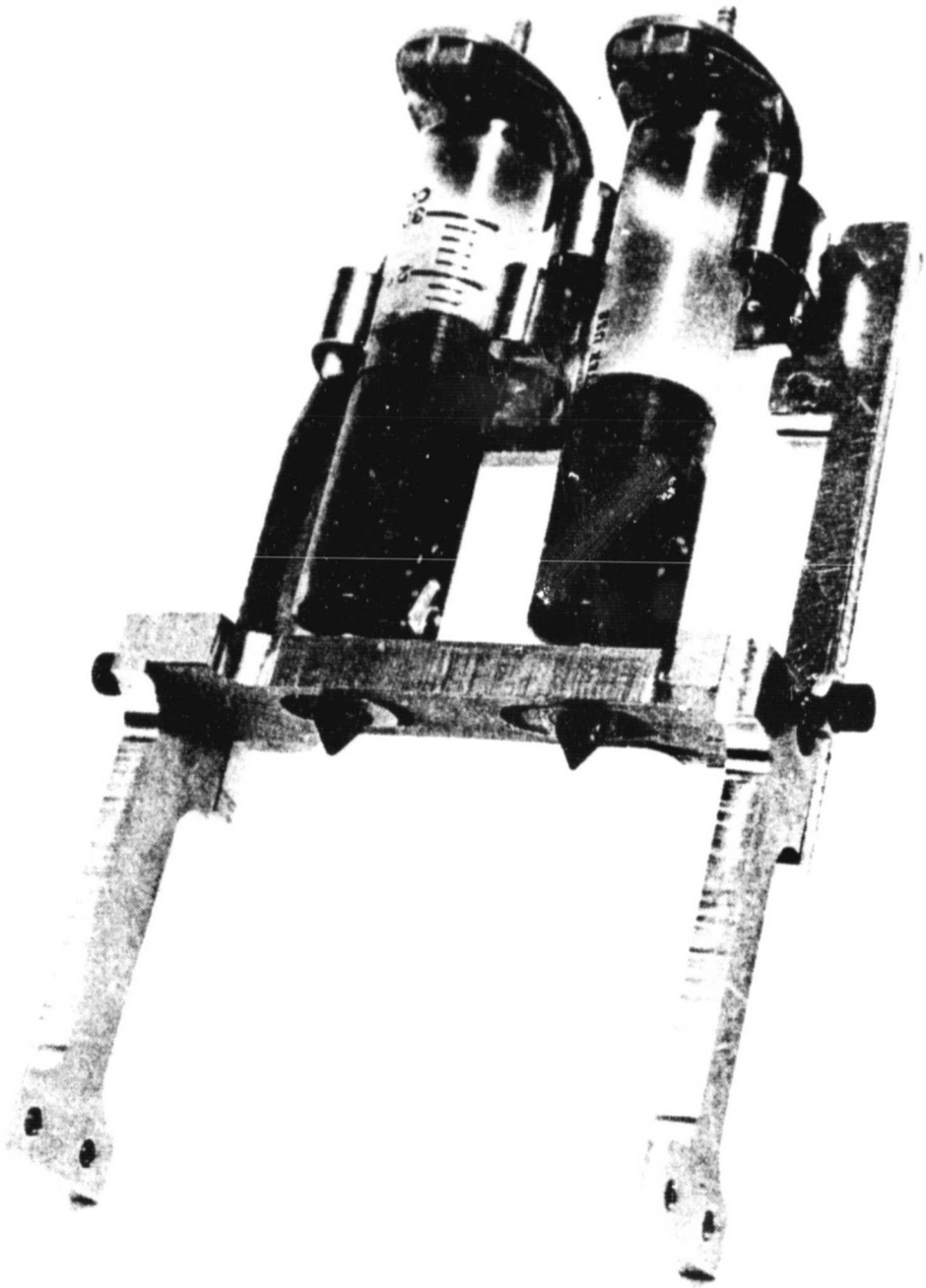

FIGURE 5-6
SOLDER PASTE DISPENSING BRIDGE

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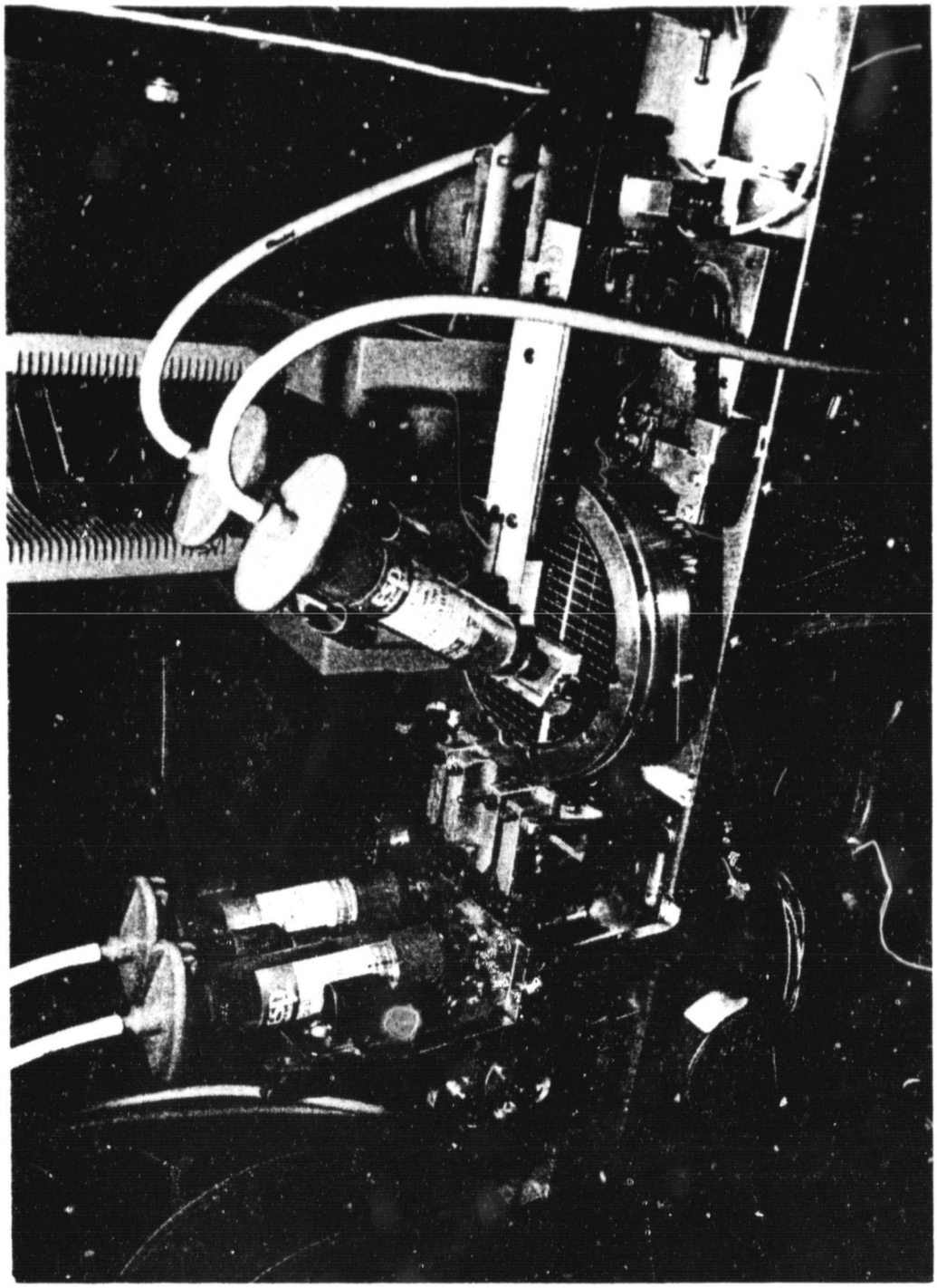

FIGURE 5-7
CELL SOLDER PASTE DISPENSER

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For the fixed solder paste dispensers, the supply tubes are mounted in clips supported by uprights while the needles ride in carriers in the bridge surface. For fast changing of the supply tubes the needles can be removed and inserted in the carriers without disturbing the aiming alignment. Both carriers are spring loaded from the center with adjusting screws on the outside. Once correctly aligned, jam nuts maintain the adjustments. This mechanism is quite flexible as the paste can be easily aimed to fall anywhere on the ribbon. Also, by varying either the air pressure and/or ribbon feed rate, the bead of solder can be made to form dashes (when the solder flow rate is less than ribbon feed rate), solid lines (when the rates are equal) or even swirls (when the flow rate exceeds the feed rate). Each set of dispensers has its own in-line pressure regulator.

The original design of the moving solder paste dispenser had the dispensing tips mounted on the end of a cantilivered screw drive with a single guide rod on the side. This lightweight mechanism was inadequate for supporting two 30cc paste reservoirs. In addition, it was slow (over 12 sec. cycle time), mechanically inefficient (the losses in the screw drive causes the motor to stall occasionally) and inaccurate due to excessive backlash and bearing slop when fully extended (which caused binding further increasing the load to the motor). It was replaced by a rack and pinion drive attached to a commercial ball slide. The ball slide has a much larger load capacity than the screw drive and can operate at much higher speeds. Other advantages to the ball slide are much higher mechanical efficiency (approximately 90% compared to 40%) and much greater tracking accuracy. The total sideways deviation is only 0.005" at full extension compared to more than 0.1" for the screw drive. (Note: contact pad width is 0.1"). For robot clearance purposes, the supply tubes are laid back at approximately 15° from the verticle. The needles also ride in carriers and an aiming device identicle to that of the fixed dispensers is used.

We briefly investigated solder coated lead material. This would eliminate the need for solder paste dispensing and all of its attendant mechanisms. Our results, however, were not encouraging. Using solder coated leads it was found that very poor bonds, or no bond at all, were formed unless flux was also applied. Even when flux was applied, the bonds were inferior to those made with solder paste. These results are consistant with the conclusions of other contractors in the LSA project. In any case, flux dispensing mechanism would be nearly indentical to one for solder paste dispensing and would cancel any mechanical simplifying. The big advantage in doing away with solder paste and/or flux is that the post-bonding cleaning (to remove flux) is no longer required, thus saving a process step.

Due to its inherent advantages, MBA feels that solder coated lead material deserves further study. A form of solder-and-flux coated lead may prove to be a workable combination with correct flux compounding.

5.2.1.1.5 Optical Orientation

The optical orientation system works on a simplified version of the principle describes in Section 5 1.2.

The optical sensor consists of a lens which focuses an image of the cell onto a mask, behind which is a photovoltaic cell. (See Figure 5-8). When the cell is in the proper orientation, the image of the bright metallization pattern is admitted by the mask (actually a series of blocking slits) raising the output of the photocell. The phenomenon involved is simply the greater reflectivity of the silver in the metallization pattern compared to the adjacent silicon surface.

Although simple in design, the sensor works flawlessly. When coupled with the correct computer program and control electronics, it will consistently orient cells to within $\frac{1}{2}^{\circ}$, which is the positional limit of our turntable.

A necessary addition is that of an auxiliary light source. This is to compensate for the unpredictable nature of the ambient light in the area that the station is to be located. A moving person or object (such as the robot) casting a shadow on the cell during orientation could

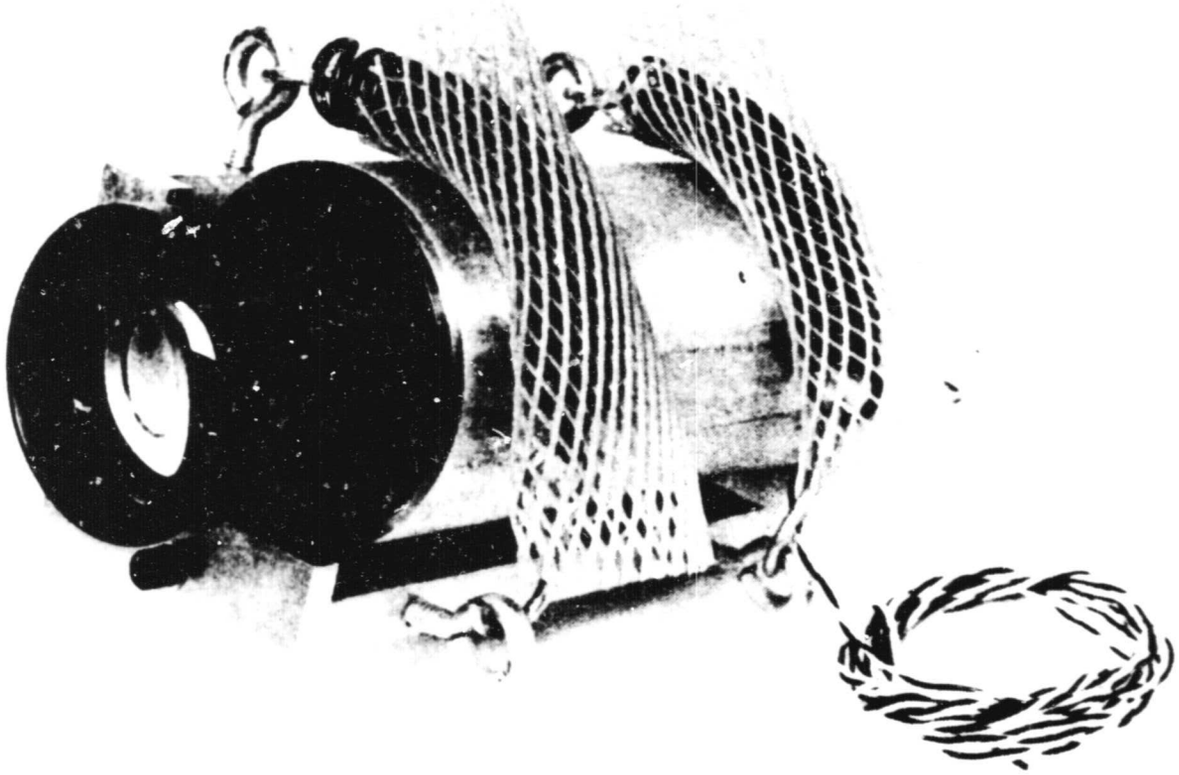


FIGURE 5-8
OPTICAL ORIENTATION SENSOR

degrade the signal sufficiently to cause problems.

The crystalline nature of the cell's surface causes secondary reflections at about 45° from the vertical. If the light source is placed at or near this angle it causes a contrast reversal as seen by the sensor, i.e., the metallization appears as a dark pattern against a bright surface. This is easily prevented by careful lamp positioning. An other problem is that there is a 60 Hz "hum" superimposed on all lamps that use line current, even incandescents. Experiments with various lamps showed regular room lamps with low temperature filaments to be the worst. In some cases the amplitude change due to the hum was greater than that we were trying to measure due to the cell rotating. It was found that higher temperature filaments (higher wattage bulbs) suffered less from this problem so we are using a 600 W movie illumination lamp and reflector as a light source. A better solution for a production machine would be to use a focused DC lamp of much lower wattage as 600 W is five to ten times more power than necessary to make the sensor work.

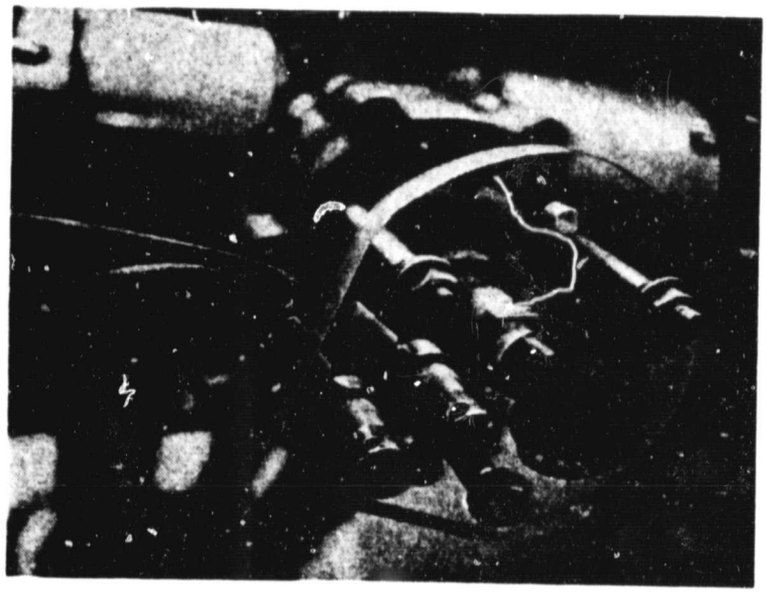
5.2.1.2 End Effector Development

Effort on end effector design was concentrated in two areas: Robot feasibility studies with a resistance-heating type bonder and experimentation with various induction coil configurations leading to the end effector design.

5.2.1.2.1 Resistance Heating End Effector

A series of tests were performed with the end effector shown in Figure 5-9. It consists of two spring loaded carbon electrodes beside a centrally mounted vacuum pick up. It works by placing one electrode on the lead and the other on the cell's surface thus forcing the current to pass through the solder joint. By using a fairly high current (≈30A)* intense local heating was achieved. This produced excellent bonds to either side of the cell with a fairly short (≈ 1 sec.) bond time. However, this was just a feasibility test. The end effector as-tested could only make

*Surprisingly, tests performed before and after bonding showed no degradation of cell output regardless of which way the current flowed.



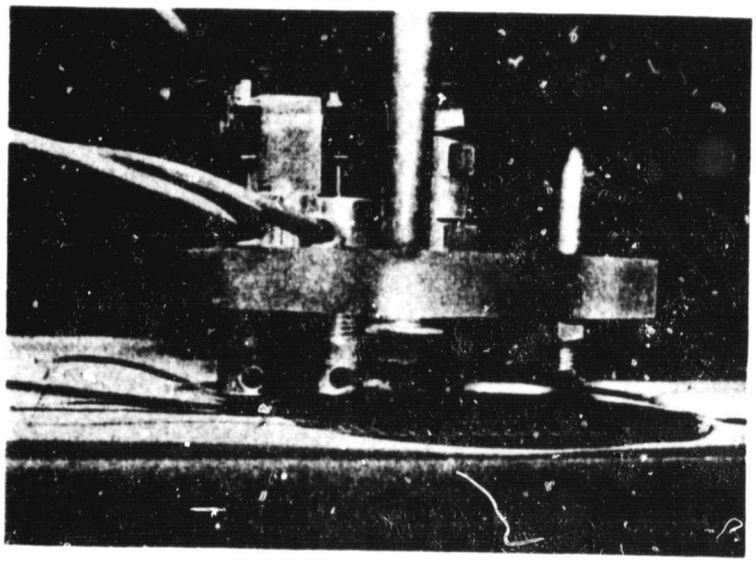


FIGURE 5-9
RESISTANCE HEATING END EFFECTOR

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short (<1") bonds and required the high precision positioning of electrodes.

5.2.1.2.2 Induction Heating End Effector

5.2.1.2.2.1 Design

For an induction heating power source we used a Taylor-Winfield Model 300 A generator. This unit produces 2.5 Kw at 450 KHz.

Several different coil shapes were tried, all designed to concentrate the induced currents along the strips of the cell where the leads are attached. It turned out, however, that the coil with the fastest heating was a simple spiral or "pancake" coil. Shown in Figure 5-10 is the coil used in the final end effector. The coil is made from ¼" thinwall square section tubing (a more efficient RF radiator than round) and measures 4" in diameter.

Figure 5-11 shows the final end effector as mounted on the robot. It consists of the coil described above encapsulated in silicone RTV . The main body is formed of Plexiglass (the material also used in the resistance heat end effector) into which the encapulated coil is bonded. This is then mounted on a stand-off made of Delrin to remove it from the steel in the robot to prevent any loss of RF energy. At the top of the stand-off is a Plexiglass flange drilled to match the robot's mounting flange. This makes the entire inside of the stand-off a vacuum chamber. Small holes molded in a matrix between the windings of the coil form the vacuum pick up. The encapsulant is thin towards the bottom to get the coil as close as possible to the cell (necessary for fast, even heating) and thick on top to act as a compliant coupling to compensate for robot positioning tolerances.

5.2.1.2.2.2 Testing and Modifications

The first end effector built to these specifications was tested and its performance was quite satisfactory. There was a problem, however, with uneven heating. This was due to the plane of the coil being non-parallel to the plane of the surface of the pottant where the cell is attached during heating. Where the coil was near the surface there was

FIGURE 5-10
END EFFECTOR COIL

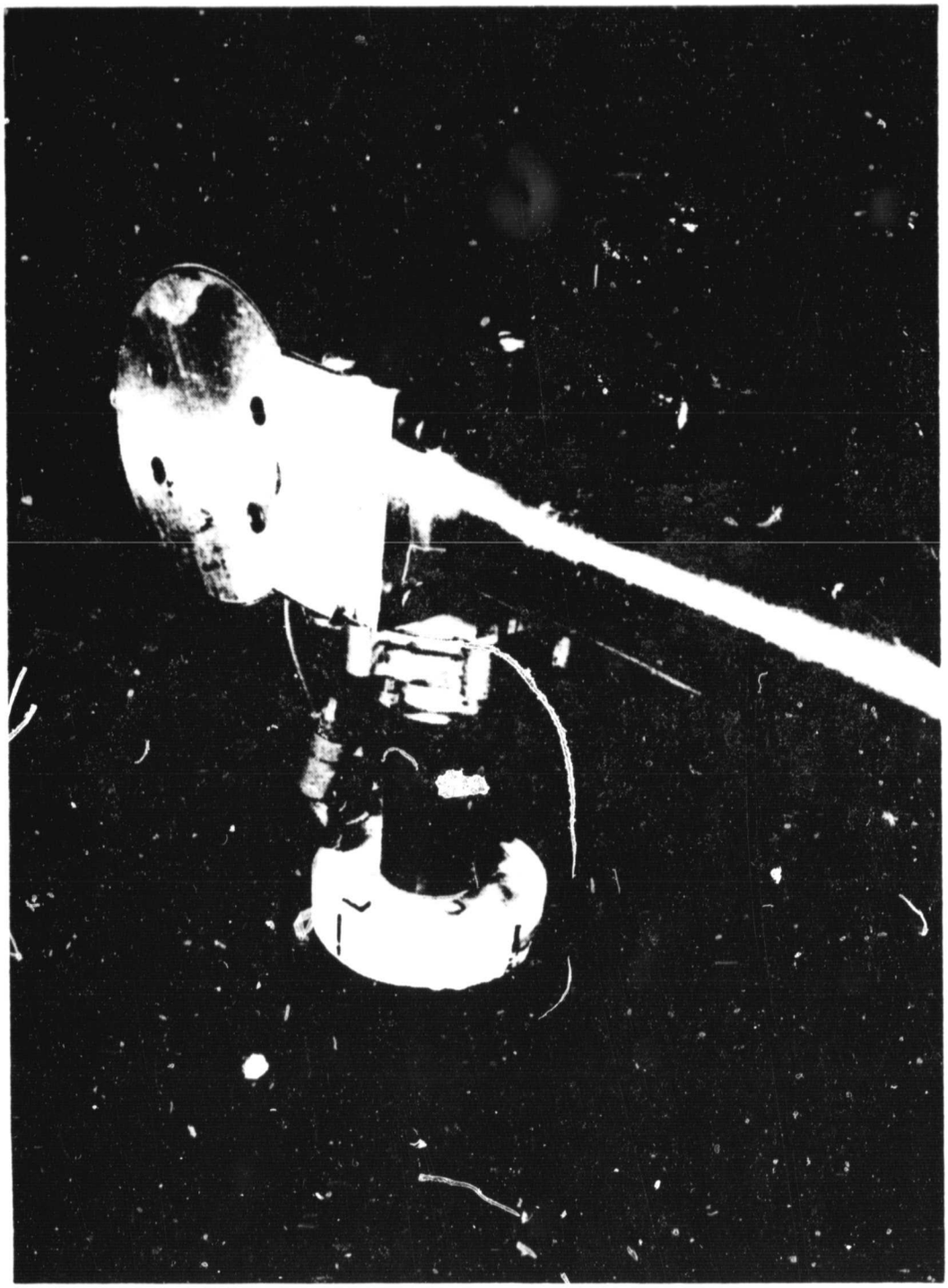

FIGURE 5-11
END EFFECTOR ON ROBOT

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a hot spot. Where the coil was deeper there was a cold spot.

The coil was carefully broken out of the potting and tested "bare". It proved to be quite efficient (bond time ≈3 sec.) with very even heating. This further supported the sensitive nature of coupling (the distance between the coil and workpiece).

With this in mind the coil was re-potted paying very close attention to the coil depth during the molding and machining operations. The coil was left somewhat deeper (about 0.5 ") than final design specs to leave some margin for experimentation.

There were two areas where the end effector performed better than expected. The vacuum matrix on the pickup surface did an outstanding job. It never failed to achieve the pickup even with broken or partial cells that exposed more than half the vacuum holes to air. This capability is necessary for rejecting broken cells. It must be remembered also that the interconnect ribbon was between the cell and pickup, further reducing the possibility of a good seal. Additionally, no cells were broken by the robot during handling tests, not even very thin (<10 mil) cells with severe "potato chip" warping (although several were broken by human handlers!).

We attribute this performance to two factors. One is the broad surface of the end effector which supports the entire cell rather than just one or two points. The other is that we are using an eductor, identical to the one described in Section 5.2.1.1.2, as a vacuum source. This low grade vacuum is very gentle on the cells and the high air flow rate makes it quite insensitive to exposed air holes.

The other area in which the end effector excelled was heat resistance. We are using General Electric RTV-11 as a potting compound which has maximum temperature limits of 400°F for continuous use and 450°F for short periods. As normal soldering operations take place at 350°F this is sufficient. However, if the cell is broken or has a crack, the induced eddy currents tend to concentrate along the discontinuity causing extreme local heating to temperature in the neighborhood of 1500°F

(based on color).

Even at these temperatures, nearly four times the design maximum for the material, the silicone did not melt, char or decompose in any manner that would damage future cells. The only damage to the end effector's surface was a dry decomposition of the silicone which ranged from a fine powder to pieces the size of eraser crumbs. Although this caused an erosion of the silicone surface, it did not seem to effect the operation of the end effector.

A problem was encountered of the cells sticking to the end effector after soldering due to the melted flux. To assure positive release of the cell, the robot was re-plumbed to produce a positive air flow out of the end effector during release. This gives the end effector the same three modes as the vacuum chuck: pressure, vacuum and ambient.

5.2.2 Electrical and Control Systems

From the outset it was decided to use digital control in the operation of the preparation station. This technique, which uses a micro computer as a system controller, allows the mechanical design of the station to be simple and straightforward. This is due to the fact that all of the "intelligence" of the system can be built into the micro processor by appropriate programming rather than relying on the elaborate mechanical design of cams and linkages. It also allows the system to be extremely flexible as changes in operating parameters (such as a new cell configuration) can be handled in most cases by simply changing the computer program rather than by a mechanical redesign.

A cost/benefits analysis showed the Radio Shack TRS-80 micro computer system (Figure 5-12) to be the most cost effective solution to these control/processing requirements. The TRS-80 uses a Z-80 micro processor and incorporates a BASIC Language interperter. The model used has the Level II BASIC (which allows access to the computer's assembly language" and 4K of RAM. This can be expanded to 16K or 32K at modest cost.

FIGURE 5-12
TRS-80 MICRO COMPUTER

The following discussion is a detailed description of the electronic hardware in the cell preparation station which interfaces the output signals from the computer with the electro/pneumo/mechanical functions of the preparation station.

5.2.2.1 Electronics Package

The electronics package performs three distinct interfacial functions with the TRS-80; mechanical equipment interface, optical orientation sensor interface and Robot interface. Figure 5-13 shows the location of the electronic package components within the preparation station.

It is necessary to convert the parallel 8 bit data and address information from the computer's output buss into discrete on/off commands for each of the devices controlled by the computer. This is accomplished by an Intel 8255 peripheral interface chip designed for this purpose. A second 8255 is used as an input for interface for feedback signals. The 8255's, inturn, interface with the following equipment.

5.2.2.1.1 Mechanical Equipment Interface

The output ports form the 8255 cannot be connected directly to the solenoid valves and stepper motors as its current capacity is far too low. In order to operate these high current devices, an intermediate driver board must be used. This board contains 22 driver circuits (only 19 are presently used) which use Darlington 2N 6055 power transistors to switch the necessary current on and off. In between each driver and the 8255 is a Monsanto 4N33 Optical Isolator. This device (which is essentially an LED connected to a photo transistor) allows information signals to travel without direct electrical connections. In this way large current surges (such as during solenoid valve operation) are prevented from reaching the 8255 thus avoiding potential damage. For the input 8255, the signals pass through a conditioning network consisting of a pair of blocking diodes and fusing resistors. This protects the 8255 in a manner similar to the optical isolators.

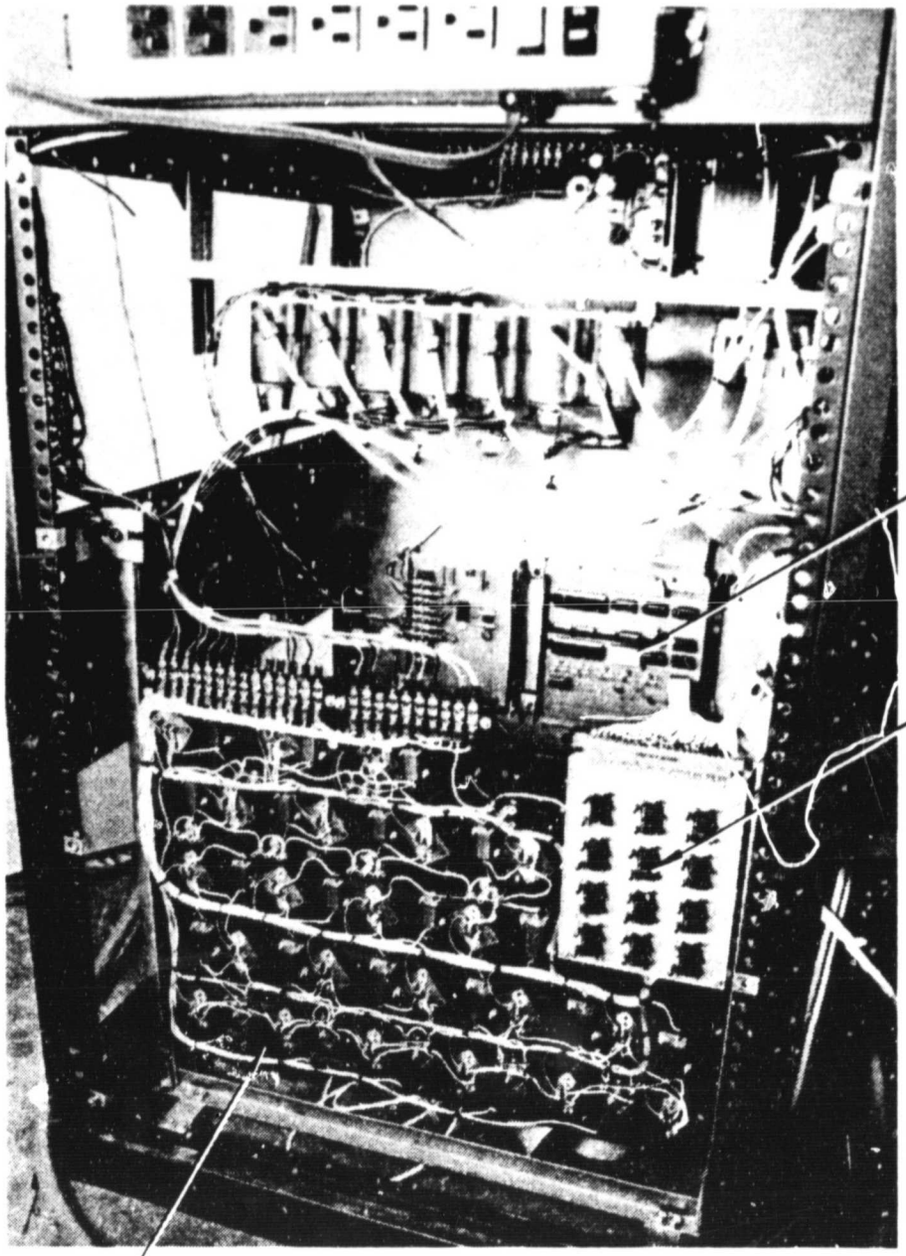

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FIGURE 5-13
ELECTRONICS PACKAGE COMPONENTS

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5.2.2.1.2 Optical Orientation Sensor Interface

The optical orientation sensor (Figure 5-8) is an analog device and its data must be converted to digital form in order to be used by the TRS-80. We used a National Semiconductor ADC 1210 analog to digital converter for this purpose. However, the output from the sensor is so extremely low that considerable amplification (on the order of 10^6 times) is required. A two stage amplifier using a pair of Motorola MC 1556 op-amps raises the signal to a level detectable by the 1210.

5.2.2.1.3 Robot Interface

The Unimate Robot was designed for use in industry where hard-wired limit switches are used to signal the completion of external tasks. Due to this "switch closure" logic, the robot is unable to understand the "binary voltage level" logic used by the electronics package. Therefore, we used reed relays, driven by the 8255, to give the robot the "switch closure" it is looking for. This also applies to the Siltec cassette unloader since it also uses "switch closure" to initiate its function.

The robot uses this switch closure two ways: for input and output. When the input or "Wait External" (WX) is programmed into the robot it will wait at that step until it receives a switch closure signifying the completion of the external task. The output or "Operate External" (OX) closes a relay inside the robot presenting a switch closure to whatever external device is being operated.

Being a piece of industrial equipment, the induction heater also uses switch closure to start. As such, it could be operated directly by the TRS-80 via the reed relays. It was decided, however, that since the robot and heater were bound in such a lock-step relationship (the heater cannot start until the robot has picked up the cell and the robot cannot release the cell until the heater has finished) that they would be considered a single unit. The induction heater is controlled only by the robot's internal program. The "heat-on" duration is controlled by the heater's built-in timer.

5.2.2.2 Computer Program

The last portion of the station to be developed was the controlling computer program. This was necessary since it was required that the electro-mechanical portions of the machine be nearly fully developed before the program could be started.

The first step in the computer program's development was to write a single unifying program that would operate all of the functions of the preparation station,signal the robot and Siltec cassette unloader and do it all with the proper sequences and durations. This first program was written in the BASIC computer language for ease of programming. BASIC, however, is quite slow running for this purpose (the cell orientation alone took over 30 sec.) so the next step was to speed up the program. This was done by rewriting some of the subroutines of the program in much faster running assembly language. The first to be rewritten was the cell orientation routine. The assembly language routine cut the orientation time an order of magnitude to just below 3 seconds.

Two other routines were rewritten in assembly language; the ones controlling the ribbon feed and solder paste dispensing arm. The time saved by speeding up these three routines dropped the cell preparation cycle time from 50 sec. (for an all BASIC program) to approximately 15sec. for the final program.

5.3 Operation Sequence

This description of the sequence of operations for the preparation station will begin with a discussion of interface network's actions. The reader should realize that when a description says "the computer commands . . ." or "the valve is commanded . . ." that this refers also to the interface network in operation. Figure 5-14 is a schematic representation of the data flow within the preparation station.

5.3.1 Command and Feedback Data Flow

The system is initialized by having the TRS-80 send out an address on its output buss that the 8255 recognizes as "itself". It is

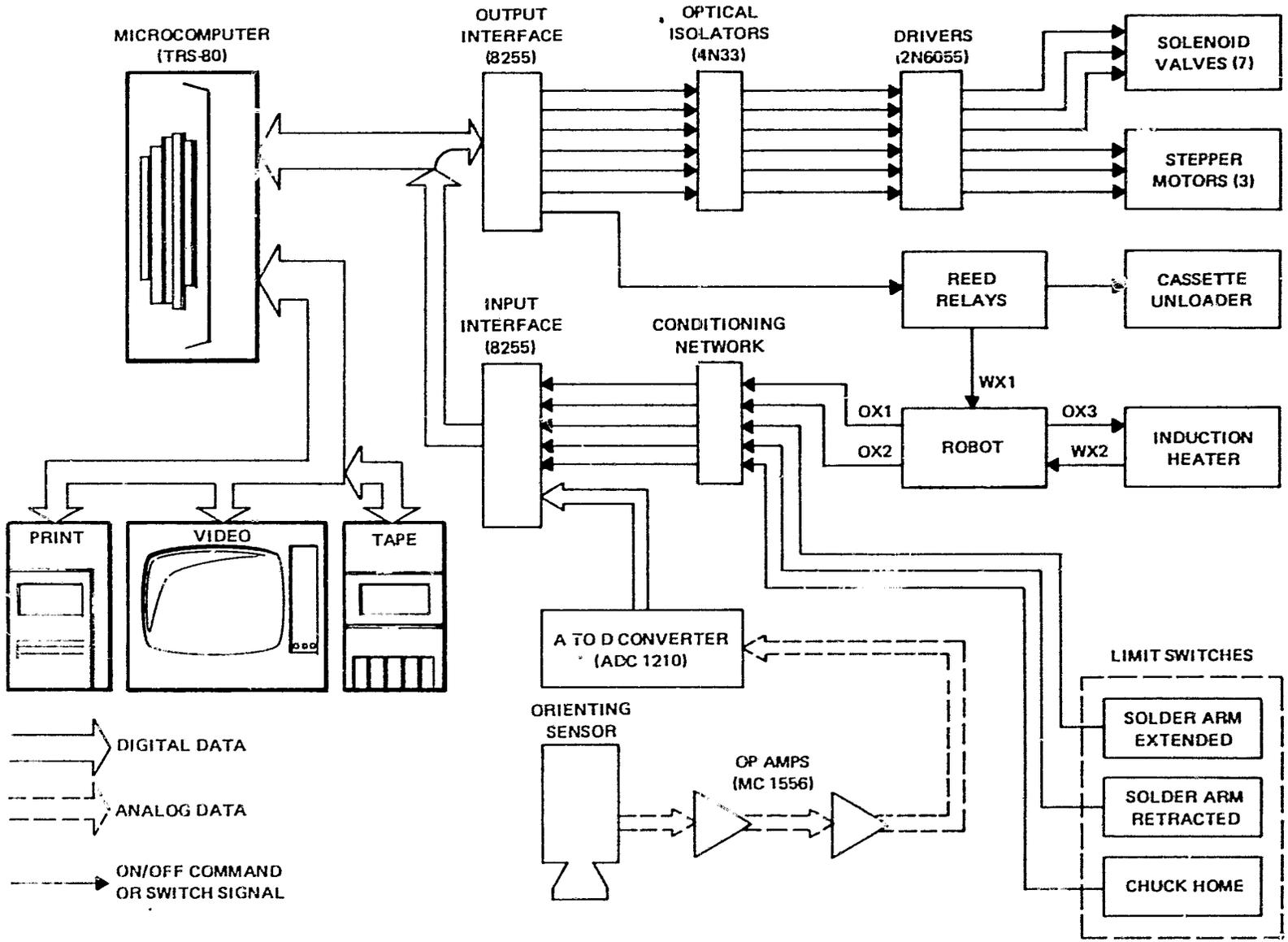

FIGURE 5-14
PREPARATION STATION DATA FLOW

then ready to accept commands from the TRS-80. A command comes in two parts: address and data. The address tells the 8255 which of its 24 output ports are to be used. The data says whether the ports chosen by the address will output a high or low (on or off). Each port is connected to a 4N33 optical isolator which electrically separates the 8255 from the power transistors. A "high" output form a 4N33 is enough to cause a power transistor to switch, turning on the current to the chosen device. A "low" output is insufficient and the transistor will switch off, turing off the current.

Each stepper motor requires four driver circuits (hence four optical isolators and four ports on the 8255) and each solenoid valve needs one. Since there are three motors and seven valves, this means a total of 19 drivers, etc. are required. The driver board has 22 power transistors on it and some room for expansion. The optical isolator board has 24 circuits available to match the 24 ports on the 8255 although only 22 are used.

The feedback from the limit switches and robot OX relays works in a similar manner. The switches and relays present high or low voltage levels (for closed or open contacts respectively) to the input ports of the second 8255. When the TRS-80 interrogates the 8255 with an address, the 8255 can respond with data indicating whether the input port at that address is high or low.

Data from the optical orienting sensor is processed the same way. The output of the analog to digital converter is connected to 12 of the input ports on the 8255. This, in effect, creates a 12 digit binary number representing the analog data from the optical sensor.

5.3.2 Sequence Steps

Following is a step-by-step description of the cell preparation, placement and interconnection cycle. Figure 5-15 is a time line representation of the process.

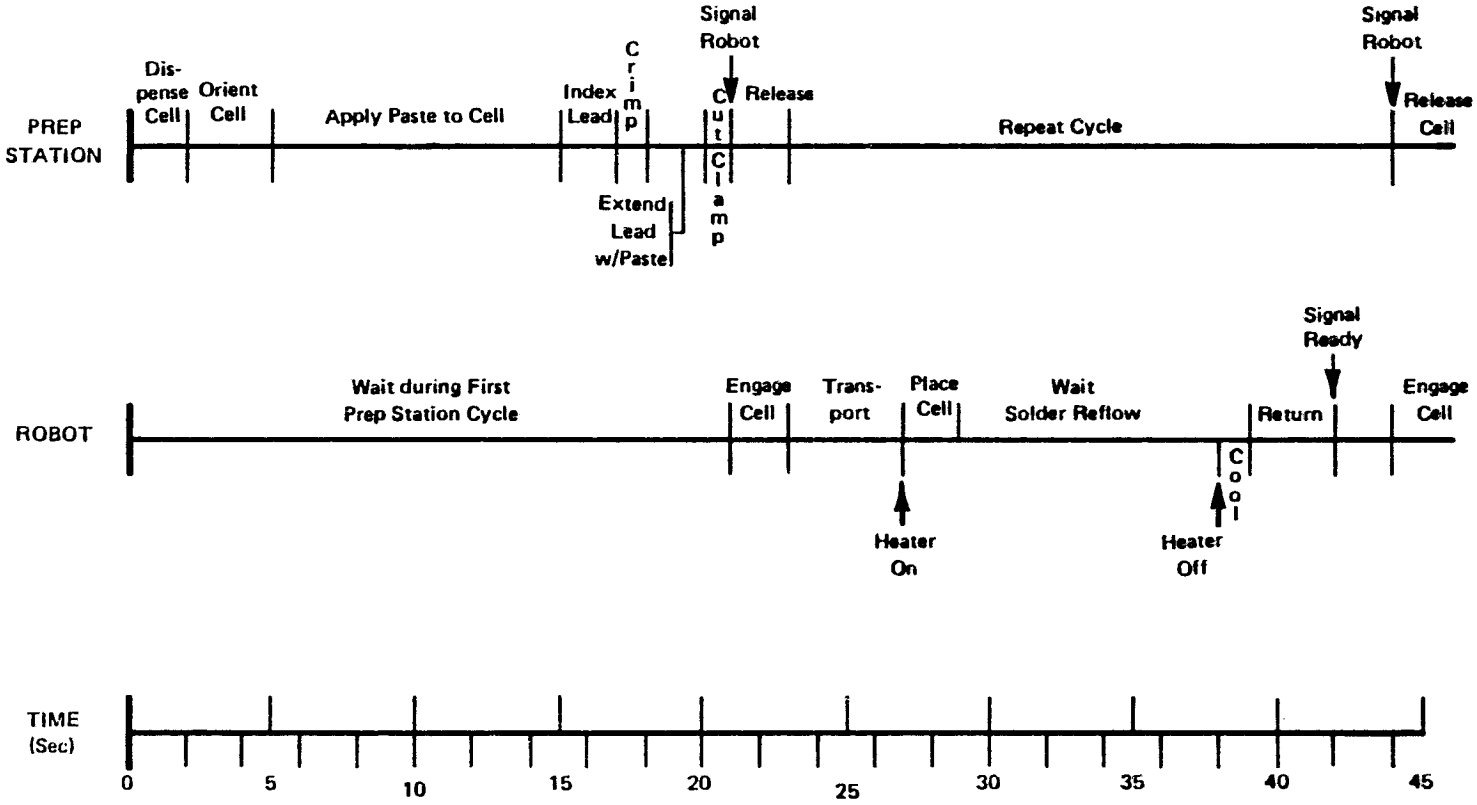

FIGURE 5-15
CELL PREPARATION AND PLACEMENT CYCLE

The gross steps involved in cell preparation and interconnection are as follows:

1) Initialize System

2) Dispense Cell

3) Orient Cell

4) Apply Solder Paste to Cell

5) Form Interconnect Leads

6) Robot Pickup (Preparation Station returns to 2 and repeats cycle).

7) Transport and Heat

8) Placement reflow (Robot returns to 6 and repeats cycle).

A detailed explanation of each of these steps follows.

1) Initialize System - This series of commands sets the preparation station to its initial conditions: The vacuum chuck is rotated until the locating pins are opposite the cassette unloader (also called the home position), the interconnect ribbon cutter is cycled to trim any excess lead and the Siltec unloader lowers the cassette to the first cell. All valves are commanded to the off position. The robot's cycle must also be started but this is not externally commandable and must be done by the operator.

2) Dispense Cell - The cassette unloader is commanded to dispense a cell. The system turns on the air to the chuck and pauses about 2 seconds to allow the cell time to travel down the belts and settle against the locating pins.

3) Orient Cell - The cell is now clamped to the chuck's surface by shutting off the air and turning on the vacuum to the chuck. The cell is then rotated 360°

in order to scan its entire surface and determine the locations of the contact pads. The analysis of optical sensor data is done real time (while the cell is rotating) so that once the scan is completed the chuck can proceed immediately (at its highest speed) to the correct orientation without stopping to analyze the data.

4) Apply Solder Paste to Cell - The moving solder paste dispenser arm is extended over the cell at maximum speed until the limit switch is reached. Air is turned on to dispense the paste while the arm retracts. The speed of retraction is calibrated (empirically) to the maximum that the flow rate of the needles will allow and remain a continuous bead. This continues for a preset distance until the dispenser reaches the end of the contact pads. Air to the dispenser is turned off and the arm retracted at maximum speed unitl the limit switch is reached.

5) Form Interconnect Leads - The ribbon is fed at full speed until it is in the correct position for crimping. Air to actuate the crimp die is commanded on for approximately 0.25 seconds and the ribbon is again fed at maximum speed until the crimp clears the paste dispensing needles. Air to the lead paste dispensers is turned on and the ribbon feed rate slowed to match the flow rate of the needles. This continues a preset distance until the front of the lead reaches the far end of the cell. At that point the ribbon feed is stopped, air to the paste dispenser is commanded off and the lead hold downs are activated. The cutter is operated for approximately 0.5 seconds to insure a good clean cut.

6) Robot Pickup - The TRS-80 now interrogates the robot to see if it is ready. When it is, a signal is sent that starts the robot's program and it moves into position over the cell. The robot signals the TRS-80 that it is in position and at the same time opens that valve creating a vacuum at the end effector. The computer then turns off the vacuum to the chuck. The lead hold downs are commanded to release and the robot lifts the cell.

7) Transport and Heat - After the robot has lifted the cell clear (about 2") it signals such to the TRS-80. The computer then commands the chuck back to the "home" position at top speed and returns to step 2 of this sequence to repeat the cycle. The robot transports the cell into position over its intended location in the panel. It then starts the induction heater which is under the robot's program control.

8) Placement and Reflow - The robot positions the cell in place and waits for the heating cycle to finish. This cycle is controlled by the induction heater's internal timer. When the timer clocks out, the heater signals such to the robot which starts its own internal timer to allow the cell to cool. These timers are continuously variable even during program execution to allow total control over heating and cooling times. The robot commands the vacuum off and the air on to release the cell. The air is turned off and the robot moves back to its wait position in front of the preparation station. It signals the TRS-80 that it is ready and waits until signaled back that a cell is ready to be picked up. The robot then repeats the cycle from step 6 of this sequence.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Critical review and verification have been performed in the areas of plasma etch, aluminum back contact, panel edge sealing, automated array layup/interconnect, and production variations due to large diameter wafers.

Work in plasma etching has reached the conclusion that plasma edge etching is superior to back etching. Verification of this process has been made with production lots of 1,000 being processed with plasma edge etching technique. Performance of the resulting cells are comparable to those cells being processed in a wet chemical back etch line. Continued production lots are being run using the plasma process.

Aluminum P+ back contacts have been produced in small lots using automated production techniques. Some problems were encountered in direct application to production size lots.

An EPDM based sealant appears to be the most applicable for low cost module edge sealing. Automation equipment could be designed to allow rapid application of the sealant and/or frame.

The feasibility of using an industrial robot as the basis for an automated layup and interconnect system has been demonstrated. The system uses a "smart" preparation station to unload and orient the cell, apply the solder paste and form the interconnect ribbon. The robot picks up this prepared cell with a vacuum-based end effector and bonds it into position in the array by reflowing the solder paste with an induction heating technique.

This system can and should be expanded into one where the robot can be used for the next steps in module production: encapsulation and final panel assembly.

APPENDIX A

SAMICS Data Inputs (Formats A, B and C)
and Completed Run For 500 Megawatt
Hard-Automation Industry

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT C

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif. 91103

INDUSTRY DESCRIPTION

C1 Industry Referent SAMICS-86

C2 Description (Optional) 1986 STANDARD Industry

INDUSTRY OBJECTIVE

C3 Industry Result New Photovoltaic Power Capability

C4 Quantity Produced 500×10^6 Peak-Watts / Year

DESCRIPTION OF THE FINAL PRODUCT OF THE INDUSTRY

C5 Reference PSM Name Packaged Solar Modules

C6 Production is Measured in Modules / Year

C7 Hardware Performance 280 Peak-Watts/Module (C4 per C6)

C8 Product Design Description (Optional) 16 Parallel connected strings of 18 series connected 4" cells. Each array is encapsulated, edge sealed and framed. The completed modules are packaged for shipment.

MAKERS OF THE FINAL PRODUCT OF THE INDUSTRY

C9 Company Reference MODULECO Market Share 40 %

Company Reference CELLCO Market Share 40 %

Company Reference _____ Market Share _____

Prepared by CRW Date 3/9/78

JPL 3039-S 11/77

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT B

COMPANY DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif. 91103

B1 Company Referent MODULECO

B2 Description (Optional) Standard SAMICS Cell-to-Module Company

B3 Product Produced PKGMOD

B4		Process	PKGMODULE
B5	Intermediate Product TMOD	Process	FINALTEST
	Intermediate Product FMOD	Process	TRIMSEAL
	Intermediate Product ENCAPMOD	Process	BOND
	Intermediate Product LAYMOD	Process	LAYUP
	Intermediate Product PREMOD	Process	PPREP
	Intermediate Product RIBBON	Process	CELLAY
	Intermediate Product	Process	
	Intermediate Product	Process	
	Intermediate Product	Process	
	Intermediate Product	Process	
	Intermediate Product	Process	
	Intermediate Product	Process	
B6	Purchased Product PCELLS		
B7	Supplier Company Reference CELLCO	Percent Supplied 100 %	
	Supplier Company Reference	Percent Supplied	

Prepared by CRW Date 3/9/78

JPL 3038-S 11/77

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT B

COMPANY DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif 91103

B1 Company Referent CELLCO

B2 Description (Optional) Standard SAMICS' Wafer-to-Cell Company

B3 Product Produced PCELLS

B4 Process PKGCELLS

B5 Intermediate Product FCW — Process FCONTACT

Intermediate Product BCW — Process BCONTACT

Intermediate Product EEW — Process EDGE.ETCH

Intermediate Product DW — Process DIFFUSION

Intermediate Product DRYW — Process DRY

Intermediate Product EACW — Process CLEAN

Intermediate Product TWAFERS — Process INSPECT

Intermediate Product ____ — Process ____

Intermediate Product ____ — Process ____

Intermediate Product ____ — Process ____

Intermediate Product ____ — Process ____

B6 Purchased Product PWAFERS

B7 Supplier Company Reference WAFERCO* — Percent Supplied 100%

Supplier Company Reference ____ — Percent Supplied ____

Prepared by CRW — Date 3/9/78

*WAFERCO is not modeled in this industry. If it were, it would be the company that produced as-sawn CZ wafers from poly-crystalline silicon.

JPL 3033-S 11/77

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

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FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] PKGMODULE

A2 [Descriptive Name] PACKING AND SHIPPING

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] PKGMOD

A4 Descriptive Name [Product Name] MODULE PACKAGED FOR SHIPPING

A5 Unit Of Measure [Product Units] MODULES

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 6 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 2.0 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	PACKER		
A9a	Component [Descriptive Name] (Optional)			
A10	Base Year For Equipment Prices [Price Year]	1977		
A11	Purchase Price ($ Per Component) [Purchase Cost]	30000		
A12	Anticipated Useful Life (Years) [Useful Life]	10		
A13	[Salvage Value] ($ Per Component)	2000		
A14	[Removal and Installation Cost] ($/Component)	1000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037–S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) PKG MODULE

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	400	SQ FT	MANUFACTURING SPACE
B3064D	.25	PRSN SHIFT	GENERAL ASSEMBLER
[illegible]	.003	PRSN SHIFT	ELECTRONICS MAINTENANCE
[illegible]736D	.003	PRSN SHIFT	MAINTENANCE [illegible]

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	.052	KWHR	ELECTRICIT
E1130 D	12	CU FT	CRATES [illegible]

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
TMOD	.999	MODULES/MODULE	TESTED [illegible]
		/	
		/	

Prepared by [illegible] Date [illegible]

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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California Institute of Technology
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PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] FINALTEST

A2 [Descriptive Name] FINAL TESTING AND LABELING

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] TMOD

A4 Descriptive Name [Product Name] TESTED MODULE

A5 Unit Of Measure [Product Units] MODULES

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 4 Units (given on line A5) Per Operating Minu

A7 Average Time at Station [Processing Time] .25 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	TESTER		
A9a	Component [Descriptive Name] (Optional)	TESTS MODULES		
A10	Base Year For Equipment Prices [Price Year]	1979		
A11	Purchase Price ($ Per Component) [Purchase Cost]	35000		
A12	Anticipated Useful Life (Years) [Useful Life]	10		
A13	[Salvage Value] ($ Per Component)	5250		
A14	[Removal and Installation Cost] ($/Component)	1000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) FINAL TEST

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A20647	200	SQ FT	MANUFACTURING SPACE A
B30647	.167	PRSN/SHIFT	GENERAL ASSEMBLER 2
[illegible]	.003	PRSN/SHIFT	ELECTRONICS MAINTENANCE
B 3736D	.003	PRSN/SHIFT	MAINTENANCE MECHANIC

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C.0328	.046	KWHR	ELECTR[illegible]

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
FMUD	.990	MODULE/MODULE	FINISHED MODULE
		/	
		/	

Prepared by Tom Philip Date [illegible]

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] TRIMSEAL

A2 [Descriptive Name] TRIM, EDGE SEAL AND FRAME MODULE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] FMOD

A4 Descriptive Name [Product Name] FINISHED MODULE

A5 Unit Of Measure [Product Units] MODULES

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 4.0 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] .25 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .95 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	SEALER		
A9a	Component [Descriptive Name] (Optional)			
A10	Base Year For Equipment Prices [Price Year]	1979		
A11	Purchase Price ($ Per Component) [Purchase Cost]	45000		
A12	Anticipated Useful Life (Years) [Useful Life]	8		
A13	[Salvage Value] ($ Per Component)	9000		
A14	[Removal and Installation Cost] ($/Component)	1000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037–S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) TRIMSEAL

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	400	SQ FT	MANUFACTURING SPACE (A)
B3064D	.167	PRSN/SHIFT	GENERAL ASSEMBLER
B3678D	.0015	PRSN/SHIFT	ELECTRONICS MAINTENANCE
B3736D	.0045	PRSN/SHIFT	MAINTENANCE MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E1232D	.76	DOLLARS	EDGE SEAL
E1100D	96	FT	ALUMINUM CHANNEL

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
ENCAPMOD	.999	MODULES/MODULE	ENCAPSULATED MODULE
		/	
		/	

Prepared by Tom Philp Date 2/23/79

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FORMAT A

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PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] BOND

A2 [Descriptive Name] HEAT AND VACUUM MODULE LAYUP

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] ENCAPMOD

A4 Descriptive Name [Product Name] ENCAPSULATED MODULE

A5 Unit Of Measure [Product Units] MODULES

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 3.33 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 9.0 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .94 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	BONDER		
A9a	Component [Descriptive Name] (Optional)	BONDS		
		MODULE		
A10	Base Year For Equipment Prices [Price Year]	1979		
A11	Purchase Price ($ Per Component) [Purchase Cost]	60000		
A12	Anticipated Useful Life (Years) [Useful Life]	7		
A13	[Salvage Value] ($ Per Component)	6000		
A14	[Removal and Installation Cost] ($/Component)	1000		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

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Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) BOND

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	700	SQ FT	MANUFACTURING SCALE A
B3066D	.25	PRSN/SHIFT	GENERAL ASSEMBLER
B3685D	.003	PRSN/SHIFT	ELECTRONICS MAINTENANCE
B3736D	.026	PRSN/SHIFT	MAINTENANCE [illegible]

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1037E	.094	KW HR	ELECTRIC

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
PREMOD	.998	MODULES/MODULE	PREPARED MODULE

Prepared by Tom [illegible] Date 2/23/79

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] LAYUP

A2 [Descriptive Name] MODULE LAYUP INTERCONNECT AND TEST

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] LAY MOD

A4 Descriptive Name [Product Name] UNENCAPSULATED MODULE

A5 Unit Of Measure [Product Units] MODULES

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 3.33 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] .90 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .94 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	MODLAY	TESTER	
A9a	Component [Descriptive Name] (Optional)	LAYS UP MODULE	TESTS MODULE	
A10	Base Year For Equipment Prices [Price Year]	1979	1979	
A11	Purchase Price ($ Per Component) [Purchase Cost]	75000	10000	
A12	Anticipated Useful Life (Years) [Useful Life]	7	10	
A13	[Salvage Value] ($ Per Component)	5000	1000	
A14	[Removal and Installation Cost] ($/Component)	1500	500	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) LAYUP

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
(Facilities and Personnel Requirements)

A16 Catalog Number (Expense Item Referent)	A18 Amount Required Per Machine (Per Shift) (Amount per Machine)	A19 Units	A17 Requirement Description
A2064D	300	SQ FT	MANUFACTURING SPACE (A)
B3064D	.25	PRSN/SHIFT	GENERAL ASSEMBLER
B3736D	.0045	PRSN/SHIFT	MAINTENANCE MECHANIC
B3688D	.0015	PRSN/SHIFT	ELECTRONICS MAINTENANCE

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
(Byproduct Outputs) and (Utilities and Commodities Requirements)

A20 Catalog Number (Expense Item Referent)	A22 Amount Required Per Machine Per Minute (Amount per Cycle)	A23 Units	A21 Requirement Description
EG1800D	.308	LBS	COPPER BUSS BAR
EG1700D	106.56	SQ FT	POLYVINYL BUTYRATE
EG1500D	106.56	SQ FT	MYLAR
EG1300D	.044	LBS	SOLDER PASTE
C1032B	.096	KWHR	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED (Required Products)

A24 (Product Reference)	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
RIBBON	.0769	MODULES/RIBBON	SERIES RIBBON OF CELLS
PREMOD	.999	MODULES/MODULE	PREPARED MODULE

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] PPREP

A2 [Descriptive Name] PREPARATION OF MODULE MATERIALS, GLASS + PVB

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] PREMOD

A4 Descriptive Name [Product Name] PREPARED MODULE

A5 Unit Of Measure [Product Units] MODULES

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 8.57 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 3.0 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .95 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	PREP	PVB STO	
A9a	Component [Descriptive Name] (Optional)	PANEL PREP MACHINE	STORAGE FOR PVB	
A10	Base Year For Equipment Prices [Price Year]	1979	1979	
A11	Purchase Price ($ Per Component) [Purchase Cost]	20,000	10000	
A12	Anticipated Useful Life (Years) [Useful Life]	7	10	
A13	[Salvage Value] ($ Per Component)	2000	1000	
A14	[Removal and Installation Cost] ($/Component)	800	1000	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) PPREP

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	360	SQ FT	MANUFACTURING SPACE (A)
B3064D	.334	PRSN/SHIFT	GENERAL ASSEMBLER
B3736D	.0045	PRSN/SHIFT	MAINTENANCE [illegible]
B3688D	.0015	PRSN/SHIFT	ELECTRONICS MAINTENANCE

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E1812D	274.24	SQ FT	FLOAT GLASS 1/8"
EG1700D	274.24	SQ FT	POLYVINYL BUTYRATE
C1032B	.108	KW HR	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
		1	
		1	
		1	

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SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] SELLAY

A2 [Descriptive Name] LAY UP OF CELL ONTO A RIBBON

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] RIBBON

A4 Descriptive Name [Product Name] SERIES RIBBON OF CELLS

A5 Unit Of Measure [Product Units] RIBBONS

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	3.33	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	.30	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	.95	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	RIB FAB		
A9a	Component [Descriptive Name] (Optional)	RIBBON FABRICATOR		
A10	Base Year For Equipment Prices [Price Year]	1979		
A11	Purchase Price ($ Per Component) [Purchase Cost]	75000		
A12	Anticipated Useful Life (Years) [Useful Life]	5		
A13	[Salvage Value] ($ Per Component)	3000		
A14	[Removal and Installation Cost] ($/Component)	1500		

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CELLAY

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	600	SQ FT	MANUFACTURING SPACE
B3064D	.25	PRSN/SHIFT	GENERAL ASSEMBLY
B3688D	.003	PRSN/SHIFT	ELECTRONICS MAINT.
B3736D	.0045	PRSN/SHIFT	MECHANICAL MAINT

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E61400D	.041	LBS	COPPER 2.330N
E61500D	1.11	SQ FT	MYLAR
E61600D	.046	LBS	SOLDER PASTE
C10328	.100	KWHR	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
PCELLS	.0454	2.030NB/CELL	SORTED PACKAGED CELLS

Prepared by Tom Philp Date 2/22/79

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] PKCCELLS

A2 [Descriptive Name] TEST AND SORT CELLS

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] PCELLS

A4 Descriptive Name [Product Name] TESTED AND SORTED CELLS

A5 Unit Of Measure [Product Units] CELLS

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 60 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 2.0 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .95 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	TESTER	CONVEYOR	
A9a	Component [Descriptive Name] (Optional)	TESTS AND SORTS CELLS	SENDS CELLS ON TO NEXT STEP	
A10	Base Year For Equipment Prices [Price Year]	1979	1979	
A11	Purchase Price ($ Per Component) [Purchase Cost]	12000	3000	
A12	Anticipated Useful Life (Years) [Useful Life]	8	7	
A13	[Salvage Value] ($ Per Component)	1800	600	
A14	[Removal and Installation Cost] ($/Component)	400	300	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) PKGCELLS

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	200	SQ FT	MANUFACTURING SPACE (A)
B3064D	.25	PRSN/SHIFT	GENERAL ASSEMBLER
B3655D	.003	PRSN/SHIFT	ELECTRONICS MAINT
B3736D	.003	PRSN/SHIFT	MECHANICAL MAINT
B3720D	.012	PRSN/SHIFT	INSPECTOR SYSTEM

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	.057	KW HR	ELECTRICITY
D1176D	.0081	MT^2	REJECTED CELLS

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
FCW	.95	CELLS / WAFER	FRONTCONTACTED WAFERS

Prepared by Tom Philp Date 2/22/79

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] FCONTACT

A2 [Descriptive Name] PRINT AND FIRED FRONT CONTACT

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] FCW

A4 Descriptive Name [Product Name] FRONT CONTACTED WAFERS

A5 Unit Of Measure [Product Units] WAFERS

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 60 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] .433 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	PRINTER	ETCHER	FURNACE
A9a	Component [Descriptive Name] (Optional)	SCREEN PRINTS FRONT CONTACT	DRY ETCH OF OXIDE	[illegible] SILICIDE CONTACT
A10	Base Year For Equipment Prices [Price Year]	1979	1979	1979
A11	Purchase Price ($ Per Component) [Purchase Cost]	33600	17000	20000
A12	Anticipated Useful Life (Years) [Useful Life]	8	5	8
A13	[Salvage Value] ($ Per Component)	6720	3400	[illegible]
A14	[Removal and Installation Cost] ($/Component)	950	800	[illegible]

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) F CONTACT

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	500	SQ FT	MANUFACTURING SPACE (A
B3064D	.167	PERSN/SHIFT	GENERAL ASSEMBLER
B3688D	.0015	PERSN/SHIFT	ELECTRONICS MAINT
B3736D	.003	PERSN/SHIFT	MECHANICAL MAINT

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E1064D	2.4	GRAMS	SILVER PASTE
C1032B	.241	KW HR	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
BCW	.996	WAFER/WAFER	BACKCONTACTED WAFERS

Prepared by Don Philp Date 7/22/79

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] BCONTACT

A2 [Descriptive Name] ALUMINUM BACK CONTACT

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] BCW

A4 Descriptive Name [Product Name] BACK CONTACTED WAFERS

A5 Unit Of Measure [Product Units] WAFERS

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 60 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] .433 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .96 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	PRINTER	FURNACE	CLEANER
A9a	Component [Descriptive Name] (Optional)	SCREEN PRINTS BACK CONTACT	DRYS AND FIRES AL.	CLEANS WAFERS
A10	Base Year For Equipment Prices [Price Year]	1979	1979	1979
A11	Purchase Price ($ Per Component) [Purchase Cost]	33600	17000	12000
A12	Anticipated Useful Life (Years) [Useful Life]	8	8	8
A13	[Salvage Value] ($ Per Component)	6720	3400	1800
A14	[Removal and Installation Cost] ($/Component)	950	850	500

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) B CONTACT

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A 2064 D	500	SQ FT	MANUFACTURING SPACE *
B 3064 D	.167	PRSN/SHIFT	GENERAL ASSEMBLER
B 3658 D	.015	PRSN/SHIFT	ELECTRONICS MAINT
B 3736 D	.003	PRSN/SHIFT	MECHANICAL MAINT

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E 61300 D	.132	LBS	ALUMINUM DRSTS
C 1032 B	.225	KW HRS	ELECTRICITY
E 1576 D	.00002	SCREENS	SCREENS

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
EEW	.998	WAFERS / WAFER	EDGE ETCHED WAFERS
		/	
		/	

Prepared by Tom Phelps Date 2/22/79

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

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Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] EDGE ETCH

A2 [Descriptive Name] PLASMA EDGE ETCH OF STACKED WAFERS

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] EEW

A4 Descriptive Name [Product Name] EDGE ETCHED WAFERS

A5 Unit Of Measure [Product Units] WAFERS

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 60 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 15 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .95 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	ETCHER	STACKER	CONVEYOR
A9a	Component [Descriptive Name] (Optional)	PLASMA ETCHER	STACKS & LOADS WAFERS INTO ETCHER	CONVEYS CASSETTES OUT
A10	Base Year For Equipment Prices [Price Year]	1979	1979	1979
A11	Purchase Price ($ Per Component) [Purchase Cost]	30000	20000	3000
A12	Anticipated Useful Life (Years) [Useful Life]	5	7	7
A13	[Salvage Value] ($ Per Component)	5000	5000	600
A14	[Removal and Installation Cost] ($/Component)	800	1000	300

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) EDGE, ETCH

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	100	SQ FT	MANUFACTURING SPACE (A
B3064D	.25	PRSN/SHIFT	GENERAL ASSEMBLER
B3688D	.03	PRSN/SHIFT	ELECT. MAINT
B3736D	.03	PRSN/SHIFT	MECH. MAINT

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E6 1150D	.0000353	CU FT	ANHYDROUS HF
E6 2200D	.00106	CU FT	CF_4
C1[illegible]	.016	KW HR	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
DW	.989	WAFERS/WAFER	DIFFUSED WAFERS

Prepared by Tom Philp Date 2/22/79

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
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PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] DIFFUSION

A2 [Descriptive Name] DOUL DIFFUSION FURNACE

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] DW

A4 Descriptive Name [Product Name] DIFFUSED WAFERS

A5 Unit Of Measure [Product Units] WAFERS

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 71.1 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 45 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .94 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	FURNACE	LOAD	CONVEYOR
A9a	Component [Descriptive Name] (Optional)	DIFFUSION FURNACE WITH BUILDING	LOADS WAFERS INTO QUARTZ BOATS + ONTO SLED	OUTGOING CONVEYOR
A10	Base Year For Equipment Prices [Price Year]	1979	1979	1979
A11	Purchase Price ($ Per Component) [Purchase Cost]	112000	16,000	3000
A12	Anticipated Useful Life (Years) [Useful Life]	7	7	7
A13	[Salvage Value] ($ Per Component)	16800	2400	600
A14	[Removal and Installation Cost] ($/Component)	1300	800	300

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) DIFFUSION

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2080D	450	SQ FT	MANUFACTURING SPACE (A)
B3064D	.25	PRSN/SHIFT	GENERAL ASSEMBLER
B3695D	.003	PRSN/SHIFT	ELECTRONICS MAINTENANCE
B3736D	.003	PRSN/SHIFT	MAINTENANCE MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E1448D	.121	CU FT	OXYGEN GAS
E1416D	1.[illegible]	CU FT	NITROGEN GAS
E1504D	.[illegible]24	LBS	PACK
C10323	1.13	KW HR	ELECTRICITY
D10163	[illegible]	CU FT	FUMES

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
DRYW	.998	WAFERS/WAFER	DRY WAFERS

Prepared by Tom Philp Date 2/22/79

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

PROCESS DESCRIPTION

JET PROPULSION LABORATORY
California Institute of Technology
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Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] DRY

A2 [Descriptive Name] _____

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] DRYW

A4 Descriptive Name [Product Name] DRY WAFERS

A5 Unit Of Measure [Product Units] WAFERS

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 60 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 2.5 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .98 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	DRYER	CONVEYOR	
A9a	Component [Descriptive Name] (Optional)	LINEAR BLOW DRYER	THROUGH DRYER AND OUT	
A10	Base Year For Equipment Prices [Price Year]	1979	1979	
A11	Purchase Price ($ Per Component) [Purchase Cost]	10000	3000	
A12	Anticipated Useful Life (Years) [Useful Life]	8	7	
A13	[Salvage Value] ($ Per Component)	1500	600	
A14	[Removal and Installation Cost] ($/Component)	500	300	

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) DRY

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	100	SQ FT	MANUFACTURING SPACE (A
B3064D	.167	PRSN/SHIFT	GENERAL ASSEMBLERS
B3688D	.003	PRSN/SHIFT	ELECTRONICS MAINTENANCE
B3736D	.003	PRSN/SHIFT	MAINTENANCE MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	.086	KW HR	ELECTRICITY

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
EACW	.999	WAFERS/WAFER	ETCHED AND CLEANED WAFERS

Prepared by Tom Phelps Date 2/22/79

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] CLEAN

A2 [Descriptive Name] DAMAGE AND TEXTURE ETCH AND CLEAN

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] EACW

A4 Descriptive Name [Product Name] ETCHED AND CLEANED WAFERS

A5 Unit Of Measure [Product Units] WAFERS

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 60 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] 68.3 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .947 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	STACKER	ETCH	CONVEYOR
A9a	Component [Descriptive Name] (Optional)	STACKS CASSETTES	ETCHING AND RINSING TANKS AND CONTROLS	UNSTACKS AND CONVEYS CASSETTES OUT
A10	Base Year For Equipment Prices [Price Year]	1979	1979	1979
A11	Purchase Price ($ Per Component) [Purchase Cost]	12,100	41,250	12,900
A12	Anticipated Useful Life (Years) [Useful Life]	7	8	7
A13	[Salvage Value] ($ Per Component)	2420	8250	2580
A14	[Removal and Installation Cost] ($/Component)	800	1300	900

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) CLEAN

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	200	SQ FT	MANUFACTURING SPACE IA
B3064D	.25	PRSN/SHIFT	GENERAL ASSEMBLER
B3688D	.003	PRSN/SHIFT	ELECTRONICS MAINTENANCE M.IN
B3736D	.020	PRSN/SHIFT	MAINTENANCE MECHANIC II

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
E1600D	.35	LBS	SODIUM HYDROXIDE
C1144D	.044	CU FT	DE-IONIZED WATER
C1016B	.20	CU FT	DOMESTIC WATER
E1352D	.052	GALS	ISO PROPYL ALCOHOL
E1640D	.0097	LBS	SULFURIC ACID
D1032D	.117	GALS	POISONOUS ACID
C1032B	.104	KLWHR	ELECTRICITY
C1064B	.22	CU FT	NATURAL GAS

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
TWAFERS	.994	WAFERS/WAFER	TESTED WAFERS
		/	
		/	

Prepared by Tom Pluta Date 2/22/79

REVERSE SIDE JPL 3037-S R 7/78

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

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PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMICS III computer program.

A1 Process [Referent] INSPECT

A2 [Descriptive Name] THICKNESS AND RESISTIVITY INSPECTION AND LOADING INTO ETCH CASSETTES

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] T WAFERS

A4 Descriptive Name [Product Name] TESTED WAFERS

A5 Unit Of Measure [Product Units] WAFERS

PART 2 – PROCESS CHARACTERISTICS

A6 [Output Rate] (Not Thruput) 60 Units (given on line A5) Per Operating Minute

A7 Average Time at Station [Processing Time] .883 Calendar Minutes (Used only to compute in-process inventory)

A8 Machine "Up" Time Fraction [Usage Fraction] .967 Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	TESTER	UNPACK	CONVEYOR
A9a	Component [Descriptive Name] (Optional)	TESTS AND SORTS WAFERS	UNPACKAGES AND LOADS INTO TESTER	OUT GOING CONVEYOR
A10	Base Year For Equipment Prices [Price Year]	1979	1979	1979
A11	Purchase Price ($ Per Component) [Purchase Cost]	45,000	20,000	10,000
A12	Anticipated Useful Life (Years) [Useful Life]	8	7	7
A13	[Salvage Value] ($ Per Component)	9,000	4,000	2,000
A14	[Removal and Installation Cost] ($/Component)	818	1000	511

Note: The SAMICS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 4.0), DDB, and SL.

JPL 3037-S R7/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) INSPECT

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	100	SQ FT	(A) MANUFACTURE & SPACE
B3064D	.25	PRSN/SHIFT	GENERAL ASSEMBLY
B3720D	.012	PRSN/SHIFT	INSPECTOR SYSTEMS
B3688D	.003	PRSN/SHIFT	ELECTRONICS MAINTENANCE
B3736D	.003	PRSN/SHIFT	MAINTENANCE MECHANIC

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
C1032B	.0565	KW HR	ELECTRICITY
D1064D	.00249	m^2	REJECTED WATER
[illegible]	[illegible]	m^2	[illegible]

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A26 Usable Output Per Unit of Input Product	A27 Units	A25 Product Name
PWAFERS	.999	WAFERS/WAFER	PACKAGED WAFERS
		/	
		/	

Prepared by Tom Philp Date 2/22/79

REVERSE SIDE JPL 3037-S R 7/78

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SAMIS III - RELEASE 1        INDUSTRY SIZE INDEX =  1

INDUSTRY: DEFAULT, 1986 500 MEGAWATT PRODUCTION

INDUSTRY OBJECTIVE: NEW PHOTOVOLTAIC POWER CAPABILITY
FINAL PRODUCT: PKGMOD, MODULE PACKAGED FOR SHIPPING
PRODUCING  280.00 PEAK-WATTS PER MODULES

QUANTITY:  500000000. =  5.0E+08 PEAK-WATTS/YEAR =>  1.786E+06 MODULES/YEAR

PRICE:     .4895 $(1975)/PEAK-WATTS =>   137.054 $(1975)/MODULES

   COMPANY: MODULECO, STANDARD SAMICS CELL TO MODULE COMPANY
   PRODUCTS: PKGMOD
   QUANTITY: 7.143E+05
   PRICE:     137.054
             $(1975)/
             MODULES
   ENERGY PAYBACK TIME =    .001 YEARS
   COMPANY MARKUP =   1.263 TIMES (DIRECT EXPENSES PLUS EXTERNAL PRODUCT COSTS)
   COMPANY PROFIT =   1.2% OF PRICE

      ***********************************************************************
      ***********************************************************************
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SAMIS III - RELEASE 1        INDUSTRY CONFIGURATION

INDUSTRY: DEFAULT, 1986 500 MEGAWATT PRODUCTION

NEW PHOTOVOLTAIC POWER CAPABILITY, EXPRESSED IN PEAK-WATTS/YEAR
                         IS PROVIDED BY
PKGMOD, MODULE PACKAGED FOR SHIPPING, EXPRESSED IN MODULES/YEAR
                           OF WHICH
 40.00% IS MADE BY MODULECO, STANDARD SAMICS CELL TO MODULE COMPANY

COMPANY: MODULECO              PRODUCTS: PKGMOD
REQUIRED PRODUCT: PCELLS, TESTED AND SORTED CELLS
     100.00% OF MODULECO'S REQ'T IS MADE BY CELLCO, STANDARD SAMICS
                                                    WAFER TO CELL
                                                    COMPANY

COMPANY: CELLCO                PRODUCTS: PCELLS
REQUIRED PRODUCT: (NONE)
```

```
PROCESS: PKGMODULE. PACKING AND SHIPPING
PRODUCT: PKGMOD    , MODULE PACKAGED FOR SHIPPING
PRODUCES:    6.0000 MODULES/MINUTE, TAKING     2.000 MINUTES/CYCLE
OPERATES  .96 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: PACKER, PACKS
      COST:   30000. $(1979)    INSTALLATION:    1000. $(1979)
      SALVAGE VALUE:    2000. $(1979) AFTER 10.0 YEARS

   QUANTITY 7.143E+05 MODULES/YEAR AT  137.0541 $(1975)/MODULES
   NUMBER OF PKGMODULE MACHINES =  1.000, OF WHICH  .750 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                          252609.
      DIRECT LABOR EXPENSES                                5302.
      DIRECT MATERIALS AND SUPPLIES                      246973.
      BYPRODUCT EXPENSES                                      0.
      DIRECT UTILITIES EXPENSES                             334.

   INDIRECT EXPENSES                          7485.
      INDIRECT LABOR EXPENSES                              6255.
      INDIRECT MATERIALS AND SUPPLIES                       691.
      INDIRECT UTILITIES EXPENSES                           539.

   BYPRODUCT INCOME                   (         0.)

   CAPITAL EXPENSES                         96955.
      EQUIPMENT REPLACEMENT                                3816.
      FACILITIES REPLACEMENT                               1401.
      AMORTIZED ONE-TIME COSTS                            64895.
      INTEREST ON DEBT                                     1647.
      RETURN ON EQUITY                                    17808.
      NON-INCOME TAXES                                      344.
      INSURANCE PREMIUMS                                   7043.

   INCOME TAXES                             79242.

   MISCELLANEOUS                            69666.

   EXTERNAL PRODUCT COST                        0.
   INTERNAL (IMPLICIT) PRODUCT COST  184953824.

   VALUE ADDED:    .708 $(1986)/MODULES =    .003 $(1986)/
PEAK-WATTS
   PROFIT =    .0% OF PRICE
   MARKUP = 1.001 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODU
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .000 YEARS

   TO PRODUCE 7.143E+05 MODULES/YEAR. THE PKGMODULE
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)

      DIRECT REQUIREMENTS

         ACCOUNT A - FACILITIES
```

```
   4.000E+02 SQ. FT. OF A20640, MANUFACTURING SPACE
                                (TYPE  A)
        @      80.30 $(1986)/SQ. FT. IMPLIES    32121.  $(1986)

ACCOUNT B - PERSONNEL
   2.933E-01 PRSN*YRS OF B3064D, GENERAL ASSEMBLER
                                (ELECTRONICS)
        @  17487.26 $(1986)/PRSN*YRS IMPLIES     5129.  $(1986)
   3.520E-03 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
        @  25475.28 $(1986)/PRSN*YRS IMPLIES       90.  $(1986)
   3.520E-03 PRSN*YRS OF B3688D, ELECTRONICS MAINTENANCE
                                MAN
        @  23748.14 $(1986)/PRSN*YRS IMPLIES       84.  $(1986)

ACCOUNT C - UTILITIES
   6.190E+03 KW HR. OF C1032B, ELECTRICITY
        @        .05 $(1986)/KW HR. IMPLIES      334.  $(1986)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
   1.429E+06 CU. FT. OF E1180D, CRATES, WOODEN
        @        .17 $(1986)/CU. FT. IMPLIES   246973.  $(1986)

ACCOUNT F - RESOURCES
(NONE)
```

```
PROCESS: FINALTEST, FINAL TESTING AND LABELING
PRODUCT: TMOD      , TESTED MODULES
PRODUCES:    4.0000 MODULES/MINUTE, TAKING      .250 MINUTES/CYCLE
OPERATES  .96 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: TESTER, TESTS MODULES
      COST:   35000. $(1979)    INSTALLATION:    1000. $(1979)
      SALVAGE VALUE:    5250. $(1979) AFTER 10.0 YEARS

   QUANTITY 7.150E+05 MODULES/YEAR AT  136.5437 $(1975)/MODULES
   NUMBER OF FINALTEST MACHINES =  1.000, OF WHICH  .625 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                          5848.
      DIRECT LABOR EXPENSES                            5404.
      DIRECT MATERIALS AND SUPPLIES                       0.
      BYPRODUCT EXPENSES                                  0.
      DIRECT UTILITIES EXPENSES                         444.

   INDIRECT EXPENSES                        6104.
      INDIRECT LABOR EXPENSES                          5170.
      INDIRECT MATERIALS AND SUPPLIES                   626.
      INDIRECT UTILITIES EXPENSES                       308.

   BYPRODUCT INCOME                  (         0.)

   CAPITAL EXPENSES                        19446.
      EQUIPMENT REPLACEMENT                            4046.
      FACILITIES REPLACEMENT                            778.
      AMORTIZED ONE-TIME COSTS                         5707.
      INTEREST ON DEBT                                  447.
      RETURN ON EQUITY                                 4833.
      NON-INCOME TAXES                                  264.
      INSURANCE PREMIUMS                               3371.

   INCOME TAXES                             6968.

   MISCELLANEOUS                            6126.

   EXTERNAL PRODUCT COST                       0.
   INTERNAL (IMPLICIT) PRODUCT COST  184909440.

   VALUE ADDED:    .062 $(1986)/MODULES =    .000 $(1986)/
PEAK-WATTS
   PROFIT =    .0% OF PRICE
   MARKUP = 1.000 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODU
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .000 YEARS

   TO PRODUCE 7.150E+05 MODULES/YEAR, THE FINALTEST
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)

      DIRECT REQUIREMENTS

         ACCOUNT A - FACILITIES
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```
   2.000E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE
                                (TYPE  A)
        @      80.30 $(1986)/SQ. FT. IMPLIES    16061.  $(1986)

ACCOUNT B - PERSONNEL
   2.942E-01 PRSN*YRS OF B3064D, GENERAL ASSEMBLER
                                (ELECTRONICS)
        @  17487.26 $(1986)/PRSN*YRS IMPLIES     5144.  $(1986)
   5.285E-03 PRSN*YRS OF 33736D, MAINTENANCE MECHANIC II
        @  25475.28 $(1986)/PRSN*YRS IMPLIES      135.  $(1986)
   5.265E-03 PRSN*YRS OF B3688D, ELECTRONICS MAINTENANCE
                                MAN
        @  23748.14 $(1986)/PRSN*YRS IMPLIES      125.  $(1986)

ACCOUNT C - UTILITIES
   8.223E+03 KW HR. OF C1032B, ELECTRICITY
        @        .05 $(1986)/KW HR. IMPLIES      444.  $(1986)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
(NONE)

ACCOUNT F - RESOURCES
(NONE)
```

```
PROCESS: TRIMSEAL , TRIM, EDGE SEAL AND FRAME MODULE
PRODUCT: FMCD      , FINISHED MODULE
PRODUCES:    4.0000 MODULES/MINUTE, TAKING      .250 MINUTES/CYCLE
OPERATES  .95 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: SEALER, SEALS MODULE EDGE
      COST:    45000. $(1979)    INSTALLATION:    1000. $(1979)
      SALVAGE VALUE:    9000. $(1979) AFTER  8.0 YEARS

   QUANTITY 7.222E+05 MODULES/YEAR AT  135.1458 $(1975)/MODULES
   NUMBER OF TRIMSEAL MACHINES =  1.000, OF WHICH  .617 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                          613813.
      DIRECT LABOR EXPENSES                                5521.
      DIRECT MATERIALS AND SUPPLIES                      608292.
      BYPRODUCT EXPENSES                                      0.
      DIRECT UTILITIES EXPENSES                               0.

   INDIRECT EXPENSES                          7630.
      INDIRECT LABOR EXPENSES                              6381.
      INDIRECT MATERIALS AND SUPPLIES                       709.
      INDIRECT UTILITIES EXPENSES                           539.

   BYPRODUCT INCOME                    (        0.)

   CAPITAL EXPENSES                         210953.
      EQUIPMENT REPLACEMENT                                6085.
      FACILITIES REPLACEMENT                               1387.
      AMORTIZED ONE-TIME COSTS                           151291.
      INTEREST ON DEBT                                     3362.
      RETURN ON EQUITY                                    36341.
      NON-INCOME TAXES                                      385.
      INSURANCE PREMIUMS                                  12101.

   INCOME TAXES                             184739.

   MISCELLANEOUS                            162414.

   EXTERNAL PRODUCT COST                         0.
   INTERNAL (IMPLICIT) PRODUCT COST  183730000.

   VALUE ADDED:  1.633 $(1986)/MODULES =    .006 $(1986)/
PEAK-WATTS
   PROFIT =    .0% OF PRICE
   MARKUP = 1.003 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .000 YEARS

   TO PRODUCE 7.222E+05 MODULES/YEAR, THE TRIMSEAL
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)

      DIRECT REQUIREMENTS

         ACCOUNT A - FACILITIES
```

```
   4.000E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE
                                 (TYPE  A)
        @      80.30 $(1986)/SQ. FT. IMPLIES    32121.  $(1986)

ACCOUNT B - PERSONNEL
   3.003E-01 PRSN*YRS OF B3064D, GENERAL ASSEMBLER
                                 (ELECTRONICS)
        @  17487.26 $(1986)/PRSN*YRS IMPLIES     5251.  $(1986)
   8.091E-03 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
        @  25475.28 $(1986)/PRSN*YRS IMPLIES      206.  $(1986)
   2.697E-03 PRSN*YRS OF B3688D, ELECTRONICS MAINTENANCE
                                 MAN
        @  23748.14 $(1986)/PRSN*YRS IMPLIES       64.  $(1986)

ACCOUNT C - UTILITIES
(NONE)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
   1.733E+07 FT. OF E1100D, ALUMINUM CHANNEL
        @        .02 $(1986)/FT. IMPLIES   376459.  $(1986)
   1.372E+05 DOLLARS OF E1232D, EDGE SEAL
        @       1.69 $(1986)/DOLLARS IMPLIES   231833.  $(1986)

ACCOUNT F - RESOURCES
(NONE)
```

```
PROCESS: BOND      , HEAT AND VACUUM MODULE LAYUP
PRODUCT: ENCAPMOD , ENCAPSULATED MODULES
PRODUCES:    3.3300 MODULES/MINUTE, TAKING     9.000 MINUTES/CYCLE
OPERATES  .94 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: BONDER, BONDS MODULE
      COST:   60000. $(1979)    INSTALLATION:    1000. $(1979)
      SALVAGE VALUE:    6000. $(1979) AFTER  7.0 YEARS

   QUANTITY 7.229E+05 MODULES/YEAR AT  134.1495 $(1975)/MODULES
   NUMBER OF BOND MACHINES =  1.000, OF WHICH  .535 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                          11144.
      DIRECT LABOR EXPENSES                            10042.
      DIRECT MATERIALS AND SUPPLIES                        0.
      BYPRODUCT EXPENSES                                   0.
      DIRECT UTILITIES EXPENSES                         1102.

   INDIRECT EXPENSES                        13746.
      INDIRECT LABOR EXPENSES                          11503.
      INDIRECT MATERIALS AND SUPPLIES                   1284.
      INDIRECT UTILITIES EXPENSES                        959.

   BYPRODUCT INCOME                   (        0.)

   CAPITAL EXPENSES                         45863.
      EQUIPMENT REPLACEMENT                            10339.
      FACILITIES REPLACEMENT                            2499.
      AMORTIZED ONE-TIME COSTS                         12859.
      INTEREST ON DEBT                                   896.
      RETURN ON EQUITY                                 10768.
      NON-INCOME TAXES                                   608.
      INSURANCE PREMIUMS                                7793.

   INCOME TAXES                             15702.

   MISCELLANEOUS                            13805.

   EXTERNAL PRODUCT COST                        0.
   INTERNAL (IMPLICIT) PRODUCT COST  183629792.

   VALUE ADDED:    .139 $(1986)/MODULES =    .001 $(1986)/
PEAK-WATTS
   PROFIT =    .0% OF PRICE
   MARKUP = 1.000 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .000 YEARS

   TO PRODUCE 7.229E+05 MODULES/YEAR, THE BOND
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)

      DIRECT REQUIREMENTS

         ACCOUNT A - FACILITIES
```

```
   7.000E+02 SQ. FT. OF A20640, MANUFACTURING SPACE
                                (TYPE  A)
        @      80.30 $(1986)/SQ. FT. IMPLIES    56213.  $(1986)

ACCOUNT B - PERSONNEL
   5.462E-01 PRSN*YRS OF B30640, GENERAL ASSEMBLER
                                 (ELECTRONICS)
        @  17497.26 $(1986)/PRSN*YRS IMPLIES     9552.  $(1986)
   1.311E-02 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
        @  25475.28 $(1986)/PRSN*YRS IMPLIES      334.  $(1986)
   6.555E-03 PRSN*YRS OF B36880, ELECTRONICS MAINTENANCE
                                 MAN
        @  23746.14 $(1986)/PRSN*YRS IMPLIES      156.  $(1986)

ACCOUNT C - UTILITIES
   2.341E+04 KW HR. OF C1032B, ELECTRICITY
        @       .05 $(1986)/KW HR. IMPLIES     1102.  $(1986)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
(NONE)

ACCOUNT F - RESOURCES
(NONE)
```

```
PROCESS: LAYUP     , MODULE LAYUP INTERCONNECT AND TEST
PRODUCT: LAYMOD    , UNENCAPSULATED MODULE
PRODUCES:    3.3300 MODULES/MINUTE, TAKING      .900 MINUTES/CYCLE
OPERATES  .94 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: MODLAY, LAYS UP MODULE
      COST:    95000. $(1979)    INSTALLATION:    1500. $(1979)
      SALVAGE VALUE:    5000. $(1979) AFTER  7.0 YEARS
   COMPONENT: TESTER, TESTS MODULES
      COST:    10000. $(1979)    INSTALLATION:     500. $(1979)
      SALVAGE VALUE:    1000. $(1979) AFTER 10.0 YEARS

   QUANTITY 7.244E+05 MODULES/YEAR AT  133.8082 $(1975)/MODULES
   NUMBER OF LAYUP MACHINES =  1.000. OF WHICH  .534 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                        16815472.
      DIRECT LABOR EXPENSES                                9900.
      DIRECT MATERIALS AND SUPPLIES                    16804448.
      BYPRODUCT EXPENSES                                      0.
      DIRECT UTILITIES EXPENSES                            1127.

   INDIRECT EXPENSES                         30420.
      INDIRECT LABOR EXPENSES                             24657.
      INDIRECT MATERIALS AND SUPPLIES                      2113.
      INDIRECT UTILITIES EXPENSES                          3650.

   BYPRODUCT INCOME                    (         0.)

   CAPITAL EXPENSES                       5183177.
      EQUIPMENT REPLACEMENT                               18451.
      FACILITIES REPLACEMENT                               9753.
      AMORTIZED ONE-TIME COSTS                          4303865.
      INTEREST ON DEBT                                    78681.
      RETURN ON EQUITY                                   850611.
      NON-INCOME TAXES                                     1863.
      INSURANCE PREMIUMS                                 219954.

   INCOME TAXES                           4089946.

   MISCELLANEOUS                          4298231.

   EXTERNAL PRODUCT COST                        0.
   INTERNAL (IMPLICIT) PRODUCT COST  152414288.

   VALUE ADDED: 43.093 $(1986)/MODULES =    .156 $(1986)/
PEAK-WATTS
   PROFIT =    .5% OF PRICE
   MARKUP = 1.035 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .000 YEARS

   TO PRODUCE 7.244E+05 MODULES/YEAR, THE LAYUP
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)
```

DIRECT REQUIREMENTS

ACCOUNT A - FACILITIES
3.000E+03 SQ. FT. OF A20640, MANUFACTURING SPACE (TYPE A)
@ 80.36 $(1986)/SQ. FT. IMPLIES 240911. $(1986)

ACCOUNT B - PERSONNEL
5.473E-01 PRSN*YRS OF B30640, GENERAL ASSEMBLER (ELECTRONICS)
@ 17497.26 $(1986)/PRSN*YRS IMPLIES 9572. $(1986)
9.852E-03 PRSN*YRS OF B37360, MAINTENANCE MECHANIC II
@ 25475.28 $(1986)/PRSN*YRS IMPLIES 251. $(1986)
3.284E-03 PRSN*YRS OF B3688D, ELECTRONICS MAINTENANCE MAN
@ 23748.14 $(1986)/PRSN*YRS IMPLIES 78. $(1986)

ACCOUNT C - UTILITIES
2.038E+04 KW HR. OF C10328, ELECTRICITY
@ .05 $(1986)/KW HR. IMPLIES 1127. $(1986)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
2.318E+07 SQ. FT. OF EG17000, POLY VINYL BUTYRATE
@ .51 $(1986)/SQ. FT. IMPLIES 11837950. $(1986)
2.318E+07 SQ. FT. OF EG15000, MYLAR
@ .18 $(1986)/SQ. FT. IMPLIES 4178101. $(1986)
6.700E+04 LBS. OF EG18000, COPPER BUS BARS
@ 11.24 $(1986)/LBS. IMPLIES 752759. $(1986)
9.572E+03 LBS. OF EG16000, SOLDER PASTE
@ 3.72 $(1986)/LBS. IMPLIES 35654. $(1986)

ACCOUNT F - RESOURCES
(NONE)

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PROCESS: PPREP     , PREPARATION OF MODULE MATERIALS, GLASS AND
                     PVB
PRODUCT: PREMOD    , PREPARED MODULES
PRODUCES:     8.5700 MODULES/MINUTE, TAKING      3.000 MINUTES/CYCLE
OPERATES  .95 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: PREP, PANEL PREP MACHINE
      COST:    20000. $(1979)     INSTALLATION:      800. $(1979)
      SALVAGE VALUE:     2000. $(1979) AFTER  7.0 YEARS
   COMPONENT: PVBSTO, STORAGE FOR PVB
      COST:    10000. $(1979)     INSTALLATION:     1000. $(1979)
      SALVAGE VALUE:     1000. $(1979) AFTER 10.0 YEARS

   QUANTITY 7.251E+05 MODULES/YEAR AT    30.8381 $(1975)/MODULES
   NUMBER OF PPREP MACHINES =  1.000, OF WHICH  .821 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                        22942384.
      DIRECT LABOR EXPENSES                            5048.
      DIRECT MATERIALS AND SUPPLIES                 22936864.
      BYPRODUCT EXPENSES                                   0.
      DIRECT UTILITIES EXPENSES                          493.

   INDIRECT EXPENSES                          6993.
      INDIRECT LABOR EXPENSES                          5850.
      INDIRECT MATERIALS AND SUPPLIES                   652.
      INDIRECT UTILITIES EXPENSES                       491.

   BYPRODUCT INCOME                    (          0.)

   CAPITAL EXPENSES                        6946269.
      EQUIPMENT REPLACEMENT                            4850.
      FACILITIES REPLACEMENT                           1278.
      AMORTIZED ONE-TIME COSTS                      5433646.
      INTEREST ON DEBT                               104374.
      RETURN ON EQUITY                              1128365.
      NON-INCOME TAXES                                  313.
      INSURANCE PREMIUMS                             273446.

   INCOME TAXES                            6634925.

   MISCELLANEOUS                           5833131.

   EXTERNAL PRODUCT COST                         0.
   INTERNAL (IMPLICIT) PRODUCT COST              0.

   VALUE ADDED: 58.423 $(1986)/MODULES =    .212 $(1986)/
PEAK-WATTS
   PROFIT =  2.7% OF PRICE
   MARKUP = 1.846 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .000 YEARS

   TO PRODUCE 7.251E+05 MODULES/YEAR, THE PPREP
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)
```

DIRECT REQUIREMENTS

ACCOUNT A - FACILITIES
3.600E+02 SQ. FT. OF A20640, MANUFACTURING SPACE (TYPE A)
@ 80.30 $(1986)/SQ. FT. IMPLIES 28909. $(1986)

ACCOUNT B - PERSONNEL
2.814E-01 PRSN*YRS OF B30640, GENERAL ASSEMBLER (ELECTRONICS)
@ 17487.26 $(1986)/PRSN*YRS IMPLIES 4921. $(1986)
3.792E-03 PRSN*YRS OF B33360, MAINTENANCE MECHANIC II
@ 25475.28 $(1986)/PRSN*YRS IMPLIES 97. $(1986
1.264E-03 PRSN*YRS OF B36880, ELECTRONICS MAINTENANCE MAN
@ 23749.14 $(1986)/PRSN*YRS IMPLIES 30. $(1986)

ACCOUNT C - UTILITIES
9.138E+03 KW HR. OF C10328, ELECTRICITY
@ .05 $(1986)/KW HR. IMPLIES 493. $(1986)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
2.320E+07 SQ. FT. OF EG17000, POLY VINYL BUTYRATE
@ .51 $(1986)/SQ. FT. IMPLIES 11849790. $(1986)
2.320E+07 SQ. FT. OF E18120, FLOAT GLASS, 1/8" SODA LIME
@ .48 $(1986)/SQ. FT. IMPLIES 11087076. $(1986)

ACCOUNT F - RESOURCES
(NONE)

```
PROCESS: CELLAY    , LAYUP OF CELLS ONTO A RIBBON
PRODUCT: RIBBON    , SERIES RIBBON OF CELLS
PRODUCES:     3.3300 RIBBONS/MINUTE. TAKING       .300 MINUTES/CYCLE
OPERATES  .95 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: RIBFAB, RIBBON FABRICATOR
      COST:    75000. $(1979)     INSTALLATION:     1500. $(1979)
      SALVAGE VALUE:     3000. $(1979) AFTER   5.0 YEARS

   QUANTITY 9.420E+06 RIBBONS/YEAR AT     6.1669 $(1975)/RIBBONS
   NUMBER OF CELLAY MACHINES =  6.000, OF WHICH   .006 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                          3793473.
      DIRECT LABOR EXPENSES                              128393.
      DIRECT MATERIALS AND SUPPLIES                     3649811.
      BYPRODUCT EXPENSES                                      0.
      DIRECT UTILITIES EXPENSES                           15279.

   INDIRECT EXPENSES                         137091.
      INDIRECT LABOR EXPENSES                            116591.
      INDIRECT MATERIALS AND SUPPLIES                     14499.
      INDIRECT UTILITIES EXPENSES                          6003.

   BYPRODUCT INCOME                    (         0.)

   CAPITAL EXPENSES                         1505078.
      EQUIPMENT REPLACEMENT                              116065.
      FACILITIES REPLACEMENT                              15119.
      AMORTIZED ONE-TIME COSTS                           987952.
      INTEREST ON DEBT                                    24127.
      RETURN ON EQUITY                                   269857.
      NON-INCOME TAXES                                     4048.
      INSURANCE PREMIUMS                                  96936.

   INCOME TAXES                             1206367.

   MISCELLANEOUS                            1060584.

   EXTERNAL PRODUCT COST                  1.2349392.
   INTERNAL (IMPLICIT) PRODUCT COST             0.

   VALUE ADDED:    .818 $(1986)/RIBBONS =    .039 $(1986)/
PEAK-WATTS
   PROFIT =    .2% OF PRICE
   MARKUP = 1.037 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .001 YEARS

   TO PRODUCE 9.420E+06 RIBBONS/YEAR, THE CELLAY
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)

      DIRECT REQUIREMENTS

         ACCOUNT A - FACILITIES
```

```
   3.600E+03 SQ. FT. OF A20640, MANUFACTURING SPACE
                                 (TYPE  A)
        @      80.30 $(1986)/SQ. FT. IMPLIES   289093.  $(1986)

ACCOUNT B - PERSONNEL
   7.043E+00 PRSN*YRS OF B30640, GENERAL ASSEMBLER
                                 (ELECTRONICS)
        @  17487.26 $(1986)/PRSN*YRS IMPLIES   123157.  $(1986)
   1.268E-01 PRSN*YRS OF B33736D, MAINTENANCE MECHANIC II
        @  25475.28 $(1986)/PRSN*YRS IMPLIES     3229.  $(1986)
   8.451E-02 PRSN*YRS OF B36880, ELECTRONICS MAINTENANCE
                                 MAN
        @  23748.14 $(1986)/PRSN*YRS IMPLIES     2007.  $(1986)

ACCOUNT C - UTILITIES
   2.829E+05 KW HR. OF C10328, ELECTRICITY
        @        .05 $(1986)/KW HR. IMPLIES    15270.  $(1986)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
   1.160E+05 LBS. OF EG14000, COPPER RIBBON
        @      22.41 $(1986)/LBS. IMPLIES  2599142.  $(1986)
   5.140E+06 SQ. FT. OF EG15000, MYLAR
        @        .18 $(1986)/SQ. FT. IMPLIES   565955.  $(1986)
   1.301E+05 LBS. OF EG16000, SOLDER PASTE
        @       3.72 $(1986)/LBS. IMPLIES   484716.  $(1986)

ACCOUNT F - RESOURCES
(NONE)
```

```
COMPANY: CELLCO, STANDARD SAMICS WAFER TO CELL COMPANY
PRODUCTS: PCELLS
QUANTITY: 2.075E+08
PRICE:          .260
          $(1975)/
          CELLS
ENERGY PAYBACK TIME =    .021 YEARS
COMPANY MARKUP =    1.381 TIMES (DIRECT EXPENSES PLUS EXTERNAL PRODUCT COSTS)
COMPANY PROFIT =    1.5% OF PRICE

   ***********************************************************************
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PROCESS: PKGCELLS . TEST AND SORT CELLS
PRODUCT: PCELLS   . TESTED AND SORTED CELLS
PRODUCES:   60.0000 CELLS/MINUTE, TAKING     2.000 MINUTES/CYCLE
OPERATES  .95 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: TESTER, TESTS AND SORTS CELLS
      COST:   12000. $(1979)    INSTALLATION:     400. $(1979)
      SALVAGE VALUE:    1900. $(1979) AFTER  9.0 YEARS
   COMPONENT: CONVEYOR, OUT GOING CONVEYOR
      COST:    3000. $(1979)    INSTALLATION:     300. $(1979)
      SALVAGE VALUE:     600. $(1979) AFTER  7.0 YEARS

   QUANTITY 2.075E+08 CELLS/YEAR AT      .2604 $(1975)/CELLS
   NUMBER OF PKGCELLS MACHINES =  8.000, OF WHICH  .673 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                        173640.
      DIRECT LABOR EXPENSES                          163001.
      DIRECT MATERIALS AND SUPPLIES                       0.
      BYPRODUCT EXPENSES                                  0.
      DIRECT UTILITIES EXPENSES                       10639.

   INDIRECT EXPENSES                      146286.
      INDIRECT LABOR EXPENSES                        125790.
      INDIRECT MATERIALS AND SUPPLIES                 17026.
      INDIRECT UTILITIES EXPENSES                      3470.

   BYPRODUCT INCOME                  (    111483.)

   CAPITAL EXPENSES                        99768.
      EQUIPMENT REPLACEMENT                           16009.
      FACILITIES REPLACEMENT                           7228.
      AMORTIZED ONE-TIME COSTS                        29153.
      INTEREST ON DEBT                                 2114.
      RETURN ON EQUITY                                22856.
      NON-INCOME TAXES                                 1549.
      INSURANCE PREMIUMS                              18852.

   INCOME TAXES                            34951.

   MISCELLANEOUS                           21704.

   EXTERNAL PRODUCT COST                       0.
   INTERNAL (IMPLICIT) PRODUCT COST  1:2096096.

   VALUE ADDED:    .002 $(1986)/CELLS =    .002 $(1986)/PEAK-WATTS
   PROFIT =    .0% OF PRICE
   MARKUP = 1.001 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .001 YEARS

   TO PRODUCE 2.075E+08 CELLS/YEAR, THE PKGCELLS
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)

      DIRECT REQUIREMENTS
```

```
ACCOUNT A - FACILITIES
   1.606E+03 SQ. FT. OF A2064D, MANUFACTURING SPACE
                                (TYPE  A)
        @      79.37 $(1986)/SQ. FT. IMPLIES   126995.  $(1986)

ACCOUNT B - PERSONNEL
   8.609E+00 PRSN*YRS OF B3064D, GENERAL ASSEMBLER
                                 (ELECTRONICS)
        @  17487.27 $(1986)/PRSN*YRS IMPLIES   150555.  $(1986)
   4.133E-01 PRSN*YRS OF B3720D, INSPECTOR SYSTEMS
                                 (QUALITY CONTROL)
        @  17811.11 $(1986)/PRSN*YRS IMPLIES     7360.  $(1986)
   1.033E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
        @  25475.29 $(1986)/PRSN*YRS IMPLIES     2632.  $(1986)
   1.033E-01 PRSN*YRS OF B3688D, ELECTRONICS MAINTENANCE
                                 MAN
        @  23748.14 $(1986)/PRSN*YRS IMPLIES     2453.  $(1986)

ACCOUNT C - UTILITIES
   1.971E+05 KW HR. OF C1032B, ELECTRICITY
        @        .05 $(1986)/KW HR. IMPLIES    10639.  $(1986)

ACCOUNT D - BYPRODUCTS
   2.801E+04 SQ. MT. OF D1176D, REJECTED CELLS
        @     -3.98 $(1986)/SQ. MT. IMPLIES  -111483.  $(1986)

ACCOUNT E - COMMODITIES
(NONE)

ACCOUNT F - RESOURCES
(NONE)
```

```
PROCESS: FCONTACT . PRINT AND FIRED FRONT CONTACT
PRODUCT: FCW      . FRONT CONTACTED WAFERS
PRODUCES:   60.0000 WAFERS/MINUTE, TAKING      .433 MINUTES/CYCLE
OPERATES  .96 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: PRINTER, SCREEN PRINTS FRONT CONTACT
      COST:   33600. $(1979)    INSTALLATION:     950. $(1979)
      SALVAGE VALUE:    6720. $(1979) AFTER  8.0 YEARS
   COMPONENT: ETCHER, DRY ETCH OF OXIDE
      COST:   17000. $(1979)    INSTALLATION:     800. $(1979)
      SALVAGE VALUE:    3400. $(1979) AFTER  5.0 YEARS
   COMPONENT: FURNACE, DRYS AND FIRES SILVER CONTACT
      COST:   20000. $(1979)    INSTALLATION:     850. $(1979)
      SALVAGE VALUE:    4000. $(1979) AFTER  8.0 YEARS

   QUANTITY 2.184E+08 WAFERS/YEAR AT     .2467 $(1975)/WAFERS
   NUMBER OF FCONTACT MACHINES =  8.000, OF WHICH  .368 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                        7486223.
      DIRECT LABOR EXPENSES                          178781.
      DIRECT MATERIALS AND SUPPLIES                 7320270.
      BYPRODUCT EXPENSES                                  0.
      DIRECT UTILITIES EXPENSES                       57173.

   INDIRECT EXPENSES                       114911.
      INDIRECT LABOR EXPENSES                         97093.
      INDIRECT MATERIALS AND SUPPLIES                 12198.
      INDIRECT UTILITIES EXPENSES                      5621.

   BYPRODUCT INCOME                   (          0.)

   CAPITAL EXPENSES                       1215554.
      EQUIPMENT REPLACEMENT                           89115.
      FACILITIES REPLACEMENT                          15071.
      AMORTIZED ONE-TIME COSTS                       834131.
      INTEREST ON DEBT                                16192.
      RETURN ON EQUITY                               175052.
      NON-INCOME TAXES                                 4407.
      INSURANCE PREMIUMS                              91588.

   INCOME TAXES                            999801.

   MISCELLANEOUS                           620853.

   EXTERNAL PRODUCT COST                        0.
   INTERNAL (IMPLICIT) PRODUCT COST    91659344.

   VALUE ADDED:    .048 $(1986)/WAFERS =    .052 $(1986)/PEAK-WATTS
   PROFIT =    .2% OF PRICE
   MARKUP = 1.030 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .003 YEARS

   TO PRODUCE 2.184E+08 WAFERS/YEAR, THE FCONTACT
   PROCESS REQUIRES:
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ALL DOLLARS ARE IN $(1986)

DIRECT REQUIREMENTS

   ACCOUNT A - FACILITIES
      4.000E+03 SQ. FT. OF A2064D, MANUFACTURING SPACE
                                   (TYPE  A)
            @      79.37 $(1986)/SQ. FT. IMPLIES   317489.  $(1986)

   ACCOUNT B - PERSONNEL
      5.991E+00 PRSN*YRS OF B3064D, GENERAL ASSEMBLER
                                   (ELECTRONICS)
            @  17467.27 $(1986)/PRSN*YRS IMPLIES   104761.  $(1986)
      1.076E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
            @  25475.28 $(1986)/PRSN*YRS IMPLIES     2742.  $(1986)
      5.381E-02 PRSN*YRS OF B3688D, ELECTRONICS MAINTENANCE
                                   MAN
            @  23748.14 $(1986)/PRSN*YRS IMPLIES     1278.  $(1986)

   ACCOUNT C - UTILITIES
      1.059E+06 KW HR. OF C1332B, ELECTRICITY
            @        .05 $(1986)/KW HR. IMPLIES    57173.  $(1986)

   ACCOUNT D - BYPRODUCTS
   (NONE)

   ACCOUNT E - COMMODITIES
      8.736E+06 GRAMS OF E1064D, SILVER (AG.) PASTE (80%)
            @        .84 $(1986)/GRAMS IMPLIES  7320270.  $(1986)

   ACCOUNT F - RESOURCES
   (NONE)
```

```
PROCESS: BCONTACT , ALUMINUM BACK CONTACT
PRODUCT: BCW      , BACK CONTACTED WAFERS
PRODUCES:   60.0000 WAFERS/MINUTE, TAKING      .433 MINUTES/CYCLE
OPERATES  .96 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: PRINTER, SCREENPRINTS BACK CONTACT
      COST:   33600. $(1979)    INSTALLATION:     950. $(1979)
      SALVAGE VALUE:    6720. $(1979) AFTER  8.0 YEARS
   COMPONENT: FURNACE, DRYS AND FIRES
      COST:   17000. $(1979)    INSTALLATION:     850. $(1979)
      SALVAGE VALUE:    3400. $(1979) AFTER  8.0 YEARS
   COMPONENT: CLEANER, CLEANS WAFERS
      COST:   12000. $(1979)    INSTALLATION:     500. $(1979)
      SALVAGE VALUE:    1800. $(1979) AFTER  8.0 YEARS

   QUANTITY 2.193E+08 WAFERS/YEAR AT     .2206 $(1975)/WAFERS
   NUMBER OF BCONTACT MACHINES =  8.000, OF WHICH  .337 ARE IDLE

   ALL EXPENSES ARE IN $(1996)
   DIRECT EXPENSES                        1299104.
      DIRECT LABOR EXPENSES                            109218.
      DIRECT MATERIALS AND SUPPLIES                   1145504.
      BYPRODUCT EXPENSES                                    0.
      DIRECT UTILITIES EXPENSES                         44383.

   INDIRECT EXPENSES                       115148.
      INDIRECT LABOR EXPENSES                           97311.
      INDIRECT MATERIALS AND SUPPLIES                   12236.
      INDIRECT UTILITIES EXPENSES                        5601.

   BYPRODUCT INCOME                   (        0.)

   CAPITAL EXPENSES                        402024.
      EQUIPMENT REPLACEMENT                             69718.
      FACILITIES REPLACEMENT                            14560.
      AMORTIZED ONE-TIME COSTS                         171934.
      INTEREST ON DEBT                                   7312.
      RETURN ON EQUITY                                  79045.
      NON-INCOME TAXES                                   4184.
      INSURANCE PREMIUMS                                55372.

   INCOME TAXES                            205963.

   MISCELLANEOUS                           127898.

   EXTERNAL PRODUCT COST                        0.
   INTERNAL (IMPLICIT) PRODUCT COST   89509392.

   VALUE ADDED:    .010 $(1986)/WAFERS =    .011 $(1986)/PEAK-WATTS
   PROFIT =    .1% OF PRICE
   MARKUP = 1.009 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .003 YEARS

   TO PRODUCE 2.193E+08 WAFERS/YEAR, THE BCONTACT
   PROCESS REQUIRES:
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```
ALL DOLLARS ARE IN $(1986)

DIRECT REQUIREMENTS

   ACCOUNT A - FACILITIES
      4.000E+03 SQ. FT. OF A20640, MANUFACTURING SPACE
                                   (TYPE  A)
            @      79.37 $(1986)/SQ. FT. IMPLIES   317489.  $(1986)

   ACCOUNT B - PERSONNEL
      6.015E+00 PRSN*YRS OF B30640, GENERAL ASSEMBLER
                                   (ELECTRONICS)
            @   17487.27 $(1986)/PRSN*YRS IMPLIES   105182.  $(1986)
      1.081E-01 PRSN*YRS OF B33360, MAINTENANCE MECHANIC II
            @   25475.28 $(1986)/PRSN*YRS IMPLIES     2753.  $(1986)
      5.403E-02 PRSN*YRS OF B36880, ELECTRONICS MAINTENANCE
                                   MAN
            @   23748.14 $(1986)/PRSN*YRS IMPLIES     1283.  $(1986)

   ACCOUNT C - UTILITIES
      8.023E+05 KW HR. OF C10328, ELECTRICITY
            @        .05 $(1986)/KW HR. IMPLIES    44383.  $(1986)

   ACCOUNT D - BYPRODUCTS
   (NONE)

   ACCOUNT E - COMMODITIES
      4.824E+05 LBS. OF E61300D, ALUMINUM PASTE
            @       2.37 $(1986)/LBS. IMPLIES  1144887.  $(1986)
      7.310E+01 SCREENS OF E1576D, SCREENS
            @       8.45 $(1986)/SCREENS IMPLIES      617.  $(1986)

   ACCOUNT F - RESOURCES
   (NONE)
```

```
PROCESS: EDGE.ETCH, PLASMA EDGE ETCH OF STACKED WAFERS
PRODUCT: EEW       , EDGE ETCHED WAFERS
PRODUCES:   60.0000 WAFERS/MINUTE, TAKING    15.000 MINUTES/CYCLE
OPERATES  .95 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: ETCHER, PLASMA ETCHER
      COST:    30000. $(1979)     INSTALLATION:      800. $(1979)
      SALVAGE VALUE:     5000. $(1979) AFTER  5.0 YEARS
   COMPONENT: STACKER, STACKS AND LOADS WAFERS INTO ETCHER
      COST:    20000. $(1979)     INSTALLATION:     1000. $(1979)
      SALVAGE VALUE:     5000. $(1979) AFTER  7.0 YEARS
   COMPONENT: CONVEYOR, OUT GOING CONVEYOR
      COST:     3000. $(1979)     INSTALLATION:      300. $(1979)
      SALVAGE VALUE:      600. $(1979) AFTER  7.0 YEARS

   QUANTITY 2.197E+08 WAFERS/YEAR AT      .2150 $(1975)/WAFERS
   NUMBER OF EDGE.ETCH MACHINES =  8.000, OF WHICH  .241 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                          320485.
      DIRECT LABOR EXPENSES                            213288.
      DIRECT MATERIALS AND SUPPLIES                    104034.
      BYPRODUCT EXPENSES                                    0.
      DIRECT UTILITIES EXPENSES                          3162.

   INDIRECT EXPENSES                        173019.
      INDIRECT LABOR EXPENSES                          149354.
      INDIRECT MATERIALS AND SUPPLIES                   20561.
      INDIRECT UTILITIES EXPENSES                        3104.

   BYPRODUCT INCOME                   (          0.)

   CAPITAL EXPENSES                         242766.
      EQUIPMENT REPLACEMENT                             82445.
      FACILITIES REPLACEMENT                             5445.
      AMORTIZED ONE-TIME COSTS                          69657.
      INTEREST ON DEBT                                   4198.
      RETURN ON EQUITY                                  45384.
      NON-INCOME TAXES                                   2292.
      INSURANCE PREMIUMS                                33346.

   INCOME TAXES                              83492.

   MISCELLANEOUS                             51947.

   EXTERNAL PRODUCT COST                         0.
   INTERNAL (IMPLICIT) PRODUCT COST     88637888.

   VALUE ADDED:    .004 $(1986)/WAFERS =    .004 $(1986)/PEAK-WATTS
   PROFIT =    .1% OF PRICE
   MARKUP = 1.006 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODU
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .000 YEARS

   TO PRODUCE 2.197E+08 WAFERS/YEAR, THE EDGE.ETCH
   PROCESS REQUIRES:
```

ALL DOLLARS ARE IN $(1986)

DIRECT REQUIREMENTS

ACCOUNT A - FACILITIES
8.000E+02 SQ. FT. OF A20640, MANUFACTURING SPACE (TYPE A)
@ 79.37 $(1986)/SQ. FT. IMPLIES 63498. $(1986)

ACCOUNT B - PERSONNEL
9.117E+00 PRSN*YRS OF B30640, GENERAL ASSEMBLER (ELECTRONICS)
@ 17487.27 $(1986)/PRSN*YRS IMPLIES 159435. $(1986)
1.094E+00 PRSN*YRS OF B37360, MAINTENANCE MECHANIC II
@ 25475.26 $(1986)/PRSN*YRS IMPLIES 27872. $(1986)
1.094E+00 PRSN*YRS OF B36880, ELECTRONICS MAINTENANCE MAN
@ 23748.14 $(1986)/PRSN*YRS IMPLIES 25982. $(1986)

ACCOUNT C - UTILITIES
5.659E+04 KW HR. OF C10328, ELECTRICITY
@ .05 $(1986)/KW HR. IMPLIES 3162. $(1986)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
1.465E+02 CU. FT. OF EG1100D, ANHYDROUS HYDROGEN FLUORIDE
@ 511.19 $(1986)/CU. FT. IMPLIES 74881. $(1986)
3.882E+03 CU. FT. OF EG1200D, CF4
@ 7.51 $(1986)/CU. FT. IMPLIES 29153. $(1986)

ACCOUNT F - RESOURCES
(NONE)

```
PROCESS: DIFFUSION, POCL DIFFUSION FURNACE
PRODUCT: DW          , DIFFUSED WAFERS
PRODUCES:    71.1000 WAFERS/MINUTE, TAKING     45.000 MINUTES/CYCLE
OPERATES  .94 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: FURNACE, DIFFUSION FURNACE WITH PULLERS
      COST:  112000. $(1979)     INSTALLATION:     1300. $(1979)
      SALVAGE VALUE:   16800. $(1979) AFTER  7.0 YEARS
   COMPONENT: LOAD, LOADS WAFERS INTO BOATS AND ONTO SLEDS
      COST:    16000. $(1979)     INSTALLATION:      800. $(1979)
      SALVAGE VALUE:    2400. $(1979) AFTER  7.0 YEARS
   COMPONENT: CONVEYOR, OUT GOING CONVEYOR
      COST:     3000. $(1979)     INSTALLATION:      300. $(1979)
      SALVAGE VALUE:     600. $(1979) AFTER  7.0 YEARS

   QUANTITY 2.222E+08 WAFERS/YEAR AT      .2106 $(1975)/WAFERS
   NUMBER OF DIFFUSION MACHINES =  7.000, OF WHICH  .309 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                          494323.
      DIRECT LABOR EXPENSES                            142132.
      DIRECT MATERIALS AND SUPPLIES                    162214.
      BYPRODUCT EXPENSES                                    0.
      DIRECT UTILITIES EXPENSES                        190578.

   INDIRECT EXPENSES                        139456.
      INDIRECT LABOR EXPENSES                          118751.
      INDIRECT MATERIALS AND SUPPLIES                   15429.
      INDIRECT UTILITIES EXPENSES                        5276.

   BYPRODUCT INCOME                   (         0.)

   CAPITAL EXPENSES                         533171.
      EQUIPMENT REPLACEMENT                            149496.
      FACILITIES REPLACEMENT                            29433.
      AMORTIZED ONE-TIME COSTS                         110176.
      INTEREST ON DEBT                                  11364.
      RETURN ON EQUITY                                 122858.
      NON-INCOME TAXES                                   7824.
      INSURANCE PREMIUMS                                 99026.

   INCOME TAXES                             132058.

   MISCELLANEOUS                             82005.

   EXTERNAL PRODUCT COST                         0.
   INTERNAL (IMPLICIT) PRODUCT COST    87259408.

   VALUE ADDED:    .006 $(1986)/WAFERS =    .007 $(1986)/PEAK-WATTS
   PROFIT =    .1% OF PRICE
   MARKUP = 1.010 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .010 YEARS

   TO PRODUCE 2.222E+08 WAFERS/YEAR, THE DIFFUSION
   PROCESS REQUIRES:
```

ALL DOLLARS ARE IN $(1986)

DIRECT REQUIREMENTS

ACCOUNT A - FACILITIES
3.150E+03 SQ. FT. OF A2086D, MANUFACTURING SPACE (TYPE B)
@ 217.99 $(1986)/SQ. FT. IMPLIES 686657. $(1986)

ACCOUNT B - PERSONNEL
7.362E+00 PRSN*YRS OF B3064D, GENERAL ASSEMBLER (ELECTRONICS)
@ 17487.27 $(1986)/PRSN*YRS IMPLIES 137428. $(1986)
9.435E-02 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
@ 25475.26 $(1986)/PRSN*YRS IMPLIES 2403. $(1986)
9.435E-02 PRSN*YRS OF B3688D, ELECTRONICS MAINTENANCE MAN
@ 23748.14 $(1986)/PRSN*YRS IMPLIES 2241. $(1986)

ACCOUNT C - UTILITIES
3.531E+06 KW HR. OF C1032P, ELECTRICITY
@ .05 $(1986)/KW HR. IMPLIES 190578. $(1986)

ACCOUNT D - BYPRODUCTS
9.374E+08 CU. FT. OF D1016B, FUMES
@ 0. $(1986)/CU. FT. IMPLIES . $(1986)

ACCOUNT E - COMMODITIES
3.975E+03 LBS. OF E1504D, PDC1
@ 30.59 $(1986)/LBS. IMPLIES 118528. $(1986)
5.500E+06 CU. FT. OF E1416D, NITROGEN GAS, REGULAR PRE-PURIFIED
@ .01 $(1986)/CU. FT. IMPLIES 39416. $(1986)
3.781E+05 CU. FT. OF E1448D, OXYGEN GAS
@ .01 $(1986)/CU. FT. IMPLIES 4270. $(1986)

ACCOUNT F - RESOURCES
(NONE)

```
PROCESS: DRY        . DRY WAFERS
PRODUCT: DRYW       . DRY WAFERS
PRODUCES:   60.0000 WAFERS/MINUTE, TAKING     2.500 MINUTES/CYCLE
OPERATES  .98 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: DRYER, LINEAR BLOW DRYER
      COST:   10000. $(1979)    INSTALLATION:     500. $(1979)
      SALVAGE VALUE:    1500. $(1979) AFTER 39.0 YEARS
   COMPONENT: CONVEYER, THROUGH DRYER AND OUT
      COST:    3000. $(1979)    INSTALLATION:     300. $(1979)
      SALVAGE VALUE:     600. $(1979) AFTER  7.0 YEARS

   QUANTITY 2.226E+08 WAFERS/YEAR AT     .2069 $(1975)/WAFERS
   NUMBER OF DRY MACHINES =  8.000, OF WHICH  .379 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                          127110.
      DIRECT LABOR EXPENSES                            109883.
      DIRECT MATERIALS AND SUPPLIES                         0.
      BYPRODUCT EXPENSES                                    0.
      DIRECT UTILITIES EXPENSES                         17222.

   INDIRECT EXPENSES                         96631.
      INDIRECT LABOR EXPENSES                           83253.
      INDIRECT MATERIALS AND SUPPLIES                   11353.
      INDIRECT UTILITIES EXPENSES                        2025.

   BYPRODUCT INCOME                   (         0.)

   CAPITAL EXPENSES                          67768.
      EQUIPMENT REPLACEMENT                              5137.
      FACILITIES REPLACEMENT                             4444.
      AMORTIZED ONE-TIME COSTS                          27579.
      INTEREST ON DEBT                                   1365.
      RETURN ON EQUITY                                  14753.
      NON-INCOME TAXES                                    987.
      INSURANCE PREMIUMS                                13503.

   INCOME TAXES                              33057.

   MISCELLANEOUS                             20527.

   EXTERNAL PRODUCT COST                         0.
   INTERNAL (IMPLICIT) PRODUCT COST    66914384.

   VALUE ADDED:    .002 $(1986)/WAFERS =    .002 $(1986)/PEAK-WATTS
   PROFIT =    .0% OF PRICE
   MARKUP = 1.003 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODU
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .001 YEARS

   TO PRODUCE 2.226E+08 WAFERS/YEAR, THE DRY
   PROCESS REQUIRES:

      ALL DOLLARS ARE IN $(1986)

      DIRECT REQUIREMENTS
```

```
ACCOUNT A - FACILITIES
   8.800E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE
                                (TYPE  A)
        @      79.37 $(1986)/SQ. FT. IMPLIES    63498.  $(1986)

ACCOUNT B - PERSONNEL
   5.981E+00 PRSN*YRS OF B3064D, GENERAL ASSEMBLER
                                (ELECTRONICS)
        @  17487.27 $(1986)/PRSN*YRS IMPLIES   104600.  $(1986)
   1.075E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
        @  25475.28 $(1986)/PRSN*YRS IMPLIES     2737.  $(1986)
   1.075E-01 PRSN*YRS OF B36880, ELECTRONICS MAINTENANCE
                                MAN
        @  23748.14 $(1986)/PRSN*YRS IMPLIES     2552.  $(1986)

ACCOUNT C - UTILITIES
   3.191E+05 KW HR. OF C1032B, ELECTRICITY
        @        .05 $(1986)/KW HR. IMPLIES    17222.  $(1986)

ACCOUNT D - BYPRODUCTS
(NONE)

ACCOUNT E - COMMODITIES
(NONE)

ACCOUNT F - RESOURCES
(NONE)
```

```
PROCESS: CLEAN     , DAMAGE AND TEXTURE ETCH AND CLEAN WAFERS
PRODUCT: EACH      , EATCHED AND CLEANED WAFERS
PRODUCES:   60.0000 WAFERS/MINUTE, TAKING    68.300 MINUTES/CYCLE
OPERATES  .95 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: STACKER, STACKS CASSETTES
      COST:   12100. $(1979)    INSTALLATION:     800. $(1979)
      SALVAGE VALUE:    2420. $(1979) AFTER  7.0 YEARS
   COMPONENT: ETCH, ETCHING AND RINSING TANKS
      COST:   41250. $(1979)    INSTALLATION:    1300. $(1979)
      SALVAGE VALUE:    8250. $(1979) AFTER  8.0 YEARS
   COMPONENT: CONVEYOR, OUT GOING CONVEYOR
      COST:   12900. $(1979)    INSTALLATION:     900. $(1979)
      SALVAGE VALUE:    2580. $(1979) AFTER  7.0 YEARS

   QUANTITY 2.228E+08 WAFERS/YEAR AT     .2059 $(1975)/WAFERS
   NUMBER OF CLEAN MACHINES =  8.000, OF WHICH  .106 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                        823096.
      DIRECT LABOR EXPENSES                          163752.
      DIRECT MATERIALS AND SUPPLIES                  539094.
      BYPRODUCT EXPENSES                               7278.
      DIRECT UTILITIES EXPENSES                      122971.

   INDIRECT EXPENSES                      232917.
      INDIRECT LABOR EXPENSES                        192406.
      INDIRECT MATERIALS AND SUPPLIES                 22177.
      INDIRECT UTILITIES EXPENSES                     18334.

   BYPRODUCT INCOME                  (        0.)

   CAPITAL EXPENSES                       435325.
      EQUIPMENT REPLACEMENT                           77771.
      FACILITIES REPLACEMENT                          28207.
      AMORTIZED ONE-TIME COSTS                       141092.
      INTEREST ON DEBT                                 8837.
      RETURN ON EQUITY                                95538.
      NON-INCOME TAXES                                 6157.
      INSURANCE PREMIUMS                              77722.

   INCOME TAXES                           169115.

   MISCELLANEOUS                          105017.

   EXTERNAL PRODUCT COST                       0.
   INTERNAL (IMPLICIT) PRODUCT COST   35149072.

   VALUE ADDED:    .008 $(1986)/WAFERS =    .009 $(1986)/PEAK-WATTS
   PROFIT =    .1% OF PRICE
   MARKUP = 1.011 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .002 YEARS

   TO PRODUCE 2.228E+08 WAFERS/YEAR, THE CLEAN
   PROCESS REQUIRES:
```

ALL DOLLARS ARE IN $(1986)

DIRECT REQUIREMENTS

ACCOUNT A - FACILITIES
1.600E+03 SQ. FT. OF A20640, MANUFACTURING SPACE (TYPE A)
@ 79.37 $(1986)/SQ. FT. IMPLIES 126995. $(1986)

ACCOUNT B - PERSONNEL
9.276E+00 PRSN*YRS OF B30640, GENERAL ASSEMBLER (ELECTRONICS)
@ 17497.27 $(1986)/PRSN*YRS IMPLIES 162205. $(1986)
7.420E-01 PRSN*YRS OF B37360, MAINTENANCE MECHANIC II
@ 25475.26 $(1986)/PRSN*YRS IMPLIES 18904. $(1986)
1.113E-01 PRSN*YRS OF B36880, ELECTRONICS MAINTENANCE MAN
@ 23748.14 $(1986)/PRSN*YRS IMPLIES 2643. $(1986)

ACCOUNT C - UTILITIES
1.634E+05 CU. FT. OF C11440, WATER - DEIONIZED
@ .41 $(1986)/CU. FT. IMPLIES 66320. $(1986)
8.171E+05 CU. FT. OF C10640, NATURAL GAS
@ .03 $(1986)/CU. FT. IMPLIES 26269. $(1986)
3.863E+05 KW HR. OF C10320, ELECTRICITY
@ .05 $(1986)/KW HR. IMPLIES 20847. $(1986)
7.428E+05 CU. FT. OF C10160, DOMESTIC WATER
@ .01 $(1986)/CU. FT. IMPLIES 9534. $(1986)

ACCOUNT D - BYPRODUCTS
4.345E+05 GALLONS OF D10320, POISONOUS ACID
@ .02 $(1986)/GALLONS IMPLIES 7278. $(1986)

ACCOUNT E - COMMODITIES
1.931E+05 GALLONS OF E13520, ISOPROPYL ALCOHOL
@ 2.29 $(1986)/GALLONS IMPLIES 440271. $(1986)
1.300E+06 LBS. OF E16000, SODIUM HYDROXIDE
@ .04 $(1986)/LBS. IMPLIES 48276. $(1986)
3.603E+04 LBS. OF E16400, SULFURIC ACID
@ .57 $(1986)/LBS. IMPLIES 20547. $(1986)

ACCOUNT F - RESOURCES
(NONE)

```
PROCESS: INSPECT  , THICKNESS RESISTIVITY INSPECTION
PRODUCT: TWAFERS  , TESTED WAFERS
PRODUCES:   60.0000 WAFERS/MINUTE, TAKING      .833 MINUTES/CYCLE
OPERATES  .97 OF THE TIME THE FACTORY IS OPERATING
   COMPONENT: TESTER, TESTS AND SORTS WAFERS
      COST:   45000. $(1979)    INSTALLATION:     818. $(1979)
      SALVAGE VALUE:    9000. $(1979) AFTER  8.0 YEARS
   COMPONENT: UNPACK, UNPACKS AND LOADS INTO TESTER
      COST:   20000. $(1979)    INSTALLATION:    1000. $(1979)
      SALVAGE VALUE:    4000. $(1979) AFTER  7.0 YEARS
   COMPONENT: CONVEYOR, OUT GOING CONVEYOR
      COST:   10000. $(1979)    INSTALLATION:     511. $(1979)
      SALVAGE VALUE:    2000. $(1979) AFTER  7.0 YEARS

   QUANTITY 2.242E+08 WAFERS/YEAR AT     .2005 $(1975)/WAFERS
   NUMBER OF INSPECT MACHINES =  8.000, OF WHICH  .222 ARE IDLE

   ALL EXPENSES ARE IN $(1986)
   DIRECT EXPENSES                        63551544.
      DIRECT LABOR EXPENSES                                165207.
      DIRECT MATERIALS AND SUPPLIES                      63373952.
      BYPRODUCT EXPENSES                                        0.
      DIRECT UTILITIES EXPENSES                            11394.

   INDIRECT EXPENSES                        143371.
      INDIRECT LABOR EXPENSES                              123783.
      INDIRECT MATERIALS AND SUPPLIES                       17018.
      INDIRECT UTILITIES EXPENSES                            2568.

   BYPRODUCT INCOME                    (     6390.)

   CAPITAL EXPENSES                       8249317.
      EQUIPMENT REPLACEMENT                                 86816.
      FACILITIES REPLACEMENT                                 4949.
      AMORTIZED ONE-TIME COSTS                            6875809.
      INTEREST ON DEBT                                      91678.
      RETURN ON EQUITY                                     991114.
      NON-INCOME TAXES                                       3080.
      INSURANCE PREMIUMS                                   265873.

   INCOME TAXES                           8157537.

   MISCELLANEOUS                          5965644.

   EXTERNAL PRODUCT COST                        0.
   INTERNAL (IMPLICIT) PRODUCT COST             0.

   VALUE ADDED:    .380 $(1986)/WAFERS =    .426 $(1986)/PEAK-WATTS
   PROFIT =  1.2% OF PRICE
   MARKUP = 1.340 TIMES (DIRECT EXPENSES PLUS INTERNAL AND EXTERNAL PRODUC
   THE ENERGY PAYBACK TIME FOR THIS PROCESS IS    .001 YEARS

   TO PRODUCE 2.242E+08 WAFERS/YEAR, THE INSPECT
   PROCESS REQUIRES:
```

ALL DOLLARS ARE IN $(1986)

DIRECT REQUIREMENTS

ACCOUNT A - FACILITIES
8.000E+02 SQ. FT. OF A2064D, MANUFACTURING SPACE (TYPE A)
@ 79.37 $(1986)/SQ. FT. IMPLIES 63498. $(1986)

ACCOUNT B - PERSONNEL
9.139E+00 PRSN*YRS OF B3064D, GENERAL ASSEMBLER (ELECTRONICS)
@ 17487.27 $(1986)/PRSN*YRS IMPLIES 159809. $(1986)
1.097E-01 PRSN*YRS OF B3736D, MAINTENANCE MECHANIC II
@ 25475.28 $(1986)/PRSN*YRS IMPLIES 2794. $(1986)
1.097E-01 PRSN*YRS OF B3688D, ELECTRONICS MAINTENANCE MAN
@ 23748.14 $(1986)/PRSN*YRS IMPLIES 2604. $(1986)

ACCOUNT C - UTILITIES
2.111E+05 KW HR. OF C1032B, ELECTRICITY
@ .05 $(1986)/KW HR. IMPLIES 11394. $(1986)

ACCOUNT D - BYPRODUCTS
1.831E+03 SQ. MT. OF D1064D, REJECTED WAFERS
@ -3.49 $(1986)/SQ. MT. IMPLIES -6390. $(1986)

ACCOUNT E - COMMODITIES
1.816E+06 SQ. MT. OF E1590D, WAFERS, SINGLE CRYSTAL SILICON
@ 34.90 $(1986)/SQ. MT. IMPLIES 63373957. $(1986)

ACCOUNT F - RESOURCES
(NONE)

APPENDIX B

Format A Data and Justifications For ROBOTBOND (Programmable Automation Process)

SOLAR ARRAY MANUFACTURING INDUSTRY COSTING STANDARDS

FORMAT A

JET PROPULSION LABORATORY
California Institute of Technology
4800 Oak Grove Dr. / Pasadena, Calif. 91103

PROCESS DESCRIPTION

Note: Names given in brackets [ ] are the names of process attributes requested by the SAMIS III computer program.

A1 Process [Referent] ROBOTBOND

A2 [Descriptive Name] Circuit Lay-up and Interconnect Using an Idustrial Robot

PART 1 – PRODUCT DESCRIPTION

A3 [Product Referent] Circuit

A4 Descriptive Name [Product Name] Interconnected Circuit of Cells

A5 Unit Of Measure [Product Units] Circuits

PART 2 – PROCESS CHARACTERISTICS

A6	[Output Rate] (Not Thruput)	0.02765	Units (given on line A5) Per Operating Minute
A7	Average Time at Station [Processing Time]	36.167	Calendar Minutes (Used only to compute in-process inventory)
A8	Machine "Up" Time Fraction [Usage Fraction]	0.98	Operating Minutes Per Minute

PART 3 – EQUIPMENT COST FACTORS [Machine Description]

A9	Component [Referent]	Robot	Prepsta	Heat
A9a	Component [Descriptive Name] (Optional)	Unimate 2000 B	Cell Preparation Station	Induction Heating Generator
A10	Base Year For Equipment Prices [Price Year]	1979	1979	1979
A11	Purchase Price ($ Per Component) [Purchase Cost]	49,685	16,500	4,000
A12	Anticipated Useful Life (Years) [Useful Life]	4.83	7	10
A13	[Salvage Value] ($ Per Component)	24,842	825	200
A14	[Removal and Installation Cost] ($/Component)	700	500	200

Note: The SAMIS III computer program also prompts for the [payment float interval], the [inflation rate table], the [equipment tax depreciation method], and the [equipment book depreciation method]. In the LSA SAMICS context, use 0.0, (1975, 6.0), DDB, and SL.

JPL 3037-S R 10/78

Format A: Process Description (Continued)

A15 Process Referent (From Page 1 Line A1) ROBOTBOND

PART 4 – DIRECT REQUIREMENTS PER MACHINE (Facilities) OR PER MACHINE PER SHIFT (Personnel)
[Facilities and Personnel Requirements]

A16 Catalog Number [Expense Item Referent]	A18 Amount Required Per Machine (Per Shift) [Amount per Machine]	A19 Units	A17 Requirement Description
A2064D	350	Ft^2	Manufacturing Space (A)
B3064D	0.125	Person/Shift	General Assembler
B3736D	0.0179	Person/Shift	Mechanical Maintenance II
B3688D	0.00893	Person/Shift	Electronics Maintenance

PART 5 – DIRECT REQUIREMENTS PER MACHINE PER MINUTE
[Byproduct Outputs] and [Utilities and Commodities Requirements]

A20 Catalog Number [Expense Item Referent]	A22 Amount Required Per Machine Per Minute [Amount per Cycle]	A23 Units	A21 Requirement Description
EA3D	0.0169	LBS	Copper Ribbon
EG1600D	0.0047	LBS	Solder Paste
C1032B	0.3083	KW-HR	Electricity
E1140D *	0.0625	$Meter^2$	Solar Cells

* Note: To run this Process in a full sequence, omit this item and get cells from within the company in Part 6 below.

PART 6 – INTRA-INDUSTRY PRODUCT(S) REQUIRED [Required Products]

A24 [Product Reference]	A28 [Yield]* (%)	A26 [Ideal Ratio]** Of Units Out/Units In	A27 Units Of A26***	A25 Product Name
PCELLS	99.8	0.003497	Circuit/Cell	Sorted Packeged Cells

Note: To run this process alone, omit this item and buy cells from outside in Part 5 above.

Prepared by Carl Witham Date 11/21/79
Updated John Hagerty 4/16/80

* 100% minus percentage of required product lost.
** Assume 100% yield here.
*** Examples: Modules/Cell or Cells/Wafer.

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REVERSE SIDE JPL 3037-S R 10/78

Line #

A6/A7 (Output Rate): Assume 7.5 sec/cell → 8 cells/min and 10 sec. for End Buss Bars

Module of 288 cells (4' x 8')

requires $\frac{288}{8} + \frac{10}{60} = \underline{36.167}$ min/circuit

→ 0.02765 circuits/min

A8 (Machine Up Time) 98% (manufacturer's estimate).

A11→A14 (Equipment Cost Factors)

Unimate 2000B

Purchase Price: $ 49,685. Includes robot base price, additional memory, teach control.

Useful Life: 40,000 hrs. (manufacturer's estimate) → 4.83 yrs.

Salvage Value: 50% (manufacturer's estimate) before overhaul → $24,842

Installation and Removal Costs: $700 Based on experience with current robot.

Cell Preparation Station

Purchase Price:	$ 10,000	Mechanical construction
	2,600	Siltec Cassette Unloader
	2,300	Computer & Interface
	1,600	Enclosure
	$ 16,500	

Line #

A11→A14 (continued)

Cell Preparation Station (continued)

Useful Life: 7 years (Engineering Estimate)

Salvage Value: 5% (Engineering Estimate) → $825

Installation and Removal Costs: $500 (Estimate)

Induction Heater

Purchase Price: $4,000

Useful Life: 10 years (Industrial Estimate)

Salvage Value: 5% (Engineering Estimate) → $200

Installation and Removal Costs: $200

A16→A19 (Direct Requirements per Machine per Shift)

Manufacturing Space: 350 ft^2 (based on current machine)

Assembler/Operator: 1 person can watch 8 robots
→ 0.125 persons/robot/shift

Maintenance:

Scheduled - 6.5 hr/1000 hr (mfg. est.) →	1.092 hr/wk	
Unscheduled (98% up time) -	3.360	
	4.452 hr/wk	
	≈ 4.5 hr/wk	

Required Maintenance 4.5 hr/wk assume 2/1 ratio mechanical to electrical.

Mechanical: $3.0 \frac{hr}{wk} \times \frac{1}{21} \frac{wk}{shift} \times \frac{1}{8} \frac{shift}{man\text{-}hr} = 0.0179$ person/shift

Electrical: $1.5 \frac{hr}{wk}$ - - - - - - - - - - - - - = 0.00893 person/shift

A20→A23 (Direct Requirements for Machine Per Minute)

Copper Ribbon

4" dia cell w/ dual ribbons full length front and back → 16 in/cell. Ribbon is 0.100" x 0.002"

16" x 0.100" x 0.002" = 0.0032 in^3/cell

for 288 cells/circuit → 0.9216 in^3/circuit

If each string of 18 is attached to a buss bar at both ends with a 1" dual lead stub → 4 in/string

4" x 0.100" x 0.002" = 0.0008 in^3/string

288/18 = 16 strings → 0.0128 in^3/circuit

Buss bar is 0.5" x 0.01" Ribbon down both 8 ft. sides of the panel

→ $8' \times 12 \frac{in}{ft} \times 2 \times 0.5'' \times 0.01'' = 0.960\ in^3/circuit$

Total Ribbon:

	0.9216
	0.0128
	0.9600
	1.8944 in^3/circuit

copper weighs 0.322 lb/in^3

→ 0.610 lb/circuit

@ 0.02765 circuits/min → 0.0169 lb/min

Solder Paste

Each cell requires 4 solder beads (one for each ribbon) 3.25" long.

For 0.015" dia bead: $\left[\frac{0.015}{2}\right]^2 \times \pi \times 3.25 \times 4 = 0.0023\ in^3/cell$

@ 288 cells/circuit → 0.662 in^3/circuit

Line #

A20→A23

Solder Paste (continued)

Solder paste weighs 0.2575 lb/in^3

→ 0.1704 lb/circuit

@ 0.02765 circuits/min → 0.0047 lb/min

Electricity

Robot	12.0 KW	manufacturer specs.
Induction Heater	5.5 KW	
Preparation Station	1.0 KW	Sum of electrical equipment in preparation station.
	18.5 KW	

= 18.5 KWH/hr → 0.3083 KWH/min

Solar Cells

100mm cell = 0.0079 m^2/cell

@ 288 cells/circuit → 2.262 m^2/circuit

@ 0.02765 circuit/min → 0.0625 m^2/min

APPENDIX C

Unimate 2000 Industrial Robot Characteristics

Unimate Industrial Robots:

The flexible way to increase productivity and reduce operating costs.

Leadership through product superiority

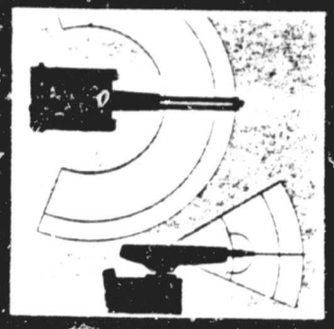
Unimation Inc. pioneered the development of the industrial robot and is the leader in the field.

Leadership through experience

Unimate benefits have been proven through millions of hours of on-the-job experience.

Leadership in customer services

Complete services, accessories and systems assure you a high return on your investment.



Leadership in product flexibility

Model selection provides best choice at minimum cost.

Leadership through product superiority

Unimation Inc. pioneered the development of the industrial robot and has maintained its leadership role through product superiority and technological ingenuity.

Today, the industrial robot is used in manufacturing operations throughout the world to perform tasks that are too hazardous, too onerous, too boring, or simply too uneconomical for humans.

In most applications, the robot can handle heavier loads more accurately and at higher speeds for longer periods of time than its human counterpart. This results in increased productivity, lower operating costs and products with greater uniformity and precision.

The proven performance of UNIMATE® industrial robots is derived from millions of hours of productive work in many different industries. Their durability is attested to by the many machines that are hale and hearty and still earning their keep after 65,000 hours of operation—that's over 32 man years of work.

The diversity of applications and proven endurance of the UNIMATE illustrate its versatility and are your assurance of a sound investment.

A matter of flexibility

Flexibility is the key to what the Unimate offers. This industrial robot not only adapts to new applications but it adapts to new requirements within an existing process.

The most efficient hard or special-purpose automation can become instantly obsolete if the product or process changes. In contrast, the sophistication of the Unimate invests it with the flexibility to adapt to changes...and in no more time than it would take a human worker.

The Unimate includes up to 6 fully programmable degrees of freedom. Its motions are hydraulically actuated for heavy payloads, smoothness of operation and durability. Its solid state, non-volatile memory has a capacity for as many as 1024 program steps point-to-point (PTP) and is easily adapted to specific job requirements.

This flexibility provides built in non-obsolescence and long term cost effectiveness. It makes the Unimate robot your best automation investment.

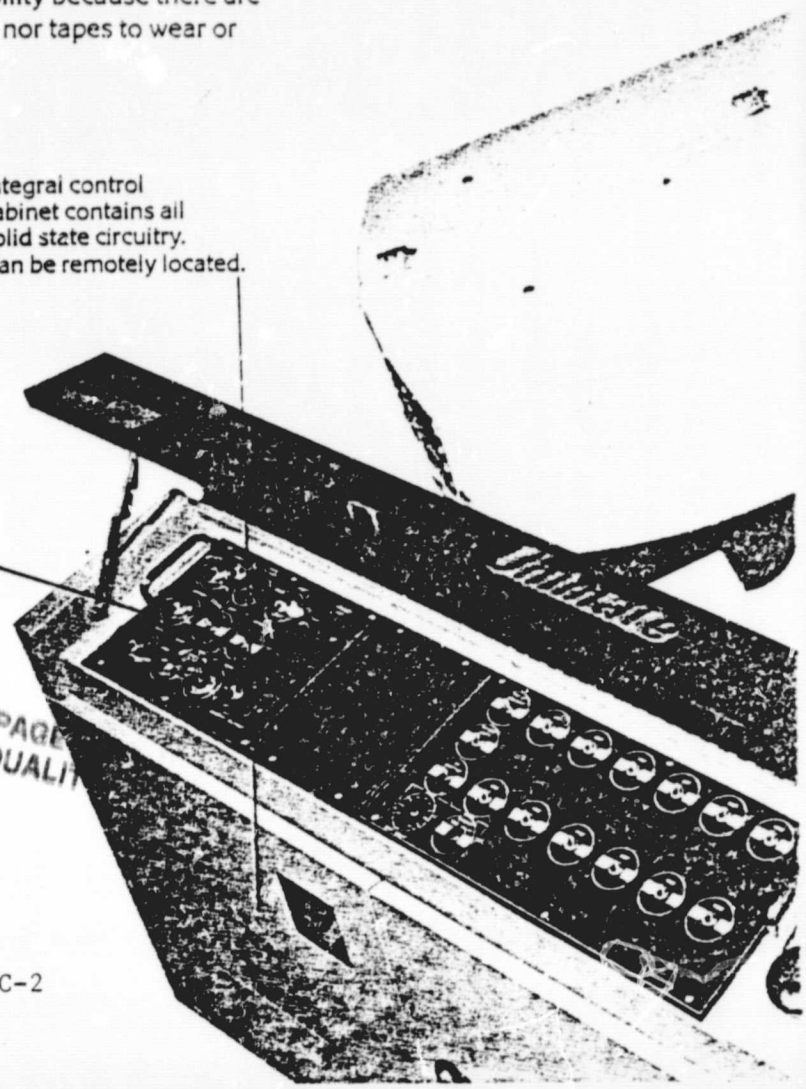
Features that count

There are several models of the Unimate robot and many available options designed to meet your needs at the lowest possible cost. The 2000 series Unimates can handle payloads up to approximately 125 lbs., while the 4000 series can handle up to 500 lb. loads. All models include the following proven design features that assure exceptional performance and reliability.

Muscle power: Hydraulic servoing of all degrees of freedom provides the power for high speed operation with smooth acceleration and deceleration.
Servo control: The control system is 100% digital. This assures positive positional accuracy with neither short nor long term drift nor the need for zeroing. Solid state electronic components are used throughout for high reliability.
Non-volatile memory: The solid state programmable memory (PROM) is the ultimate in reliability because there are no moving parts nor tapes to wear or stretch. Retention of memory, regardless of electrical power loss or transients, is indefinite. Many memory sizes and functional arrangements are available.
Controls and interlocks: Operator controls are conveniently arranged in the control cabinet. Electrical connections are easily accessible to interlock the Unimate with the equipment it serves, including programmable functions to insure safe and efficient operation. In addition, interfacing within a computer controlled hierarchy is readily accomplished.

Millions of hours of field performance assure unsurpassed reliability.

Sturdy covers protect equipment and enclose all pinch points.



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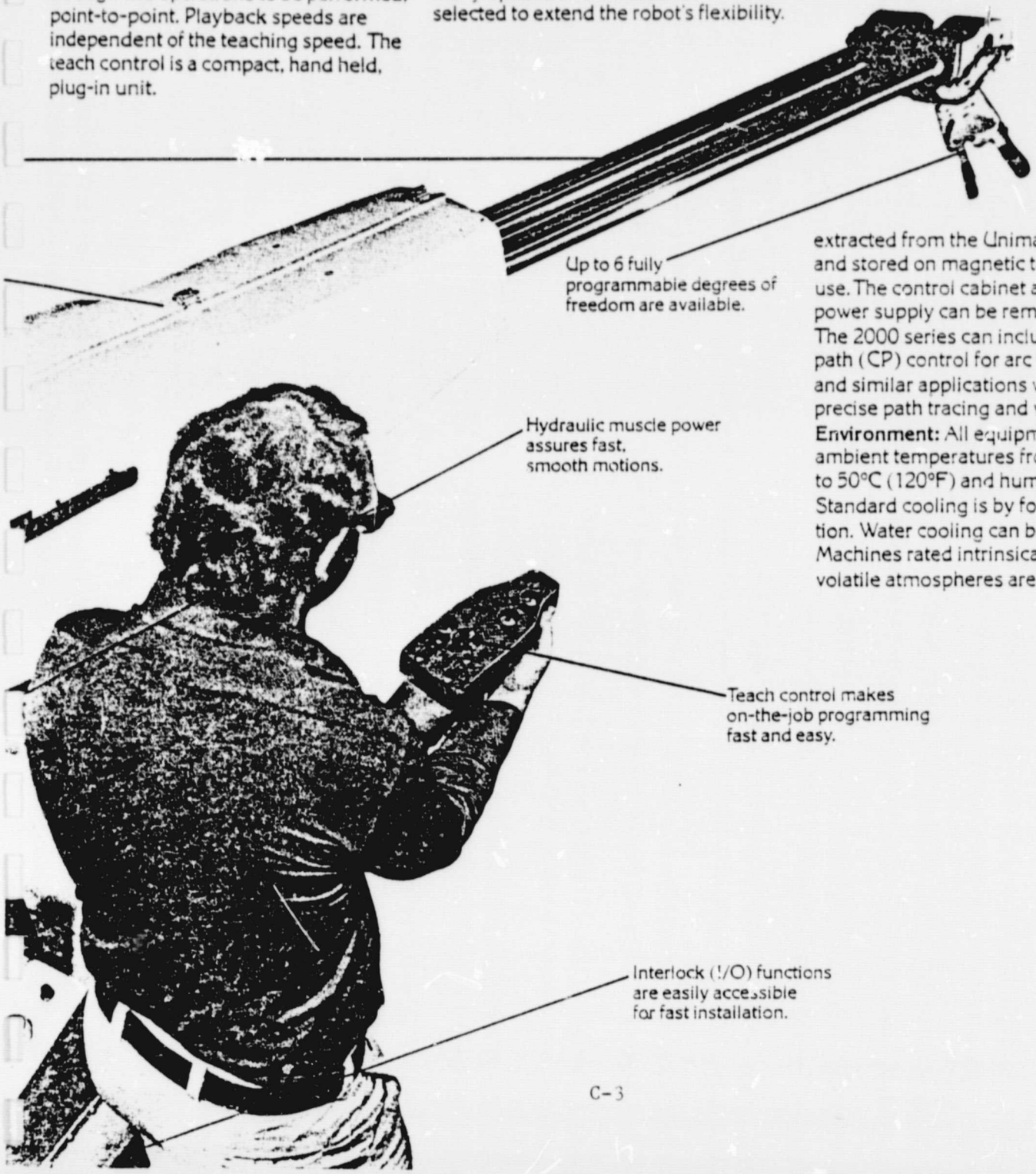
No. of degrees of freedom: All models are available with from 2 to 6 fully programmable degrees of freedom.

Easy to teach: The Unimate is designed for "on-the-job" training. No computer type programming preparation or cumbersome hard wire sequencing is required. Within one hour, anyone can learn to teach Unimate the job because the robot is literally led by the hand through the operations to be performed, point-to-point. Playback speeds are independent of the teaching speed. The teach control is a compact, hand held, plug-in unit.

Easy to maintain: Simple procedures help to assure proper maintenance of the Unimate. You get proper maintenance schedules and instructions for sustained, trouble free operation. Modular construction, combined with definitive trouble shooting guides also helps you to maintain the robot.

Options and accessories: In addition to the essential features already described, many options and accessories can be selected to extend the robot's flexibility. For example, multiple programs can be stored in the memory and called upon at random; base and sub routines can be taught to facilitate complex material handling and palletizing operations; portions of programs can be altered to accommodate external variables without interrupting the operation; motions can by synchronized with continuously moving conveyors; and programs can be extracted from the Unimate's memory and stored on magnetic tape for future use. The control cabinet and the hydraulic power supply can be remotely located. The 2000 series can include continuous path (CP) control for arc welding, routing and similar applications which require precise path tracing and velocity control.

Environment: All equipment is rated for ambient temperatures from 5°C (40°F) to 50°C (120°F) and humidity to 90%. Standard cooling is by forced air circulation. Water cooling can be provided. Machines rated intrinsically safe for volatile atmospheres are also available.



Leadership through experience

Unimate performance has been proven through millions of hours of experience, worldwide, in metal working, material handling, casting and forging, glass manufacturing, automotive assembly—in tasks that are monotonous, tiring, disagreeable, dangerous and debilitating to humans.

Check these Unimate benefits

Increased productivity—from 25% to 40% and more as reported by Detroit Diesel, Fiat, Doehler-Jarvis.

Increased product quality and fewer rejects—says Chrysler, Inland Die Casting Corp., Evinrude—in some cases by a factor of 70%.

Improved capital equipment utilization—Unimate "up-time" of better than 98% assures high equipment utilization says Volvo, Ford, Bauer Products, Alfa Romeo, Briggs & Stratton.

Inflation resistant—the Unimate you hire today will be working at the same hourly rate 5 years from now says Cast Specialties, Advance Pressure Castings, Texas Instruments.

Fast, easy installation—fast response time means accrued benefits sooner says Chrysler, Lunkenheimer, Twin City Die Casting.

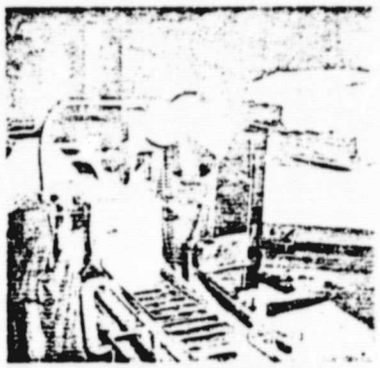
Round-the-clock output—no second or third shift production slow down reported by Pemco Die Cast Corp., Ford, Tube Turns.

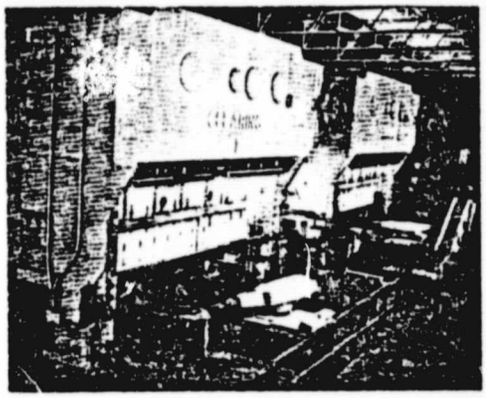
Flexibility—permits use in custom shop and batch processing environments says Dittmann Neuhauss, Doehler Jarvis, Evinrude.

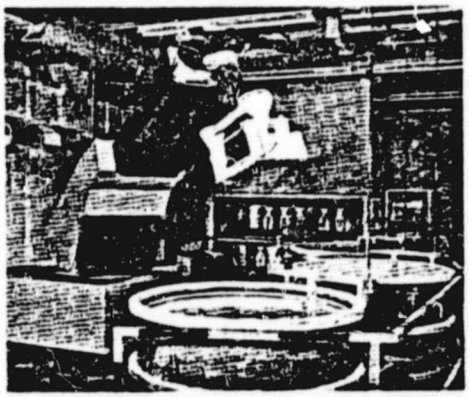
Reduced in-process inventory and material handling—as experienced at Rockwell International, Texas Instruments, Tube Turns, International Harvester.

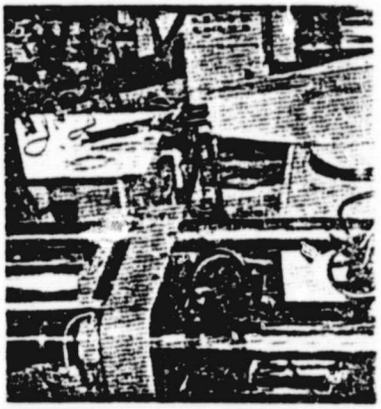
Improves competitiveness—says Lunkenheimer, Chevrolet, Superior Die Casting.

Reduces indirect and hidden costs—less die maintenance, reduced energy consumption, less lost production due to illness and absenteeism, lower costs for OSHA compliance reported by Chevrolet Superior Die Casting, Fiat, Del Mar Die Casting, A. O. Smith.









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These are but a few of the benefits that Unimate industrial robot users have reported. They are some of the reasons why our customers continue to add Unimates to their work forces. Consider the applications depicted on these pages. The answers to your automation needs may well be illustrated.

Our extensive library of application and technical bulletins and movie films is at your disposal. Our experience will serve you well.

1. Punch and stamping press transfer

A Unimate robot is a real OSHA problem-solver when operating with punch and stamping presses. A battery of Unimate robots in a press transfer line guarantees consistent throughput, shift after shift. Change over in batch run processing can be done in minutes by using Unimation's Cassette Program Storage Unit which preserves Unimate programs on magnetic tape.

2. Investment casting

Scrap rates as high as 85% have been reduced to under 5% when Unimates are used in this highly sophisticated process. The robot's dexterity and repeatability assure consistent mold quality never before achieved in the dipping process. Unimate robots are being used singly or in totally automated DNC systems in which dozens of different wax molds, weighing from a few pounds to over 300 lbs. are processed by as many as 10 robots.

3. Materials handling

From raw material in the back door to finished goods out the front door, materials handling is a necessary evil that costs money and is often labor intense. The Unimate robot becomes a real problem solver because it has the muscle, dexterity and versatile memory to pack or transfer goods in complex palletized arrays without product damage or lost counts. And it's cheaper than special-purpose equipment that is quickly made obsolete by product change.

4. Forging

One of the toughest industrial jobs is forging. Unimate robots operate forge hammers, presses, upsetters and trim presses without fatigue or the need for relief operators. In some cases a Unimate will do the work of six men per shift, yielding a handsome payout.

5. Die casting

Because productivity gains with Unimate robots are so dramatic, it is often unnecessary to invest in additional die cast machines. Scrap rate reductions of as much as 70% are common. The Unimate can unload the die cast machine, quench the part, feed a trim press, load inserts, service two die cast machines, ladle aluminum and perform die care. The robots flexibility and consistency are cost-cutting benefits that guarantee a high return on investment for both custom and captive shops.

6. Automotive assembly

Unimation Inc.'s family of robots spot-welds automobile and truck assemblies for almost every major manufacturer throughout the world. Applications include construction of sub-assemblies, body sides, underbodies and front structures, as well as body framing and respot. Consistency of spot location and weld integrity yield automotive assemblies of the highest quality. The Unimate robot's versatile memory easily accommodates any product mix. And, with the aid of Unimation's Program Editor, program adjustment to accommodate variations such as metal fit ups are easily made without interrupting the production cycle.

7. Machine tool loading

Two-fisted Unimate robots hold the key to machine tool productivity. Rapid loading and unloading of work pieces assures high utilization of costly capital equipment. Using Unimate robots to simultaneously serve several machine tools reduces in-process inventory and costly material handling, and has reduced piece part costs by as much as 65%. A Unimate machining system is the ultimate in automated parts manufacturing.

8. Continuous path applications

Velocity and path control add to the versatility of the Unimate 2000 series. Capable of being operated in either point-to-point (PTP) or continuous path (CP) modes, this model is ideally suited to arc (gas) welding, routing, sealant application, mold spraying and bake out, degating, pad machining and grinding, flame cutting and other process tasks requiring smooth, accurate, three-dimensional paths and velocity control. In either mode, Unimation's point-to-point, lead-it-by-the-hand teaching method is retained.

Leadership in customer : vices:

From grippers to testers, seminars to service training, spare parts to systems, your needs are met by Unimation's experienced staff of sales, applications and service engineers, training instructors and service order dispatchers. The many services and accessories offered by Unimation Inc. are designed to give you full support and to assure you of a high return on your investment in Unimate robots.

Hand designs

The hands that can be used on the Unimate fall into three general categories: mechanical grippers, surface-lift devices and tools.

Mechanical grippers employ movable, finger-like levers, paired to work in opposition to each other. A single hand might have one or several sets of opposed fingers. Likewise, a robot might have more than one hand.

Surface-lift devices are exemplified by vacuum pick-ups and electromagnets for handling durable, delicate (glass) or ferrous materials with flat or curved surfaces. Tools that serve as robot hands include spot welding guns, impact wrenches, spray heads or arc welding torches.

Unimation engineers have accumulated a substantial library of hand-tooling designs based on these three general categories. With this kind of experience, our engineers have the know-how and ingenuity to design, build and test robot hands to meet any special requirements your application demands.

Accessories

Cassette Program Storage. This accessory unit lets you reassign the Unimate to another task at the push of a button. Once the Unimate has been taught a specific job the program sequence can be extracted from the robot's memory and stored on magnetic tape cassettes for later re-insertion. The unit is powered from the Unimate and plugs into the robot's test connector. It's as simple to use as any tape recorder.

Program Editor. This accessory is also portable and facilitates minor alterations in Unimate programs without interrupting the operating cycle. One or all degrees of freedom can be modified on any step of the program to accommodate for tool wear, fixture variations, metal fit ups and the like.

Unimate Tester. This accessory is designed to help facilitate maintenance and troubleshooting on the Unimate robot. It's portable and is supplied in a metal carrying case. A self-contained electrical cable is used to attach the tester to the Unimate test connector. The use of the tester as a valuable diagnostic tool is thoroughly covered in the Unimate training schools and equipment manuals.

Interface Controls. Several different control units are available to facilitate alternate or random selection of Unimate programs. For interfacing with a master process computer we supply the E.I.A. standard RS-232-C serial data transmitter system.

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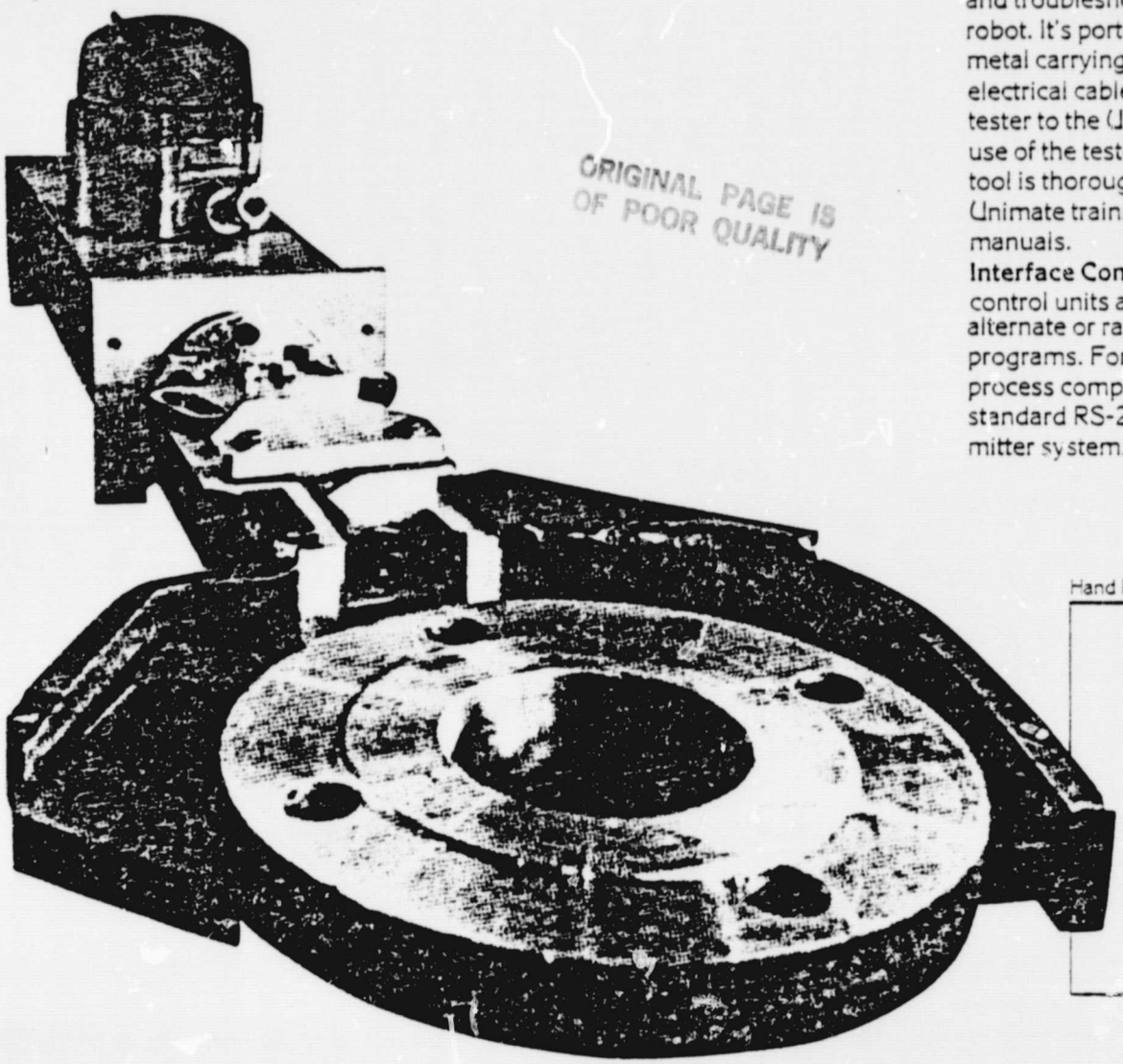
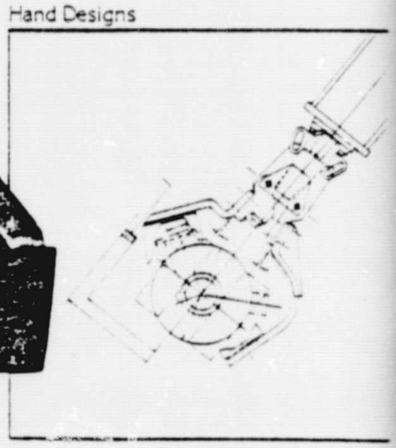


Hand Designs



Services

Robot Seminars. Unimation Inc. conducts periodic seminars on robotics tailored to specific application areas such as machine tool loading, punch and stamping press operations, resistance and arc welding, and die casting. These are hard-hitting, shirtsleeve sessions that give you the practical information you need to evaluate the use of Unimates in your operation. At your request also, we will develop a custom seminar to fit your specific company needs.

Customer Training Program. Our customer training program is designed just for you. We teach your personnel how to operate, maintain and repair the equipment, at our facility or in your plant. With qualified in-house capability, you can assure yourself of high and uninterrupted Unimate performance.

Customer Service Program. Our staff of field service engineers is available to assist you with your installation, service needs and spare parts requirements.

Systems

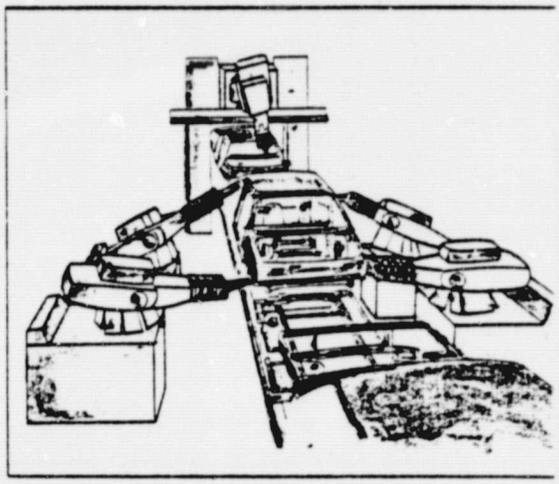
Unimation engineers have gained extensive experience in virtually every field of manufacturing. The result is a capability to design and build systems around the robot which offers you the most efficient, flexible means available to cut costs and improve productivity. A system can be as simple as one robot and some workpiece orienting devices, or a multiplicity of robots integrated into a totally computerized manufacturing process.

Systems supplied by Unimation range from brick handling equipment including palletizing conveyors, kiln car indexer, process controller and robot to automotive assembly lines with 15 to 30 robots, car body shuttle conveyor, supervisory control and spot weld guns. Machining systems for processing parts from raw castings to finished goods have been developed using conventional or NC machine tools and employing the principles of group technology.

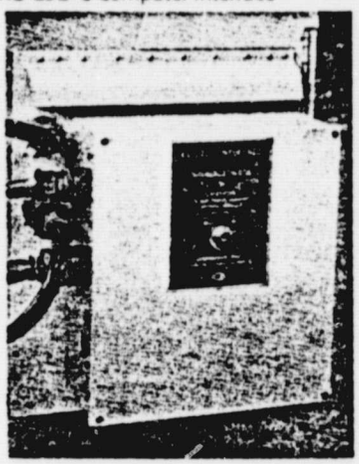
These systems provide the ultimate in flexibility, insure quality of product, can be on stream fast, and result in impressive productivity gains.

Our applications engineers stand ready to help your staff upgrade your manufacturing process. Give us a call. We welcome the opportunity to work with you.

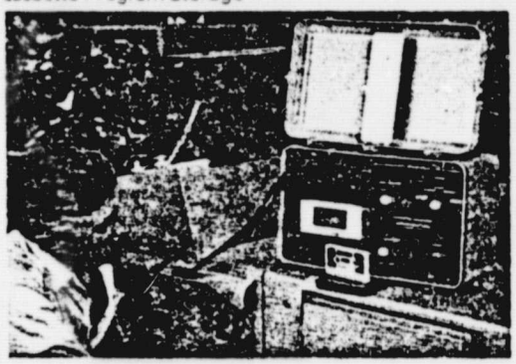
Engineered systems designed by Unimation provide the ultimate in flexibility and productivity.



RS-232-C Computer Interface



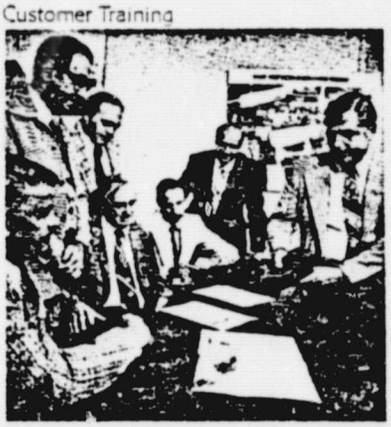
Cassette Program Storage



Unimate Tester

Program Editor

Customer Training



Leadership in product flexibility

MODEL SPECIFICATIONS*	2000B		2000C		2100B		2100C		4000B	
Floor Space/Weight	space	weight	space	weight	space	weight	space	weight	space	weight
Manipulator	20 sq ft 1.86 m²	2800 lb 1271 kg	12 sq ft 1.11 m²	2200 lb 1000 kg	20 sq ft 1.86 m²	2900 lb 1318 kg	12 sq ft 1.11 m²	2300 lb 1045 kg	22 sq ft 2.04 m²	5000 lb 2273 kg
Hydraulic Supply (with fluid)	Integral		9.6 sq ft 0.90 m²	500 lb 227 kg	Integral		9.6 sq ft 0.95 m²	500 lb 227 kg	Integral	
Control Cabinet	Integral		6.3 sq ft 0.59 m²	300 lb 136 kg	Integral		6.3 sq ft 0.59 m²	300 lb 136 kg	6.3 sq ft 0.59 m²	300 lb 136 kg
Mounting position	Floor		Any		Floor		Any		Floor	
No. of Degrees of Freedom	2-6		2-6		2-6		2-6		2-6	
Positioning Repeatability (PTP)	0.05 in (1.27mm)		0.05in (1.27mm)		0.05in (1.27mm)		0.08in (2.03mm)		0.08in (2.03mm)	
Power requirements	460, 3Ø 60Hz, 11KVA		460, 3Ø 60Hz, 11KVA		460, 3Ø 60Hz, 11KVA		460, 3Ø 60Hz, 11KVA		460, 3Ø 60Hz, 34KVA	
Load capacity										
Max. lift (full extension)	300 lb (136 kg)		300 lb (136 kg)		300 lb (136 kg)		270 lb (123 kg)		450 lb (205 kg)	
Standard Wrist, Torque										
Bend	1000 in-lb (11.5 kg-m)								3500 in-lb (40.3 kg-m)	
Yaw	600 in-lb (6.9 kg-m)								2800 in-lb (32.2 kg-m)	
Swivel	800 in-lb (9.2 kg-m)								2300 in-lb (26.5 kg-m)	
Heavy Duty Wrist, Torque										
Bend	2000 in-lb (23 kg-m)								11000 in-lb (126.5 kg-m)	
Yaw	1200 in-lb (13.8 kg-m)								2800 in-lb (32.2 kg-m)	
Swivel	800 in-lb (9.2kg-m)								N/A	
Memory options										
Point-to-Point	UP TO 1024 POINTS, OTHER OPTIONS AVAILABLE									
Continuous Path	UP TO 500 in. OF TRAVEL								N/A	
Interlocks	UP TO A TOTAL OF 24 I/O CHANNELS									
Speeds/Travel	REQUEST DETAILED SPECIFICATIONS									
Environment	40°F (5°C) to 120°F (50°C), Humidity 0-90%									

For more detailed installation and performance data and available options, contact Unimation Inc. Unimation Inc. reserves the right to make changes in equipment specifications at any time without notice.

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Unimation Inc.®

A subsidiary of Corporation

Headquarters:
Shelter Rock Lane
Danbury, Connecticut 06810
Telephone: (203) 744-1800

Midwest Regional Office:
32500 W. Eight Mile Road
Farmington, Michigan 48024
Telephone: (313) 477-1255

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APPENDIX D

Butyl Based Sealant Characteristics

MEMBER

SEALED INSULATING GLASS MANUFACTURERS ASSOCIATION

SIGMA

REQUIREMENT: Develop a new base sealant for sealed insulated glass with three primary benefits:

1. The seal should have outstanding MVT values and peel adhesion; resistance to weathering and elongation; and allow the manufacturer to extend his warranty.

2. Elapsed time between production and shipping should be significantly lower than with conventional sealants.

3. The sealant, and its method of application, should be cost-effective: that is, the sealant should be significantly lower in cost per gallon than existing sealants, and the way it is used should enable the sealed insulated glass manufacturer to produce units so efficiently that many of his manufacturing costs can be reduced.

It is the third benefit, cost-effectiveness, that can determine how efficiently insulated glass is produced.

The sealant system that combines technological advances with visible cost-effectiveness will satisfy both manufacturing demands and customer demands. It will make its own case with manufacturers, based on its efficient sealing properties and its money-saving abilities.

PRODUCT: A sealant with these three primary benefits is now available. It's H. B. Fuller Thermo-Seal 1081, the new Butyl hot-melt sealant developed specifically for insulated glass. It includes a number of high-technology advances.

CHEMICAL BASE—Butyl. COLOR—Grey. TESTED UNDER SIGMA SPECIFICATION—65-7-2. YEAR—1974. STATUS—Passed.

MOISTURE VAPOR TRANSMISSION: a) Lower than the Butyl commonly used to manufacture double-seal windows.

b) A single application shows MVT values better than the combination Butyl/polysulfide construction

DEAD LOAD SLUMP TEST: Greater resistance to Dead Load Slump than existing thermoplastic hot melts.

ELONGATION: Over 1000% elongation as measured on an Instron testing machine with corresponding tensile strength significantly better than polysulfides.

OVERLAP SHEAR TEST: Several times higher in shear strength when compared to existing thermoplastic hot melts, and approaches the values obtained with polysulfides.

PEEL ADHESION TEST: Considerably better adhesion to glass and aluminum than polysulfides and comparable to other thermoplastic hot melts. Test method: ITS-C0230-C.

TOXICITY: Requires no toxic or hazardous catalyst to effect cure.

Thermo-Seal 1081 is a Butyl sealant. This sealant, used in the sealed insulated glass industry, has provided manufacturers with good adhesion, good peel strength; a high resistance to weathering and to ultraviolet breakdown; high dead load slump resistance; and more than 1000% elongation with corresponding tensile strength

significantly higher than polysulfides. Overlap shear strength is also correspondingly high.

Thermo-Seal 1081 is a one-component Butyl sealant. Unlike other sealants, Thermo-Seal 1081 has no solvent content. There is no evaporation of partial components, which eliminates toxicity. Thermo-Seal 1081 is 100% solids, which restricts sealant breakdown over long periods of time. Thermo-Seal 1081 maintains its stability, and its adhesive qualities, throughout the estimated life of the window unit.

Thermo-Seal 1081 is a hot-melt Butyl sealant. The application of the sealant in this way offers an exceptionally flexible seal that sets very quickly. The hot Butyl exhibits excellent flow characteristics, and its quick set eliminates sealant crystallization. In addition, hot-melt Butyl gives the sealed insulated glass manufacturer a seal with a considerably lower Moisture Vapor Transmission characteristic.

Thermo-Seal 1081, then, is a one-component, Butyl hot-melt sealant that offers the manufacturer the following product benefits:
• Excellent sealing qualities • Extreme stability • Low MVT value
• No toxicity • Long life

SYSTEM: When Thermo-Seal 1081 is considered as part of a system, it offers the sealed insulated glass manufacturer a good opportunity to capitalize on cost-effective unit fabrication.

Because of Thermo-Seal 1081's superb qualities, double-sealing can be eliminated. This allows the manufacturer to simplify his production line. And one-component Thermo-Seal 1081 eliminates the need for complicated two-pump application systems, as well as the problems inherent in two-component sealant balancing, handling, and quality control.

Because Thermo-Seal 1081 is used in a hot-melt form, application is fast. However, the real test of effectiveness comes from the window unit's "ready time"—polysulfide sealants must be allowed to cure for several hours, perhaps longer. Thermo-Seal 1081 Butyl sets in minutes; clean-up can be accomplished at the work-station; and the window unit is ready for shipment as soon as it comes off the line.

H. B. Fuller is able to offer the equipment necessary to ensure proper and profitable application of Thermo-Seal 1081 to the sealed insulated glass industry.

Thermo-Seal 1081 allows the sealed insulated glass manufacturer to take advantage of several cost-effective system benefits.
• The ability to produce sealed window units in less total elapsed time
• The ability to control product quality on-station
• The ability to lower production costs due to equipment simplification
• The ability to lower total unit costs due to increased production-line efficiency

APPENDIX E

Accelerated Weathering Test Specifications For SIGMA and CE Glass

COMPARISON OF CE GLASS REQUIREMENTS VERSUS SIGMA REQUIREMENTS

SIGMA Requirements

A. The new SIGMA requirements are summarized as follows:

1. No failure of 9 out of 10 units at partial vacuum of 3.0 inches of mercury for 2 1/2 hours at 75°F.

2. Initial Dew Point -60°F

3. Accelerated Weathering

   a. 2 weeks @ 140°F and 100% R.H.
   b. 240 cycles which include

      i. 2 hrs. @ -20°F
      ii. 1 hour spray @ 140°F
      iii. 1 hour dry U.V. @ 120°F

4. Summary

   The accelerated weathering summary is as follows:

   a. 2 weeks @ 140°F and 100% R.H.
   b. 240 cycles from -20 to 120°F
   c. 240 hours dry U.V. at 120°F
   d. 10 days spray @ 140°F

B. CE GLASS Requirements - 8 weeks of testing - 2 weeks in each apparatus

1. Initial Dew Point -60°F

2. 50,000 cycles at 150°F and 100% R.H. and ± 8 inches of water pressure/vacuum cycling

3. 2 weeks at 150°F and 100% saturation plus continuous U.V. exposure

4. 2 weeks at Dry U.V. at 150°F continuous

5. 70 cycles from 0°F to 105°F

C. Summary

1. Both SIGMA and CE GLASS have identical requirements for initial Dew Point.

2. SIGMA tests each unit once for partial vacuum, CE GLASS subjects each unit to 50,000 cycles of partial vacuum and pressure at 150°F and 100% R.H. which greatly exceeds the SIGMA requirement.

3. SIGMA gives each unit 240 cycles of -20°F to 140°F while CE GLASS subjects each unit to 70 cycles from 0°F to 150°F. The increase in temperature of 10°F is equivalent to a .7X factor (each 15°F rise doubles the rate of chemical activity) so that 70 cycles at 150°F is equivalent to 120 cycles @ 140°F. It is felt that the CE GLASS test is more rigorous because of the higher temperature.

4. SIGMA subjects units to a total of 240 hours at dry U.V. at 120°F - while CE GLASS subjects units to 336 hours of dry U.V. at 150°F.

5. SIGMA subjects units for 24 days at 140°F and 100% R.H. - while CE GLASS subjects units for 2 weeks at 150°F and 100% R.H. while the units are continually exposed to U.V. Light.

D. Conclusion

In all aspects of testing CE GLASS subjects the units to a more rigorous test cycle than the SIGMA spec. tests. It is felt that 8 weeks of testing in the CE GLASS test cycles is considerably more rigorous than the SIGMA specification requirements.

APPENDIX F

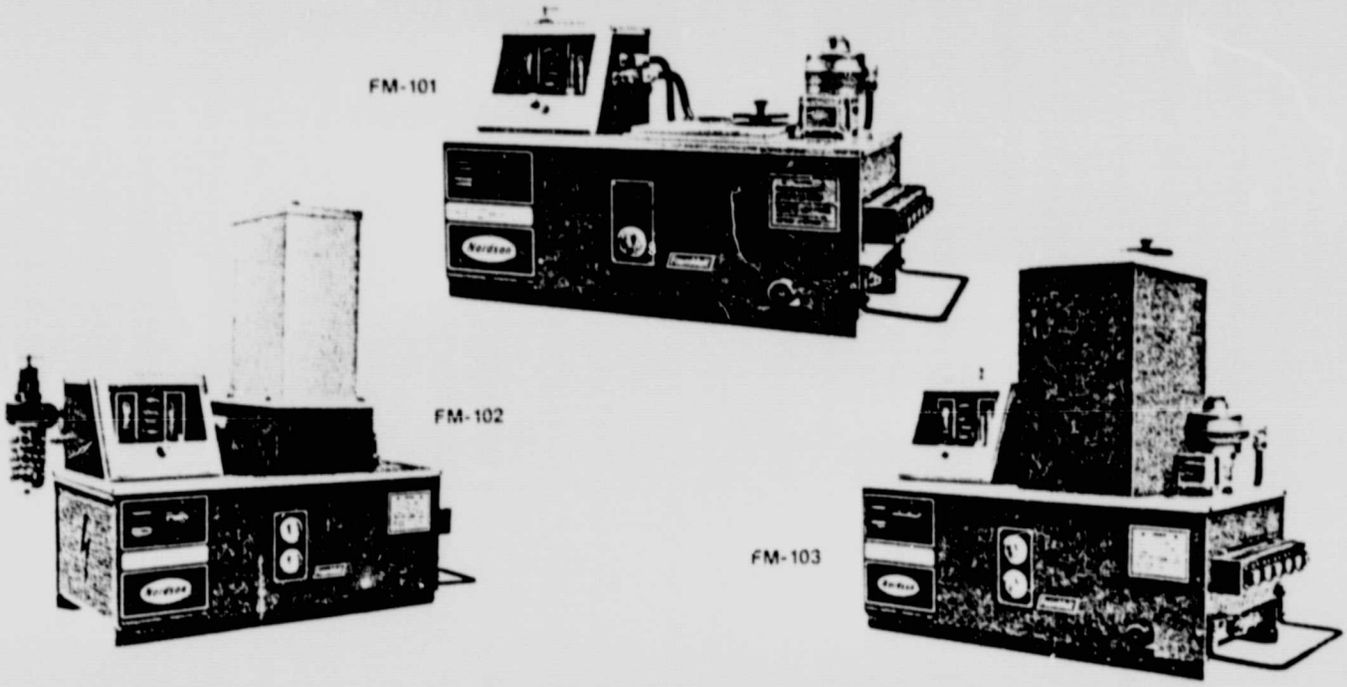
Hot Melt Application Equipment Manufacturers Data

Nordson

Applicators

FoamMelt™

MODELS FM-101, FM-102, FM-103



This equipment is designed to deliver a wide range of hot melt adhesives utilizing the Nordson FoamMelt process. In this process, gas and hot melt adhesive are combined under pressure to form a homogeneous solution. When deposited on a substrate by a conventional automatic gun, the gas expands to form a foamed adhesive with enhanced performance characteristics.

All three FoamMelt units utilize a unique Nordson designed gear pump that provides a constant output without fluctuation in system pressure. This gear pump is capable of handling both high and low viscosity hot melt adhesives, as well as tacky materials such as pressure-sensitives. The standard air motor drive, being a load sensitive device, changes speed but delivers adhesive automatically with changes in system demand.

The FoamMelt Process Improves Adhesive Performance

Performance of almost all hot melt adhesives is enhanced when applied with FoamMelt equipment. Although the degree of improvement varies with the specific adhesive and application, the following changes can be expected to take place to a greater or lesser degree in all cases:

Extended Open Time-Increased time during which an effective bond can be made facilitates joining of larger workpieces and depositing longer beads of hot melt without losing tack.

Faster Set Time-Once joined, adhesive applied by the FoamMelt method sets more quickly, reducing the amount of time parts must be held together prior to handling and further operations.

Superior Bonding-Improved dispersion and penetration of porous substrates upon compression results in bonds with up to double the strength of the same material applied conventionally.

Extended Adhesive or Sealant Mileage-Users report 40 to 70% more production with the same amount of hot melt.

Thinner Films-Film thickness can be reduced as much as 80% for neater, almost invisible bonds.

Other benefits realized with FoamMelt equipment include: less thermal distortion of heat sensitive substrates...better void or gap filling...reduced tendency to run or sag when applied to a vertical substrate...and better flow at a given temperature.

FoamMelt™

Models FM-101, FM-102, FM-103

Three different melting systems are available in order to accommodate a variety of adhesives and a wide range of melting and operating requirements:

Model FM-101:

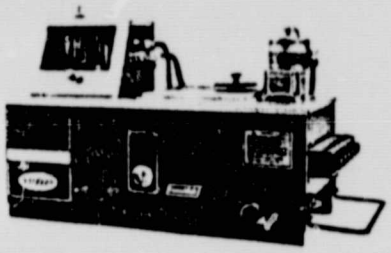
Is a conventional pot type melter with cast-in heating elements; it has a 20 lb. storage capacity and nominal melt rate of 25 lbs. per hour. Handles most hot melt adhesives, with the exception of the most degradation sensitive materials.

Model FM-102:

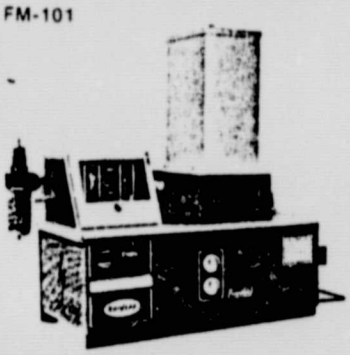
Has a patented grid melter with six cartridge heaters and a limited volume reservoir with cast in heaters. Independent temperature controls for both grid and reservoir minimize adhesive degradation. The patented hopper is cooled externally to assure progressive melting of adhesive. Hopper capacity 25 to 40 lbs. Melt rate 15 to 125 lbs. per hour depending on the adhesive melt characteristics. Recommended for the handling of high performance hot melts susceptible to thermal or oxidative degradation.

Model FM-103:

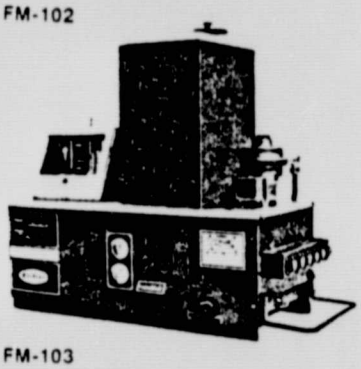
Also has grid melter but has a warmed hopper to facilitate handling of irregular sized or tacky materials. The extension above the grid also helps to achieve higher melt rates while holding material in residence well below the application temperature, thus reducing the tendency for degradation or the formation of char.



FM-101



FM-102



FM-103

SPECIFICATIONS

	FM 101		FM 102 and FM 103	
	U.S.A.	Metric	U.S.A.	Metric
Type System	Circulating			
Tank Capacity	20 lbs	9.1 kg	*n.a.	*n.a.
Reservoir Capacity	*n.a.	*n.a.	1.5 lbs	.68 kg
Hopper Capacity	*n.a.	*n.a.	25-40 lbs	11.3-18.1 kg
Melt Rate Per Hour	27 lbs	12.25 kg	15-125 lbs	6.7-18.1 kg
Tank Temperature Range (std)	300°-400°F	149°-204°C	*n.a.	*n.a.
Grid and Reservoir Temperature Range	*n.a.	*n.a.	150°-450°F	66°-232°C
Tank Heating Method	Cast-in Element (two heaters)		*n.a.	*n.a.
Unit Heating Method	*n.a.	*n.a.	Grid Melter (six cartridge heaters)	
Reservoir Heating Method	*n.a.	*n.a.	Cast-in Element (2)	
Pumping Rate Per Hour	125 lbs	56.7 kg	125 lbs (max)	56.7 kg (max)
Operating Air Pressure	5-80 psi	35-5.6 kg/cm²	5-80 psi	35-5.6 kg/cm²
Type of Gun	Automatic (H-20A and AD-24)			
Weight	150 lbs	68 kg	170 lbs	77 kg
Height	19.37 in.	492 mm	[illegible]	[illegible]
Width	33.8 in.	858 mm	33.8 in.	858 mm
Depth	13.75 in.	350 mm	13.75 in.	350 mm
Electrical	230 VAC 3/1 phase 50/60 Hertz, 6900 Watts Maximum		230 VAC 3/1 phase 50/60 Hertz, 11500 Watts Maximum	

*Not Applicable

Nordson — *For Better Ways to Apply Coatings and Adhesives*

Nordson Corporation, 555 Jackson Street, P.O. Box 151, Amherst, Ohio 44001 · 216-988-9411

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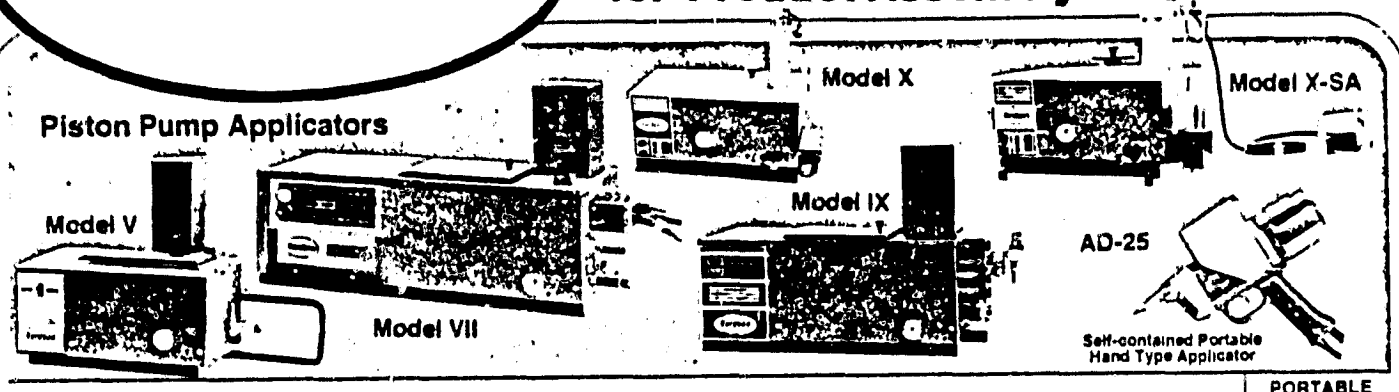
Nordson®

HOT MELT APPLICATION UNITS for Product Assembly

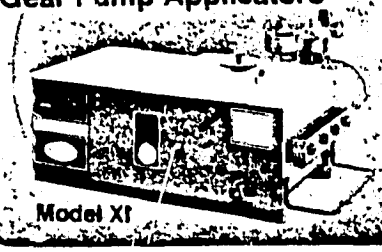
Piston Pump Applicators



	TANK TYPE APPLICATORS							PORTABLE APPLICATORS
Model	IV and V	VII	IX	VIII and X	X-SA	XI	XII and XIIA	AD-25
Type System	Non-circulating	Circulating	Non-circulating	Non-circulating	Non-circulating	Internally Circulating		Self-Contained
Tank Capacity	17 lbs 7.2 kg	20 lbs. 9.1 kg	20 lbs. 9.1 kg	8 lbs. 3.6 kg	8 lbs. 3.6 kg	20 lbs 9.1 kg	25-40 lbs 11.3-18.1 kg	Hopper 5 oz —141.8 gr
Melt rate per hour	20 lbs.* 9.1 kg	27 lbs.* 12.3 kg	27 lbs.* 12.3 kg	8 lbs.* 3.6 kg	8 lbs.* 3.6 kg	24 lbs.* 10.9 kg	15-125 lbs.* 6.7-56.2 kg	4 lbs.* 1.8 kg
Maximum Operating Temperature	400°F 204°C	450°F 232°C	400°F 204°C	400°F 204°C	400°F 204°C	400°F 204°C	450°F 232°C	550°F 288°C
Tank heating method	Cast-in Element	Cast-in Element	Cast-in Element	Cast-in Element	Cast-in Element	Cast-in Element	Cast-in Element & Cartridge Heater	Cartridge Heater
Type of Pump	Single Piston, Dual-Acting	Single Piston, Dual-Acting	Single Piston, Dual-Acting	Single Piston, Single-Acting	Single Piston, Single-Acting	Gear	Gear	N/A
Pumping rate—maximum per minute	0.9 lbs. 408 gr	2 lbs. 907 gr	2 lbs. 907 gr	62 lbs. 289 gr	0.6 cu. in. (10 cc) per cycle (.34 oz. or 10 gr.)	2 lbs 907 gr	2 lbs 907 gr	4 lbs. per hr 1.81 kg. per hr
Operating air pressure	10-60 psi 7-4.2 kg/cm²	20-80 psi 1.4-5.6 kg/cm²	20-80 psi 1.4-5.6 kg/cm²	10-60 psi 7-4.2 kg/cm²	20-80 psi 1.4-5.6 kg/cm²	5-80 psi .35-5.6 kg/cm²	5-80 psi .35-5.6 kg/cm²	N/A
Number of Hoses	4 maximum (Model IV) 2 maximum (Model V)	Depends on hose length (maximum—40 feet)	6 maximum	1-Model X 2-Model VIII	None	6 maximum	6 maximum	N/A
Hose length in feet	Auto 4, 6, 8, 10, and 16 Hand 8, 16, and 24	1, 2, 3, 4, 5, 6, 8, and 10	4, 6, 8, 10, and 16	2, 4, 6, 8, and 10	N/A	4, 6, 8, 10, and 16	4, 6, 8, 10, and 16	N/A
Type of Gun	Automatic or Hand	Automatic	Automatic or Hand	Automatic or Hand**	Semi-Automatic	Automatic or Hand	Automatic or Hand	Hand
Number of Guns	4 maximum (Model IV) 2 maximum (Model V)	8	6 maximum	1-Model X 2-Model VIII	1	6 maximum	6 maximum	N/A
Weight	55 lbs. 25 kg	160 lbs. 72.6 kg	160 lbs. 72.6 kg	34 lbs. 15.4 kg	34 lbs. 15.4 kg	135 lbs 61.2 kg	155 lbs 70.3 kg	2.5 lbs 1.134 kg
Height	19.5 in. 495 mm	20.75 in. 527 mm	20.75 in. 527 mm	14.8 in. 376 mm	14.5 in. 368.3 mm	17.8 in. 452 mm	XII 32.25 in. 819 mm XIIA 28.25 in. 718 mm	11 in. 279.4 mm
Width	28.5 in. 724 mm	38.5 in. 978 mm	38.5 in. 978 mm	17.5 in. 445 mm	17.5 in. 445 mm	28.8 in. 731.5 mm	28.8 in. 731.5 mm	2-11/16 in. 68 mm
Depth	12.5 in. 318 mm	13.8 in. 351 mm	13.8 in. 351 mm	11 in. 280 mm	10.5 in. 266.7 mm	13.2 in. 335 mm	13.2 in. 335 mm	11" length 280 mm
Electrical	230 VAC, 50/60 hertz	230 VAC and 460 VAC, 50-60 hertz	230 VAC, 50-60 hertz 3 phase only, 24 Amps	230 VAC, 50-60 hertz	230 VAC, 50-60 hertz	230 VAC, 50-60 hertz	230 VAC, 50-60 hertz	115 VAC

*Melt rates vary greatly depending on the melt characteristics of each particular adhesive. Figures shown are approximate for medium viscosity materials (5,000-15,000 centipoise). **Model VIII Automatic only. N/A Not Applicable

Gear Pump Applicators

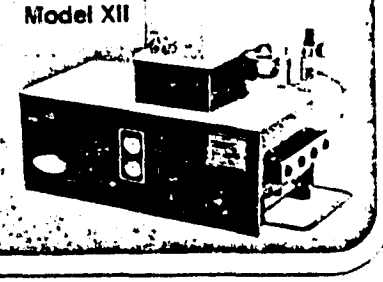


Model XI

Write for technical information on Nordson's complete line of hot-melt application equipment. NORDSON CORPORATION, Jackson St., Amherst, OH 44001. Phone 216-988-9411. Also available in Canada, Mexico, Europe, Asia, Australia, South Africa, and Japan.

Nordson

Model XII



Nordson® Application Systems Accessories

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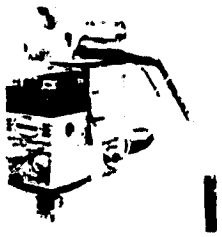
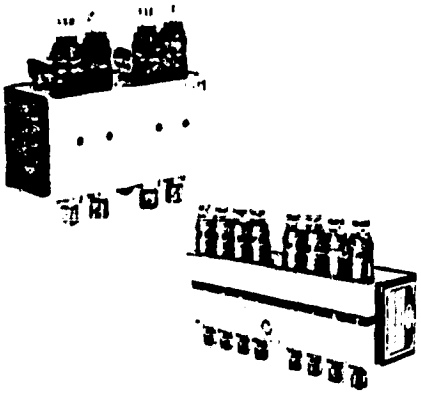
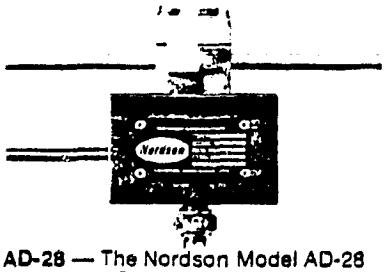
Automatic Extrusion Heads



H-20 — Compact modular design makes the Nordson H-20 Automatic Hot Melt Gun easy to mount on most assembly lines. It is air operated and controlled by a solenoid valve. Separate service block contains all hose connections, thermostat, heater and mounting face.

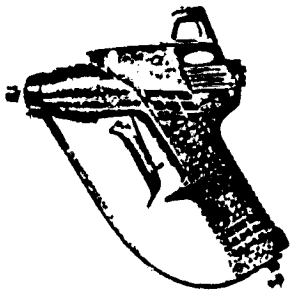


AD-24 — Modular design of this hot melt gun features drop-in cartridge inserts which fit into an aluminum block drilled and ported to supply air and adhesive. Adaptable to circulating and non-circulating systems, the AD-24 can be used with virtually all Nordson hot melt units and is available with two, four, or eight drop-in cartridges.

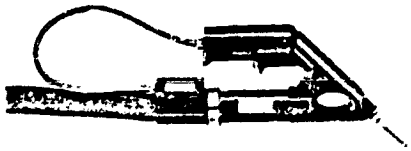


AD-28 — The Nordson Model AD-28 Automatic Gun contains two cartridge heaters which are designed to maintain and control the adhesive application temperature within the gun. One special version of the Model AD-28 is capable of increasing heat at the gun by 100°F (37.8°C) depending on the adhesive used and the flow rate requirements. The AD-28 features a bellows assembly in the extrusion head rather than a packing cartridge assembly.

Hose Fed Hand Guns



H-21 — Light, compact, and reliable, the Nordson H-21 Hand Gun provides excellent maneuverability and easy trigger pull to minimize operator fatigue. Good visibility over the gun top makes it easy to precisely place adhesive in product assembly operations. Positive trigger action assures clean cutoff with no drip or drool, preventing adhesive waste.



AD-27 — Among the many features of the Nordson AD-27 Hot Melt Hand Gun is an "ever-cool" handle. Melted adhesive is *not* fed through the gun's handle, thus, it remains "ever-cool." This unique handle can be affixed to the gun in two different positions. Normal position is as illustrated, however, the handle can be detached and re-affixed at a 180° angle for easy operating when the hose is suspended from an overhead position. Additional features include: a long extended nozzle for pinpoint placement of hot melt adhesive; it is lightweight (2½ pounds — 1.13 kg); and the AD-27 has a bellows assembly at the extrusion tip rather than a packing cartridge assembly.

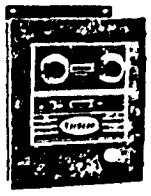
NORDSON'S "BETTER WAYS"

Each year, hot melt adhesives assume a larger and more important role in product assembly operations throughout the world. As the leading supplier of hot melt application equipment, Nordson Corporation is involved with the latest technology to efficiently and economically apply these adhesives.

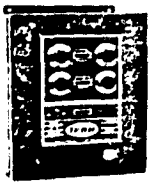
Nordson does not manufacture hot melt adhesives. Nordson is dedicated to the engineering and manufacture of quality equipment to provide — *"For Better Ways to Apply Coatings and Adhesives."*

Time Controls

CST-1 Hot Stitch Control — The CST-1 Hot Stitch Control is a solid state timing device that will produce an intermittent or stitch pattern in use with Nordson hot melt application systems. It can be used on various specialized applications requiring a stitch pattern of deposition. The CST-1 can also be used with Nordson's Pnu-Bond cold glue spray systems as a skip-gap control.



CT-6 Time Interval Control — The Nordson CT-6 Time Interval Control is a solid state "delay-duration" device designed for use in applications requiring precise time delay and an off-on cycle in response to an external signal. It provides a selection of sequential timing in the range from 2 to 1,000 milliseconds.



CT-7 Time Interval Control — The CT-7 Time Interval Control by Nordson is a solid state device that is designed for use in applications for automatic, sequential triggering of hot melt guns. The CT-7 has four timers and two output channels which may operate as two separate channels in a Parallel mode, or they may operate together in a Series mode which can be programmed to provide a wide variety of application systems.

CT-8 Time Interval Control — The CT-8 Time Interval Control is a solid state device used to actuate the automatic, sequential triggering of hot melt guns and pumps. The CT-8 Timer may be used in conjunction with a single-acting pump applicator and automatic gun or guns in palletizing or other such applications.

Nordson®

For Better Ways To Apply Coatings and Adhesives

Nordson Corporation

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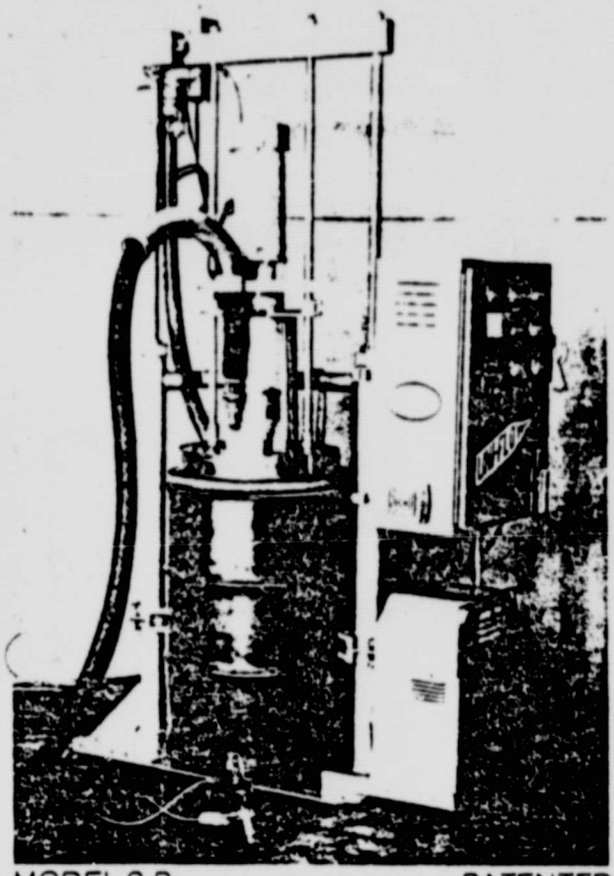
UNI-FLOW



MODEL S.P. PATENTED

Break through in application technology for high volume — high viscosities.

The Uni-Flow system was designed to handle high viscosity thermoplastic sealants and adhesives while solving the problems associated with previously available systems. The technological advances incorporated in the Uni-Flow system allow it to melt down and deliver hot melts under nearly ideal conditions for top performance.

If You Couldn't Pump Before, You Can Pump Now!

Pumping - Metering - Dispensing from 55 gallon drum. Molten viscosities from 1,000 cps to 9,000,000 cps.

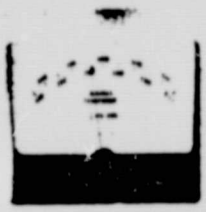
Advantages of the UNI-FLOW System . . .

- positive displacement—no skips or gaps in the bead
- faster throughput than other systems —up to 20 lbs./min.
- takes standard 55 gallon drums—save expense by allowing the user to buy in less expensive bulk form
- positive heat control at all zones—virtually eliminates burn-up of material and burn-out of the equipment in hot spots and applies the hot melt at optimum temperature —100°F to 500°F continuous
- can be adapted to automatic extrusion systems

Developed & Manufactured By:

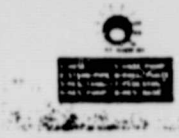
INDUSTRIAL MACHINE MANUFACTURING, CO.
1005 Holly Spring Road
Richmond, Virginia 23224 804-232-5661

Features:



METER READOUT

Provides a continuous readout of each of the eight temperature zones by use of a platinum resistance sensor common to the controller circuit (i.e. meter reads the exact temperature sensed by the controller).



FOLLOWER PLATE

Newly designed follower plate contains 21 replaceable cartridge heaters producing a total heating capacity of 21.3 KW over 5400 square inches of finned surface area. A low watt density of six watts per square inch prevents localized material overheating, charring, cross-linking, etc.

RUN/STANDBY SWITCH

This switch turns the unit back to a lower pre-set "stand-by" temperature during non-use periods, making it possible to bring the unit up to operating temperature within five minutes after returning switch to the "run" position.

HAND GUN

Capable of producing variable bead diameters with low force, finger tip control. The trigger has a special 12 to 1 force multiplier linkage permitting minute valve openings for the first half inch of trigger travel. This enables the operator to fill corners or start a bead without a large, surging glob. The hand gun also has an adjustable stop for producing a fixed bead diameter at full trigger travel, alleviating operator finger fatigue.

HEATED FLEXIBLE HOSE

The hose incorporates an internal electric resistance heater which is in direct contact with the material (not a wrap around type heater as in conventional hoses). The heater is actually inside the teflon liner of the metal braided hose. This produces much more efficient heat transfer than in conventional hoses, thus permitting higher material temperatures without overheating or degrading the teflon liner. The material temperature is precisely controlled by a platinum temperature sensing probe also located inside the hose and in direct contact with both the sealant and the heating element. The meter reading of the hose temperature is actually a direct readout of the material temperature at the nozzle.

DISPENSING PUMP

The positive displacement gear pump dispenses up to 15 lbs. per minute with non-surging flow at rated pressure for a smooth, gap-free bead.

TEMPERATURE CONTROLLERS

These specially designed plug-in, 2" x 2" solid state temperature controllers are capable of holding each of the eight heat zones to within 3° to 4°F. of set-point. A red "[illegible]" on the card provides easy visual inspection for proper functioning.

Specifications:

OVERALL SIZE:	width 32 inches; length (panel face to back post) 55 inches; height (beam fully raised) 116 inches.
WEIGHT:	900 lbs (empty)
AIR REQUIREMENTS:	80 psi minimum, 100 psi recommended, 150 psi maximum.
AIR CONSUMPTION:	less than 1 scfm continuous.
ELECTRIC SERVICE REQUIREMENTS:	208/240/480 vac, 3 phase, 100 amp entrance.
POWER CONSUMPTION:	63 amps/at 240 vac (start-up only, 20 min. average start-up time); 31 amps (continuous dispensing)
TEMPERATURE RANGE:	100° to 500° F (continuous).
MATERIAL FLOW RATE:	approximately 15 lbs/minute at 50,000 cps; 1.2 lbs/minute at 9 million cps.
START-UP TIME:	20 minutes average (from 65° F).

Automatic Dispensing GUN Available.

Developed & Manufactured By:
INDUSTRIAL MACHINE MANUFACTURING, CO.
1005 Holly Spring Road
Richmond, Virginia 23224 804-232-5661

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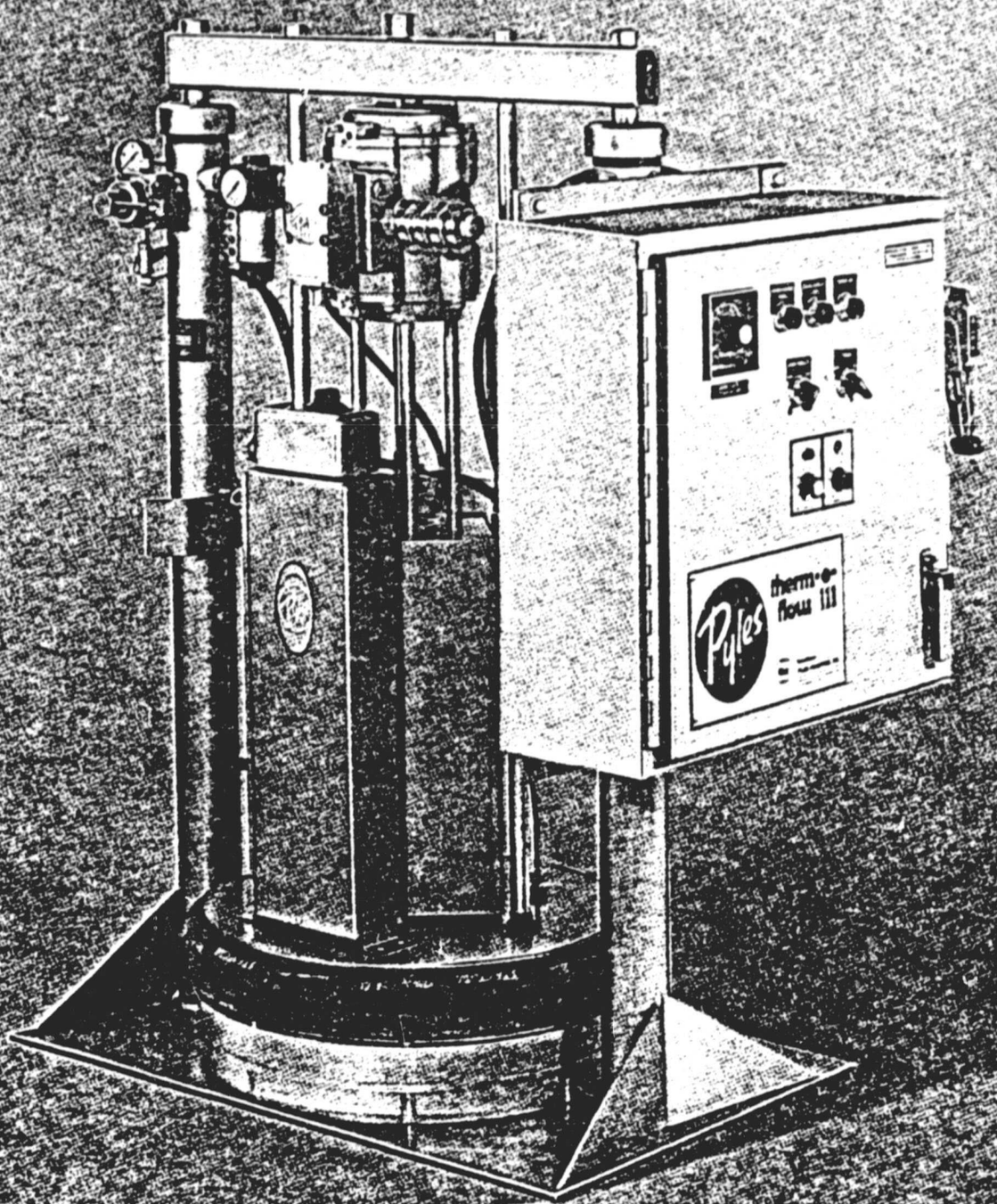
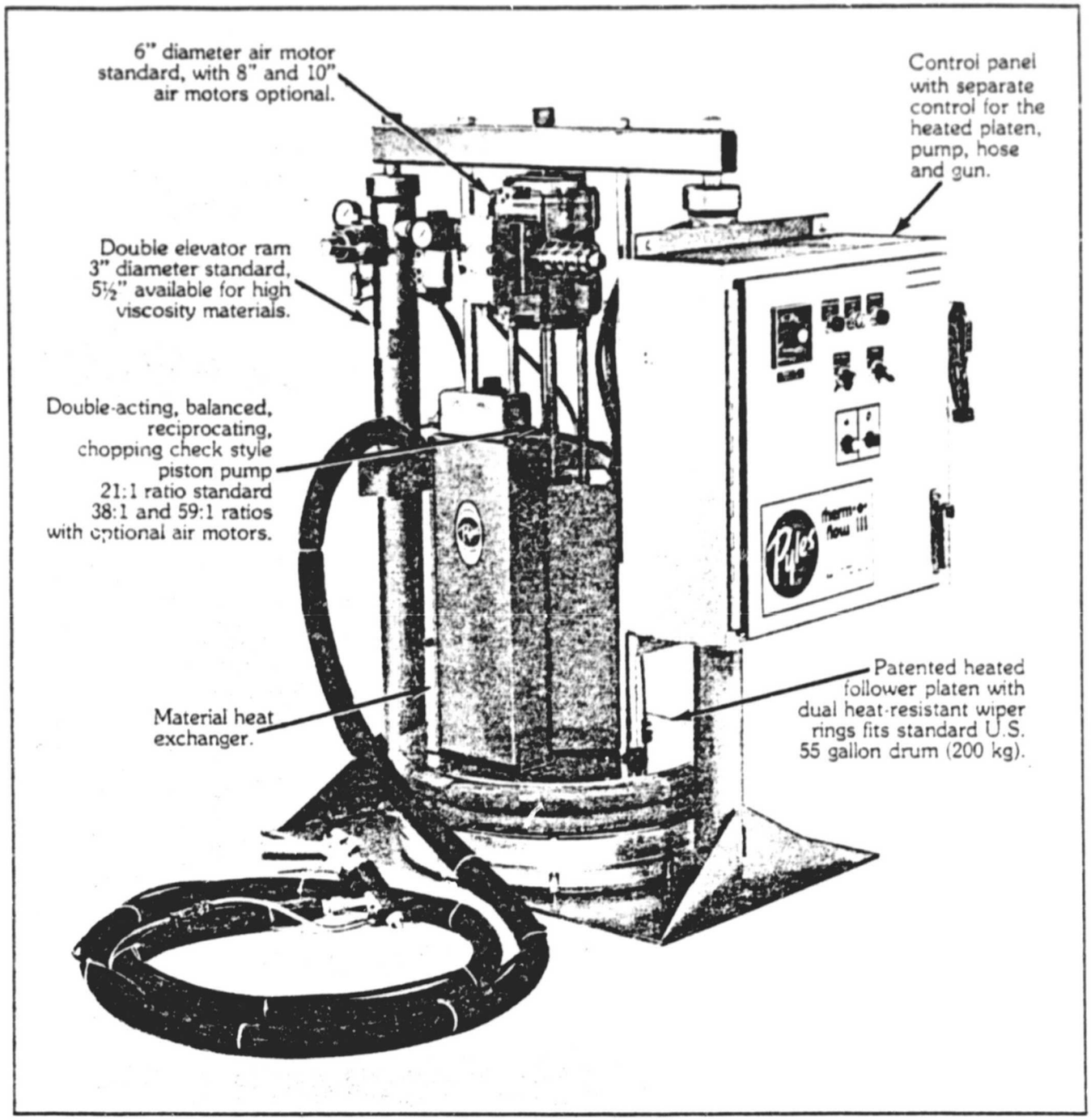
Pyles® therm-o-flow® III

HOT MELT APPLICATION SYSTEMS





- ☐ Pumping
- ☐ Metering
- ☐ Mixing
- ☐ Measuring
- ☐ Dispensing

Pyles Industries, Inc. through an extensive research and development program, has perfected a system for handling materials with a wide viscosity range at elevated temperatures. Materials with molten viscosities from 500 cps to 4,000,000 cps may be applied directly to the part from the original bulk shipping containers. No longer is there a need to handle reprocessed materials in block, chip, granular or pillow form in hopper type dispensers. Pyles Industries **thermo-o-flow III** will allow you to develop tomorrow's production methods and materials today.

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Pyles®

therm-o-flow® 111 PRODUCT INFORMATION

OPERATING PRINCIPLES

Material in its bulk 55 gallon shipping container is placed on the base plate of the unit. The elevator is lowered to bring the heated follower platen into contact with the surface of the material. The upper layer of the material is melted and with the assistance of the follower ram pressure, is forced into the pump. The heated pump then pressure feeds the material through a heat exchanger, heated hose and gun to the substrate. As material is pumped from the container, the elevator lowers automatically to keep continuous contact between the material and the heated follower platen.

SYSTEM FEATURES

- Handles any meltable material direct from the original 55 gallon shipping container.
- Heats only the material about to be used to application temperature in a completely closed environment. This demand heating principle eliminates induced polymerization, thermal degradation, and oxidation caused by uneven heat, bulk heating for extended periods, and heating in open atmosphere.
- Temperature control ranges from 0 to 450° F (235 °C). Accuracy is ± 1% of the scale reading.
- The follower platen covers the material and protects it from the contamination and wipes the container clean of material.
- The system may be used to bulk feed existing hopper type units.

TECHNICAL DATA

- Heat is transferred by a cast-in element secured to the follower platen. The platen temperature can be maintained at ± 2% of the scale reading. Adjustable in 10° increments from ambient to 400° F (205° C).
- Heating capabilities depend on the specific heat of the materials selected. The heat available at the follower is rated at 39,000 BTU. There are 630 square inches of effective heating surface below the follower platen.
- Basic pumping unit is a Pyles' standard 716-11-200 double elevator, double-acting 21:1 ratio chopping check pump. Ratios of 38:1 and 59:1 are available.
- Start up time for an enterely cold system is 30 to 45 minutes. Start up time when changing to a new drum is 7 to 15 minutes.
- For materials with application temperatures between 400° and 450° F (205° - 235° C), the standard five zone heating system may be used to increase the material temperature from the melting point to the final application temperature.
- Output rates must be determined for each individual material and application. Completing and returning the "Request for Quotation" form sheet will enable us to do this for you.
- Special units are available on request for applications requiring output temperatures in excess of 400° F (205° C).

SYSTEM COMPONENTS

23208 23240 23380 23480	Basic **therm-o-flow 111** complete with 3" double elevator ram, heated follower platen and pump, air and electrical heating controls. Model number indicates voltage required.

A 5½" elevator ram is available for high viscosity materials. To specify, add — 50 to the base model number (e.g. 23240—50).

ACCESSORIES

23000-45	Heat Exchanger
23000-60	Low Material Level Indicator Kit
23000-61	Automatic Dual Pump Crossover Control
23000-65	7 Day Pre-Production Start Up Timer
23000-75	Tamper Proof Control Cover Kit

SPECIFICATIONS:

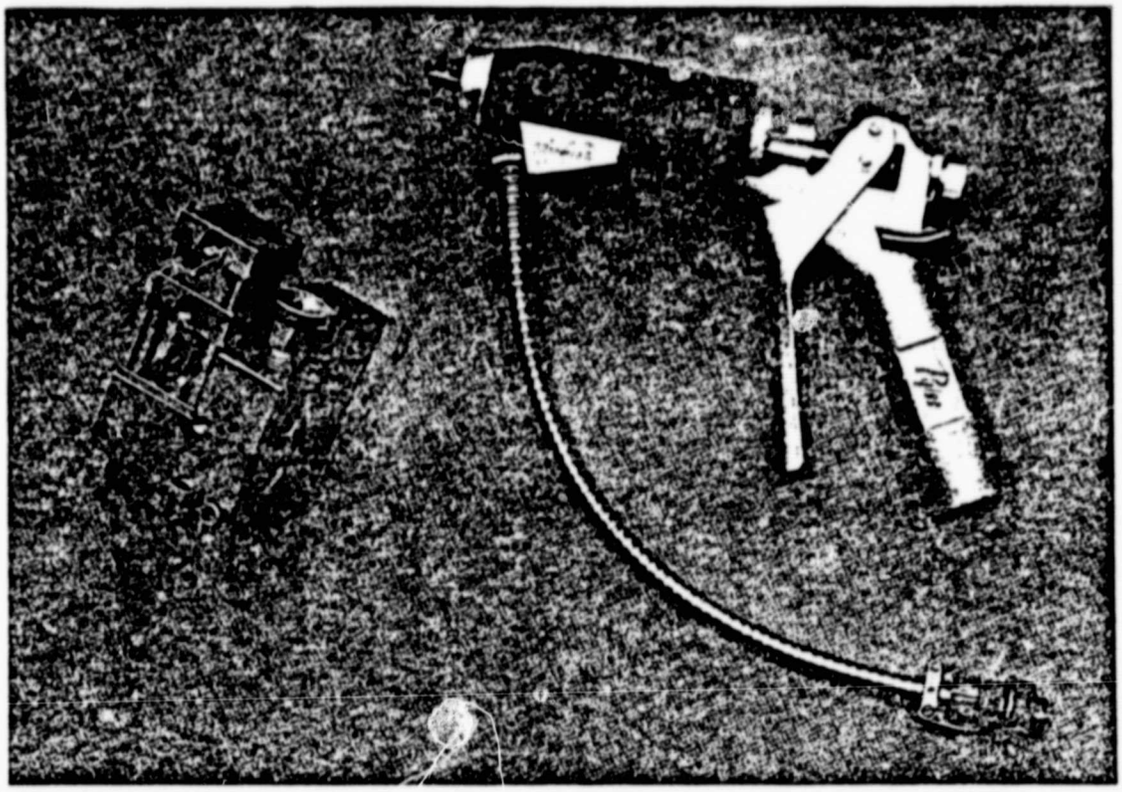
Air Supply
20 SCFM at 90 PSIG

Electrical
30; 208, 240, 380, or 480 VAC; 50 or 60 Hz; 14kW

Dimensions
Width 46" (116.8 cm)
Depth 25" (63.5 cm)
Height Full Up 91" (231 cm)
Full Down 54" (137 cm)

Weight
675 lb. (306 kg)

GUNS AND HOSES



22000-200-R Automatic Gun **22000-100 Manual Gun**

22000-100	Manual dispensing gun with cartridge heater. Nozzle orifice .031" standard. Other orifices and configurations available upon request.
22000-200-R	Automatic dispensing gun with heater, controller, and thermometer. Double air operated, requires a 4-way valve to actuate. Nozzle orifice .016" standard, other orifices available.
22000-85	Temperature controller. One required for each hose and manual gun.

Standard Heated Hose Assemblies (2,000 PSI W.P. — 6,000 PSI B.P.)

22008-B	.312 ID x 8' long,	¼" NPT-M	(7.9 mm x 243.8 cm)
22015-B	.312 ID x 15' long,	¼" NPT-M	(7.9 mm x 457.2 cm)
22020-B	.312 ID x 20' long,	¼" NPT-M	(7.9 mm x 609.6 cm)
23010-B	.500 ID x 10' long,	½" NPT-M	(12 mm x 304.8 cm)
23015-B	.500 ID x 15' long,	½" NPT-M	(12 mm x 457.2 cm)
23020-B	.500 ID x 20' long,	½" NPT-M	(12 mm x 609.6 cm)

High Pressure Heated Hose Assemblies (4,000 PSI W.P. - 12,000 PSI B.P.). **NOTE: THESE HOSES ARE REQUIRED WITH THE OPTIONAL 38:1 AND 59:1 PRESSURE RATIOS.**

23010-C	.650 ID x 10' long,	¾" NPT-M	(16.5 mm x 304.8 cm)
23015-C	.650 ID x 15' long,	¾" NPT-M	(16.5 mm x 457.2 cm)
23020-C	.650 ID x 20' long,	¾" NPT-M	(16.5 mm x 609.6 cm)

Kent-Moore

PYLES INDUSTRIES, INC.

SUBSIDIARY OF KENT-MOORE CORPORATION
28990 WIXOM ROAD ■ WIXOM, MICHIGAN 48096
TELEPHONE: (313) 349-5500

FORM 1 302/002
4-77 3M
Replaces 1 302/001