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PROCESS DEVELOPMENT FOR AUTOMATED SOLAR CELL AND
MODULE PRODUCTION. TASK 4: AUTOMATED ARRAY ASSEMBLY

Quarterly Report No. 4

MASTER

By
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PROCESS DEVELOPMENT FOR AUTOMATED SOLAR CELL AND MODULE PRODUCTION

TASK 4: AUTOMATED ARRAY ASSEMBLY

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ABSTRACT

Construction of the components of an automated solar cell layup and interconnect system is now complete. This system incorporates a Unimate 2000 B industrial robot with an end effector consisting of a vacuum pick up and induction heating coil. The robot interfaces with a "smart" cell preparation station which correctly orients the cell, applies solder paste and forms and positions the correct lengths of interconnect lead. The system is controlled and monitored by a TRS-80 micro computer.

The entire system presently undergoing integration prior to formal testing.

A survey of elastomer manufacturers has shown transfer molded EPDM to be a strong candidate for the edge sealing material.

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1.0 INTRODUCTION

In the previous Quarterly Report we analyzed various methods of cell handling, lead bonding and the tradeoffs involved with determining how much of the work the robot should do versus system cycle time. These analyses led to the selection of an optimum candidate method as detailed below.

The best bonding method for this purpose is induction heating as it can bond all four leads simultaneously and does not require physical contact with the cell. Cell handling is best achieved by plenum/vacuum techniques as these spread handling loads over the entire cell and reduce the possibility of breakage. For the robot to work most efficiently (i.e. fastest) the number of operations it performs must be reduced to those which can be done "in transit". 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 synchronize all of this activity.

Significant progress has been made towards meeting these goals. Construction of the mechanical components (except the end effector) is now complete and all vendor-supplied components have been delivered and tested. We are now in the in the integrate-and-test phase of the project. A detailed discussion of the status and progress of the various components comprise the balance of this report.

2.0 TECHNICAL DISCUSSIONS

2.1 Preparation Station

It was originally intended to produce an interim, simpler, version of the preparation station that would produce only stub leads to be bonded to cells with end-tab type metalization patterns such as those used by Applied Solar, Solar Power, etc. This would require only a short ($\approx 1''$) lead and only one dab of solder paste in a single spot. An artist's conception of this machine appeared in the previous Quarterly Report. It was, however, decided to skip this interim step and go directly to a final configuration (Fig. 1). This final configuration is simply an expansion of the interim version and involves a pair of leads which span the cell (per the metalization pattern of the Arco Solar cell used). However, this means duplicating all of the lead handling mechanisms (feed rollers, cutting blocks, crimping dies and hold-downs) as well as extending the lead length from 1" to the nearly 8" called for by the dual-redundancy concept employed by Arco Solar. It also means finding a method of dispensing solder paste across the entire diameter of the cell and the last 4" of the interconnect lead, rather than just a single dot on each. A detailed report on each of these components follows.

2.1.2 Vacuum Orientation Chuck

The vacuum/pressure chuck was the first component completed but it has undergone some refinement. As originally designed it operated in two modes: pressure and vacuum.

The first mode (slight positive pressure) makes the chuck an air table allowing the cell to glide out 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 (Fig. 2). The second mode, vacuum, retracts the pins and clamps the cell to the chuck with a force of 50-70 lbs, more than sufficient for subsequent operations. 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

FIGURE 1
OVERALL VIEW

FIGURE 2
VACUUM CHUCK WITH EXTENDED PINS

breaks the vacuum to release the cell, but does not cause cell motion or extend the pins.

2.1.2 Ribbon Feed

The ribbon feed assembly (Fig. 3) consists of several mechanisms, each of which will be discussed separately.

2.1.2.1 Drive Rollers

The original prep station design had two sets of drive rollers for the 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 have been narrowed to allow the close (1.625") spacing two feeds side-by-side which is necessary for the simultaneous application of the two leads. Both feeds are driven by a single pin tooth belt located between them.

2.1.2.2 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 was sufficient for creating stub leads but in the current scheme the crimp must be placed in the center of an 8" lead. It was determined that these 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 were unavoidable. Therefore, in our current 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 (approx. 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.

FIGURE 3
PLAN VIEW OF STATION

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.

2.1.2.3 Hold Down

Interconnect lead hold downs (Fig. 4) have been provided in the prototype to prevent lead motions during robot hovering and pick up maneuvers. This is performed by two small, padded arms operated by a single cylinder on a common linkage which clamp the leads to preparation station'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.

2.1.3 Solder Paste Dispensing

There are two sets of solder paste dispensers on the preparation station. One pair is mounted on the cutter assembly and dispenses paste on the second half of the lead as it emerges from the feed assembly. The other pair is mounted on a cantilevered screw drive which first extends out over the cell then lays down a bead of solder while retracting (Fig. 5). Each dispensing needle has its own paste reservoir which are manifolded together through solenoid valves to a Tridak 100V dispensing system regulator.

The Tridak system has been tested and found to give very uniform results over a wide range of dispensing rates.

We are currently investigating cells with solder screen printed on the contacts as well as solder coated lead material. These would eliminate the need for solder paste dispensing and all of its attendant mechanisms. Our preliminary results, however, are not encouraging. Using solder coated leads only (no screen printed cells were available) it was found that very poor bonds, or no bond at all, were formed unless flux was also applied. These results are consistent with the conclusions of other contractors in the LSA project. A flux dispensing mechanism would be nearly identical 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.

FIGURE 4
INTERCONNECT LEAD HOLD DOWN

FIGURE 5
SOLDER PASTE DISPENSING HEAD

Over the next period, we will experiment with solder coated lead in conjunction with screen printed cell. This combination may prove workable as the solder is already bonded to both members and need only be flowed together. If it is successful, a cost/time tradeoff analysis must be performed between the inexpensive solder paste with flux cleaning vs. the relatively expensive screen printed cells and coated leads with no cleaning.

2.1.4 Optical Pattern Recognition

The optical sensor consists of a lens which focuses an image of the cell onto a mask, behind which is a photo cell. The phenomenon involved is simply the greater reflectivity of the silver in the metalization pattern over the adjacent silicon surface. When the cell is in the proper orientation, the image of the metalization pattern is admitted by the mask (actually a series of blocking slits) raising the output of the photocell.

A prototype sensor has been built and tested. It was found to give a unique output at proper cell orientation and at a signal level detectable by the micro computer. The actual sensor has been designed and built. (Fig. 6). It is currently undergoing tests prior to mounting on the preparation station and is expected to have a resolution within 1° of cell rotation.

A further 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 degrade the signal sufficiently to cause problems.

2.1.5 Siltec Cassette Unloader

The Siltec Unloader has been delivered and tested and appears to be functioning normally. Figure 7 shows the unit after mounting in the preparation station framework. Directly in front of the unloader is the mounting flange to be used for the preparation station itself. There is one further modification to be done to the Siltec. Presently, the cells emerge from the cassette and stop at the edge of the unloader. The machine is being modified to extend the drive belts out approx. 2" to the edge of the vacuum chuck.

FIGURE 6
OPTICAL ORIENTATION SENSOR

FIGURE 7
SILTEC UNLOADER IN STATION FRAMEWORK

2.2 End Effector

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

2.2.1 Resistance Heating

Several tests were performed with the end effector shown in Figure 8. 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 both sides 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 short (<1") bonds and required the high precision positioning of electrodes. As mentioned in the previous Quarterly Report, we are investigating induction heating as our ultimate bonding method.

2.2.2 Induction heating

We are using a Taylor-Windfield 2.5kW generator and initial tests are very promising. A simple hand wound coil, when connected directly to the generator, will bond leads in less than one second. The leads can be of any number and length since the entire cell is heated. When the coil is placed at the end of a 10 ft. extension cable (Fig. 9) bond time increases to approximately 5 seconds.

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. Figure 10 is a sketch of the final

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

FIGURE 8
RESISTANCE HEATING END EFFECTOR

FIGURE 9
INDUCTION HEATER WITH COIL

FIGURE 10
FINAL END EFFECTOR DESIGN

end effector design, now under construction. It consists of a 4" diameter pancake coil fabricated from $\frac{1}{4}$ " square section tubing (a more efficient RF radiator than round) encapsulated in a resilient, heat resistant elastomer such as silicone RTV. The main body is formed of a rigid, non-conductive material such as Plexiglass (the material also used in the resistance heat end effector). The top is flanged and drilled to match the robot's mounting flange making the entire inside cavity a vacuum chamber. Small holes drilled in a matrix between the windings of the induction coil form the vacuum pick-up. The encapsulant is thin towards the bottom to get the coils 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.

The coil shown on the test stand in Fig. 10 is an early pancake coil encapsulated in a polysulfied potting compound (normally used to seal electrical connectors). A larger version of this coil was used in a demonstration to produce the string shown in Figure 11.

2.3 Micro Processor/Control Electronics

A cost/benefits analysis showed the Radio Shack TRS-80 micro computer system (Fig. 12) to be the most cost effective solution to our control/processing requirements. The TRS-80 uses a Z-80 micro processor and incorporates a BASIC Language interpreter. The model used has the Level II (Assembly Language access) BASIC and 4K of RAM. If it is shown that more memory is required, it can be expanded to 16K or 32K at modest cost.

A board which interfaces the output signals from the computer with the electro/pneumo/mechanical functions of the preparation station has been designed and is under construction. In addition to the interface logic the board has four functions: 1) via relay drivers, it must operate solenoid valves, relays and other high-current devices from the very low level computer output signals. 2) Encode and transmit signals to drive the stepper motors. 3) Translate the micro computer signals to the rather primitive (switch closure) interface logic of the robot and back again. 4) Provide signal amplification and A to D conversion for the optical orientation sensor.

FIGURE 11
CELL STRING ASSEMBLED WITH INDUCTION HEATER

FIGURE 12
TRS-80 MICRO COMPUTER

After a brief "shake down" period, the TRS-80 is now functioning properly. It has already been used in-house in a feasibility demonstration of its high speed synchronization capability. In this test, using a simplified version of our interface board, the TRS-80 was used to individually fire up to 64 pyrotechnic devices with millisecond spacing, as well as start several pieces of recording equipment. The times between each individual firing and the lead times to start each of the recording devices were all continuously variable by the operator via keyboard inputs. The program took only one day to write, debug and go through three updates. The engineer in charge of the TRS-80 in that test (who is also responsible for it and all electronics on this contract) termed its performance "exemplary".

2.4 Edge Seal

The edge seal effort has been continuing with a tradeoff analysis between EPDM (hot melt) and Butyl rubber (both hot melt and cold setting).

Inquiries with more than a dozen elastomer manufacturers have allowed us to make some preliminary conclusions.

2.4.1 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 stabilize the panels and provide edge protection for frameless panels during shipping

and handling (frameless panels allow much higher packing densities for shipping and where-housing). Unfortunately, cold Butyl cannot perform this function, but due to its other advantages we will continue our investigation into its use.

2.4.2 Heat Curing

There are two heat curing (hot melt) elastomers under investigation: Butyl rubber and EPDM. Both materials are comparable 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 manufacturers are supplying EPDM to companies making thermal solar panels. Butyl has been tried early on as a panel sealant and 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 includes several "recepies" with his 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).

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 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. 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.

Work during the next period will be to experiment with the various elastomers discussed and further investigate the manufacturing methods.

3.0 CONCLUSIONS

Construction of the preparation station is complete. All in-house mechanical components have been built and all vendor supplied components delivered. The computer has been delivered and debugged. The interface board, which connects the computer to the stations mechanical components, is under construction. During a feasibility demonstration, the computer with a simpler version of the interface board turned in a very impressive display of high precision control while requiring very little preparation time. The entire system is currently undergoing intergration prior to formal testing.

Concurrent with this testing, our main effort during the next period will be directed towards the refinement of the end effector design. While the basic design configuration is pretty well "locked in", there are several material combinations that have to be evaluated and some proportional (size) tradeoffs that must be resolved.

Our current time goal is to have a fully operational, although not fully optimized, system by the end of November. This would allow us to bring samples of the machine's output (strings of interconnected cells), and motion pictures of the system in operation to the next Project Integration Meeting in early December.

Preliminary investigations into materials and techniques show that transfer molded EPDM best satisfies current edge sealing requirements.