DOE/USDA Joint Project to Design and Manufacture Prototype Equipment

Federal Manufacturing & Technologies

J. G. Fuller

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Final Report
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Contents

Section	Page
Abstract.....	1
Summary.....	1
Discussion.....	3
Scope and Purpose.....	3
Activity.....	3
Reasons for FM&T Involvement.....	3
Technical Approach	3
Mechanical Design.....	6
Industrial Controller Design.....	17
Accomplishments	17
Future Work	17
Appendices	
A. Instructions for Using the Washing System.....	19
B. Instructions for Using the Encapsulating System.....	24
C. Encapsulating System Program Sequence Table.....	35

Illustrations

Figure		Page
1	Design, Assembly, and Prove-In of the Prototype Hardware	5
2	A Tray of Boll Weevil Larvae	6
3	Automated Washing System Sink	6
4	Automated Washing System	7
5	Mechanisms to Break Up Diet	7
6	Need for a Flexible Projection	8
7	Harvesting Boll Weevil Larvae	8
8	Safety Grate Properly Placed	9
9	Bug Box	9
10	Air Blower	10
11	Arrangement of Manual Process	10
12	Slider Plate Used to Minimize Capital Costs	11
13	Distribution of Larvae Into Bug Box	11
14	Parafilm® Separation Method	12
15	Parafilm® Presented to Grippers	13
16	Pulling the Parafilm® From the Roll	13
17	Pressing Pockets	13
18	Hot Wire Cutting Mechanism	14
19	Tumbling to Distribute the Larvae	14
20	Preparing to Drop Larvae Into Pockets	15

21	Getting a Cover Sheet.....	15
22	Stripper Mechanism	16
23	Stripper Grabbing Parafilm® Sheet.....	16
24	Stripper Peeling Sheet From Slider Plate.....	16

Table

<i>Number</i>		<i>Page</i>
1	Process and Technology Benefits to the Kansas City Plant	4

Abstract

Design, assembly, prove-in, and performance testing of prototype equipment for the United States Department of Agriculture's Subtropical Agriculture Research Laboratory (SARL) were completed by the Department of Energy's Kansas City Plant. The plant is operated by AlliedSignal Federal Manufacturing & Technologies (FM&T). The prototype equipment was developed as part of the USDA's efforts to mass produce parasitic wasps for organic control of boll weevils in cotton crops. This development was part of the Production Capability Assurance Program and also part of the Work For Others program. Design and assembly of this prototype equipment led to some new FM&T processes and technologies and exercised many others as described in the text and, at the same time, met the needs of the USDA.

Summary

Engineers and scientists from the Department of Energy's Kansas City Plant partnered with entomologists from the Department of Agriculture's Agricultural Research Service and their Animal and Plant Health Inspection Service to create automation equipment that could significantly impact how the boll weevil pest is controlled in the southern United States. Successful partnerships such as this led to the signing of a Memorandum of Understanding between the Secretaries of Energy and Agriculture on November 5, 1995. One section of the MOU states:

"The purposes of the cooperation and coordination are: to facilitate cooperative technology, research, development, transfer, utilization and commercialization efforts; to ensure rapid technology transfer between USDA and DOE organizations; and to coordinate and jointly plan, as appropriate, research and development, technology transfer, outreach and related activities."

Prior to the official signing, the spirit of the MOU was being realized by DOE and USDA. The Department of Energy's Kansas City Plant, the USDA's Agricultural Research Service laboratory in Weslaco, Texas, and the USDA's Animal and Plant Health Inspection Service facility in Mission, Texas, formed a partnership to automate the process of augmenting natural pest control. Specifically, this partnership began to develop the equipment necessary to mass propagate *Catolaccus grandis*, a tiny wasp that is a natural parasite of the boll weevil in the third instar larva stage.

The USDA's biologists and entomologists teamed with the engineers from DOE and mapped the labor-intensive process used by USDA researchers to rear *Catolaccus grandis*. As USDA increased the number of acres treated by *Catolaccus grandis*, the lack of mass propagation equipment became a barrier to larger field trials. The economic benefits of mass propagation as a viable technology relies heavily on automating the process. The most labor-intensive step in the manual process of mass propagating

Catolaccus grandis was encapsulating boll weevil larvae in Parafilm® "bubbles." USDA and the Kansas City Plant developed a plan to design and build a single prototype encapsulation system to be used by USDA in field trials.

The leveraged partnership between USDA and DOE was advantageous to both. The DOE's Kansas City Plant manufactures highly complex nonnuclear mechanical, electrical, opto-electronic, and rubber/plastic hardware

for nuclear weapons. The DOE requires that the Kansas City Plant maintain a viable technology base that is responsive to weapon component production requirements. This includes the development, improvement, and maintenance of core technologies. USDA's challenge exercised many critical technical disciplines necessary to the DOE. USDA benefited by receiving encapsulation equipment that reduced the manual labor required to encapsulate boll weevil larvae.

Discussion

Scope and Purpose

This is the final summary of the Production Capability Assurance Program and Work For Others activities associated with the DOE/USDA Joint Project to Design and Manufacture Prototype Equipment (Wasp Project). The prototype was successfully designed, assembled, and implemented into the Subtropical Agriculture Research Laboratory's (SARL) research program. This report summarizes the activities at FM&T associated with the design and manufacturing of prototype washing, drying, and encapsulating systems, as well as preliminary designs for other prototype equipment associated with the entomological research at SARL.

Activity

Reasons for FM&T Involvement

The production of firesets and other advanced components for nuclear weapons requires a great deal of technical competency. In the recent past, this competency has been maintained by supplementing the workload with various demonstration programs. After the demonstration programs were canceled, some associates normally assigned to fireset production were without a design project to exercise their necessary skills. Included in the duties that needed to be exercised by a development program such as firesets are project management and mechanical design. This project maintained these skills for future programs that will require large-scale fireset manufacturing.

Similarly, the loss of the fireset demonstration programs impacted other areas of FM&T.

Mechanical engineering typically assigns several engineers in support of fireset activities to produce stronglinks, flat cables, etc. Without a fireset in development, the fireset group needed assurance that mechanical engineering exercised and maintained the capabilities required to support future fireset development. Additionally, mechanical engineering needed to further develop its limited capability in animating three-dimensional Pro/Engineer (Pro/E) models. This project provided an excellent opportunity to exercise these mechanical design tools.

Also, a fireset development project requires tremendous support from test equipment but minimal support without a development program. Assurance that test equipment maintained and exercised its capabilities required to support a fireset development program was critical to the success of future fireset designs. Test equipment also needed to develop capability with industrial controllers in order to simplify the task of interlock handling and mechanism timing for future projects. This project exercised the necessary aspects of test equipment for future fireset development while providing an application to develop necessary skills with regard to these controllers.

The process and technology benefits derived from this project are listed in Table 1.

Technical Approach

The design, assembly, and prove-in of the prototype hardware followed the steps in the flowchart shown in Figure 1.

Table 1. Process and Technology Benefits to the Kansas City Plant

	<i>New P&Ts *</i>	<i>P&Ts That Would Not Have Been Exercised During This Period</i>	<i>P&Ts That Would Have Been Exercised Anyway During This Period</i>
Firesets	Knowledge in hydraulics and pneumatics. Sheet metal module of Pro/Engineer.	Manufacturing of sheet metal parts. Large assembly modeling in Pro/Engineer.	Utilization of Pro/Engineer Component and Assembly Modeling. Design for Manufacturability. Design Analysis. Project Management.
Mechanical Engineering	Experience with pneumatics, hydraulics, and sensors and their interface with a programmable logic controller. Machine design of a large-scale, complex system including each of the following steps: initial conceptual design, creating detailed drawings, establishing purchased material requirements, component procurement, final assembly, modifications, and prove-in.	Prototype design responsibility for a \$250,000 project. Significant usage of the Pro/Engineer design tools.	Scheduling, project planning, interfacing with customers.
Test Equipment	Integrating different mechanical systems (pneumatics, hydraulics, stepper motors, solenoids, sensors, and actuators) into a single microprocessor controlled unit. Design, fabrication, and programming of sophisticated industrial controllers.	Systems design and integration using computer solid modeling. Stress analysis on machine components. Kinematic motion analysis on drive components. Interfacing with through-beam optical sensors. Industrial controller work.	Electrical and electronic design and fabrication. Tester hardware design and software development. Test Equipment fabrication.
Other (Specify)	Interfacing stepper motor control with a microprocessor. (Mechanical) Machining of soft silicone bonded to aluminum. (Model Shop)	Stepper motor hook-up and programming. (Mechanical) Alignment of linear bearing packs. (Machine Repair) Safety enclosure and safety interlocks assembly. (Millwright and Electronics Fabricator) Proximity sensor alignment. (Machine Repair) Through-beam optical sensor alignment. (Machine Repair)	Static charge dissipation. (Electronics Fabricator) Conventional machining. (Model Shop) Facilities hook-ups. (Pipefitter and Electrician) Machining, maintenance, and installation of equipment. (Many) Packaging and shipping. (Packer/Shipper)

* P&T stands for processes and technologies as developed or exercised because of the Wasp Project.

Figure 1. Design, Assembly, and Prove-In of the Prototype Hardware

Mechanical Design

Washing System

Manual Process

A solution containing boll weevil eggs is sprayed into a tray of gelatinous artificial diet and then the tray is sealed. (See Figure 2.) The eggs hatch in the diet and use it as a food source for development. When the boll weevils reach the third instar larval stage, the larvae must be harvested from the artificial diet in order to be presented to the *Catolaccus grandis*. Any amount of artificial diet remaining with the weevil larvae will clog vacuum holes during encapsulation, so all of the diet must be removed.

Figure 2. A Tray of Boll Weevil Larvae

The first step in removing the larvae from the diet requires a five-gallon bucket and an aerated water supply. Five to ten trays of diet are emptied into the bucket and then blasted with a stream of cold aerated water. An associate then reaches down into the bucket and breaks the diet up by hand. The bubbles in the aerated water cause the weevil larvae to rise to the surface where they are scooped out of the bucket with a strainer. This process is repeated until a majority of the weevil larvae are thought to have been removed from the diet.

Next, the weevil larvae are spread out on an absorbent blotter where all remnants of the artificial diet are removed. This process involves the use of tweezers to manually pick the pieces of artificial diet from among the weevil larvae.

When all of the artificial diet has been removed, the weevil larvae are ready for the drying process.

Automation Concept

In order to keep risk at a minimum in an extremely tight schedule, the current manual method was emulated as much as possible. A stainless steel sink was designed with an approximate five-gallon capacity, and a faucet with an aerator was positioned above. (See Figure 3.)

Figure 3. Automated Washing System Sink

In order to simulate the manual process of fingers breaking up the diet, a rotating unit with flexible projections was designed to mesh with rigid projections from the side wall of the sink. As the crankshaft rotated, the flexible projections rotated. When they reached the bottom of the rotation cycle, the flexible projections would drag slightly on the flat bottom of the sink and push any unbroken artificial diet up along the curved portion of the wall until it reached the stationary rigid projections. As the rotating projections continued past this point, the artificial diet would drag through and be broken up.

As the weevil larvae came free of the artificial diet, the aerated water would float them to the top. To aid the process of floating the weevil larvae, an air pump and aerator were connected to the dishwasher connection of a garbage disposal located at the bottom of the sink on the flat portion. This adjustable flow of bubbles also aided in keeping the weevil larvae and artificial diet out of the garbage disposal while weevil larvae were being harvested. The weevils are then manually skimmed off the top of the water and set on a blotter for diet removal as before. The washing system is illustrated in Figure 4. (Removal of all artificial diet from the boll weevil larvae was deemed too expensive to automate.)

Figure 4. Automated Washing System

When the last of the weevil larvae were skimmed off the water, a solenoid would open and the garbage disposal would turn on. This would break up the last of the artificial diet and ensure it did not clog up the drain.

Separating Boll Weevil Larvae From the Artificial Diet

As stated earlier, the artificial diet is a thick, gelatinous block which houses the boll weevil larvae and supplies them with their nutritional

needs for development. The larvae eat the diet and leave waste (frass) behind. The frass softens the gelatin somewhat and causes the gelatinous block to have a variable consistency: softer where there is more frass and firmer where there is none.

The frass-filled gelatin breaks up quickly when exposed to a stream of water. The firm gelatin breaks up very little due to the water stream. Thus, a device was needed to break up the firm gelatin to free the larvae located there.

Rigid projections of about one inch in length were created out of a single piece of aluminum. The aluminum piece was then sharply bent so that the projections pointed toward the center of the sink, and then gently bent to conform to the radius of the sink. (See Figure 5.) The aluminum piece was then bolted to the wall of the sink, and the bolts were sealed to prevent leaking.

Figure 5. Mechanisms to Break Up Diet

Rotating projections which could remain close enough to the sink wall to pull along the unbroken diet to the location of the rigid projections needed to be longer than the distance between the center of the sink and the flat spot at the bottom of the sink. (See Figure 6.) Thus, a flexible projection was devised which would bend around the flat spot at the bottom of the sink and would remain in close proximity to the sink wall at the radius. This was accomplished by threading Teflon tubing onto short bolts that were threaded through the base of the

rotating mechanism. Using this approach, nearly 100% of the diet is broken up in under two minutes.

Figure 6. Need for a Flexible Projection

Floating Boll Weevil Larvae for Harvest

The density of weevil larvae is greater than the density of water. In the manual process, it was the bubbles in the aerated water that would collect around the weevil larvae and cause them to float to the surface. Any larvae not floating due to the aerated water were encouraged upward by hand.

The automated sink also uses aerated water to encourage the weevil larvae to float, but with the rotating mechanism shredding the artificial diet, it is unsafe to encourage by hand those that do not float upward. Thus an air hose was connected to an aquarium style of aerator inside the garbage disposal. This constant source of bubbles from underneath, in conjunction with the aerated water, was able to float more than 95% of the weevil larvae in the sink. This yield was as good as the manual process and deemed to be acceptable.

Harvesting Boll Weevil Larvae

After the boll weevil larvae are automatically floated to the top, a skimmer is used to manually lift the larvae out of the water and place them onto an absorbent blotter. (See Figure 7.) This starts the drying process of the larvae.

Figure 7. Harvesting Boll Weevil Larvae

Disposing of the Artificial Diet

Once all of the boll weevil larvae are placed onto the blotter, tweezers are used to pick any specks of artificial diet that were skimmed from the top of the water along with the larvae. The artificial diet must be removed in order to prevent clogging hazards at the encapsulation stage.

Required Maintenance of the Washing System

The washing system is constructed of stainless steel which is resistant, but not immune, to rusting. At the end of the day, or when the washing system has been used for the last time for a day, the interior should be dried with an absorbent towel.

After each use, the sink should be flushed with water, and the garbage disposal should be engaged. This will clean the sink of any residue and prevent the solenoid switch from becoming clogged. If the solenoid switch does become clogged, flushing the system with water while turning the solenoid on and off should clear the clog.

Safety Features of the Washing System

The washing system has rotating parts in the interior of the sink to shred the artificial diet. To prevent the possibility of injury, safety interlocks are located outside the sink just below the main flat surface. A custom metal grate will enable the washing machine when it is properly placed over the top of the sink.

(See Figure 8.) If the metal grate is removed, the washing machine will cease to function until the grate is returned to its proper place.

Figure 8. Safety Grate Properly Placed

Drying System

Manual Process

The manual drying process begins while the boll weevil larvae are on the absorbent blotter and the artificial diet is removed. After the diet is completely removed, the larvae are shaken in a coarse corn grit that removes any remaining moisture. Next, they are shaken in a finer corn grit and then stored there until they are ready to use.

Automation Concept

As with the manual process, the automated drying process begins when the artificial diet is being removed from among the weevil larvae while they are on the absorbent blotter. The coarse corn grit could not be used since the larger corn grit could later clog the vacuum holes during the encapsulation process. The weevil larvae were coated in fine corn grit, however, and then placed into a "bug box" (Figure 9) and set in front of an industrial blower. The moving air would continue to dry the weevil larvae as they secreted fluid.

Figure 9. Bug Box

Applying Corn Grit to the Boll Weevil Larvae

The weevil larvae are coated with the fine corn grit before being placed into a bug box. If they are not put into the encapsulating system within 15 minutes, the larvae will stick together and multiple larvae will be encapsulated into a single cell. To avoid this, a grit pan was designed to attach to the bug box. The grit pan-bug box combination is then shaken to recoat the weevil larvae in the fine corn grit. To maximize encapsulating system yields, this needs to be done immediately prior to mounting the bug box into the encapsulating system.

Air Flow Over the Boll Weevil Larvae

A squirrel cage air blower is used to keep the boll weevil larvae dry while they are stored in a bug box but waiting in queue to be attached to the encapsulating system. (See Figure 10.) This blower maintains a room temperature wind velocity between 15 and 20 miles per hour. Larvae are best for encapsulating if they are not stored in front of the air drier for more than 15 minutes without another coating of the fine corn grit.

Figure 10. Air Blower

Required Maintenance of the Drying System

The drying system requires no special maintenance outside that necessary to keep the air blower operational.

Encapsulating System

Manual Process

After the boll weevil larvae are washed and dried, they are submitted to a group of eight or nine individuals who encapsulate them. Arrangements for the manual process are shown in Figure 11.

At Station 1, an associate takes a four-inch by ten-inch piece of precut Parafilm® out of a box, strips the backing off of it, and presents it to the associate at Station 2. This associate sandwiches the Parafilm® between two silicone-backed aluminum plates and presses them in a hydraulic unit. At this time, the associate at Station 3 drags a vacuum unit over the array of holes in the top silicone-backed aluminum plate in order to create an array of depressions in the Parafilm® sheet. The associate at Station 3 then removes the

Figure 11. Arrangement of Manual Process

bottom silicone-backed aluminum plate and passes the top plate with the Parafilm® sheet attached to Station 4. At Station 4, the associate shakes a Plexiglas box full of weevil larvae so that the larvae align into depressions in a Teflon vacuum plate. The array of weevil larvae being held by the Teflon vacuum plate is positioned precisely over the array of depressions created at Station 3 in the Parafilm® sheet, and then the vacuum is toggled to a positive air pressure so that the weevil larvae are blown into the depressions. This does not precisely place one weevil larva into each depression, so the associates at Stations 5a and 5b must manually pick and place weevil larvae until each depression is filled with exactly one larva. Once Station 5 has placed exactly one weevil larva into each depression, the associate at Station 6 strips the backing off of a precut Parafilm® sheet and aligns it with the outer edges of the sheet with weevils in its depressions. The associate at Station 6 then

aligns a silicone-backed aluminum plate once again, creating a sandwich with the Parafilm® sheet on the inside of two silicone-backed aluminum plates. The associate at Station 7 then takes the sandwich and places it into a second hydraulic unit which seals the two Parafilm® sheets into a single "bubblepack" with one larva in each bubble. Lastly, the associate at Station 8 removes the bubblepack from the silicone-backed aluminum plates and places the finished sheet into a box. The silicone-backed aluminum plates are set back in the middle of the table and the process continues.

The process listed above follows one sheet through the eight stations. In reality, each station is continuously working to keep the next station busy in a continuous flow environment.

Automation Concept

Once again, in order to minimize design time and design risk, the manual process was emulated wherever possible. An encapsulating system was desired which would automatically cut the Parafilm® sheets, press the pockets or depressions into the Parafilm® sheets, evenly distribute the boll weevil larvae into the depressions, seal another Parafilm® sheet on top of the first to create a bubblepack, strip the finished sheet off the machine, and put it into a box. To reduce capital costs, a philosophy of utilizing a single hydraulic unit was developed by instituting a slider plate which would move back and forth from station to station. (See Figure 12.) In this scenario, the forming of pockets would be limited to every other hydraulic cycle, and sealing the bubble packs would be performed on the alternate cycles.

Figure 12. Slider Plate Used to Minimize Capital Costs

Loading Boll Weevil Larvae Into the Encapsulating System

After the larvae are washed and dried, and after the diet has been picked out of the boll weevil larvae, each quadrant should be loaded with approximately the same number of larvae. (See Figure 13.) The array of larvae will be 7 x 17 for each sheet for a total of 119 larvae per sheet. The bug box is designed to hold larvae for two sheets to be manufactured side by side. Since the larvae will eventually begin secreting fluids and sticking together, only enough larvae need to be loaded into the bug box to support the number of cycles which can be run before this secretion begins.

About 800 to 1000 Larvae in Each Quadrant

Figure 13. Distribution of Larvae Into Bug Box

As an example, if the larvae begin secretion after 15 to 20 minutes and each cycle takes one and a half minutes to run, then the bug box needs to be loaded with enough larvae to handle ten to 13 cycles. Since each sheet corresponds to two quadrants of the bug box and the sheet is an array of 7 x 17 larvae, one quadrant on each sheet will be 7 x 8 and the other will be 7 x 9. Using the larger of the two quadrants for calculation, each cycle requires 63 (7 x 9) larvae per quadrant. To perform 10 to 13 cycles requires that a minimum of 630 to 819 larvae be placed in each quadrant. To ensure that each pocket is filled with a larva, additional larvae should be available in each quadrant so that plenty are tumbling on the last cycle. This requires that about two or three additional cycles worth of larvae (126 to 189) be included in each quadrant. Thus, about 800 larvae are needed to complete 10 cycles (15 minutes) and about 1000 larvae are needed to complete 13 cycles (20 minutes.)

Separating the Parafilm® From the Parafilm® Backing

The same properties that make Parafilm® a perfect choice for an encapsulating material make it a poor choice from a handling standpoint. Parafilm® sticks to itself and seals when a pressure of 250 psi is applied or when heat is present at a lower pressure. It also sticks fairly well to metals, rubbers, and plastics and even slightly to the non-stick backing used to separate the Parafilm® from itself on the roll. Any misalignment between the backing and the Parafilm® also allows the Parafilm® to stick to itself.

In order to overcome this problem, an air jet is positioned so that it blows up between the Parafilm® as shown in Figure 14. The air jet is kept properly positioned as the Parafilm® roll empties and becomes smaller in diameter by pressing up against the roll and being held

in place with spring tension. The air movement separates the Parafilm® from the backing before it reaches the point of mechanical separation. If the backing is sticking to the Parafilm® at the point of mechanical separation, the backing has a tendency to pull through and remain stuck to the Parafilm®.

Figure 14. Parafilm® Separation Method

Preparing the Parafilm® for the Grippers

After the backing is removed, the Parafilm® is fed around two posts as shown in Figure 14 in order to guarantee a constant configuration of the film as it is presented to the feeder mechanism. From there, the film is threaded between two thin metal plates as shown in Figure 15. This helps in precisely positioning the Parafilm® so that the grippers will have a fairly uniform amount of Parafilm® to grab. The top and bottom feeder plates also help provide a slight amount of drag on the Parafilm® so that any momentum built up while pulling the Parafilm® will not allow it to move from its proper presentation position.

Figure 15. Paraform® Presented to Grippers

Pulling the Paraform® From the Paraform® Roll

Once the Paraform® is positioned correctly in the feeder mechanism, it is ready to be pulled and distributed onto the slider plate. This is done with a pneumatic gripper. The grippers are raised pneumatically to provide ample clearance for the Paraform® to fit between the bottom of the gripper and the top of the slider plate. Then the slider plate moves to a position so that the gripper is above the Paraform®, and the pneumatic gripper is lowered. Both the bottom of the gripper and the top of the slider plate are lined with a silicon rubber which provides the friction necessary to pinch the Paraform® firmly when the gripper is lowered. Once the Paraform® is firmly held, the slider plate moves in the direction shown in Figure 16, and the Paraform® is pulled from the roll.

Figure 16. Pulling the Paraform® From the Roll

Pressing Pockets in the Paraform®

Once the Paraform® has been dispensed by the grippers to its proper position underneath the press, it is ready to have pockets pressed. (See Figure 17.) First, a hydraulic press is engaged, and a silicone-backed metal plate lowers to the slider plate surface. Then, a 7 x 17 array of dowel pins is engaged pneumatically which lowers and forms depressions in the Paraform® sheet. A vacuum is applied inside the slider plate cavity to hold the pockets down while the dowel pins are retracted. The pneumatic cylinders are released and the dowel pins rise back up into a cavity inside the press. Finally, the hydraulic cylinders release and a spring tension raises the press back to its original position. With the pockets formed and the press and dowel pins raised up out of the way, the pockets are formed and ready to accept larvae.

Figure 17. Pressing Pockets

Cutting the Paraform® to Length

Before the grippers and the slider plate can continue moving, the Paraform® sheet must be cut from the roll. Many methods of cutting were tried but were unsuccessful due to the pliability of the Paraform®. The method which proved successful was the installation of a spring-loaded hot wire mechanism. (See Figure 18.)

Figure 18. Hot Wire Cutting Mechanism

When the press lowers to the slider plate as described above, an electric current is run through a wire. A small resistance is placed in series with the wire to control the wire's temperature and prolong its life. The electric current heats the wire and the wire passes easily through the Parafilm®. When the press is raised back up to its home position, the electric current is turned off. Due to the heat expansion characteristic of metals, a spring load was added to one end of the hot wire. As the wire heats due to the electric current, it expands in length. The spring tied to the wire contracts and keeps the wire taut. After the current is removed, the wire contracts again and the spring expands.

Aligning the Boll Weevil Larvae

With an array of pockets formed in a sheet of Parafilm®, the boll weevil larvae must be arranged in an identical array so they can be distributed one per pocket. This is accomplished with a vacuum tumbler plate as shown in Figure 19.

The boll weevil larvae are enclosed in an area formed by one quadrant of the bug box on the top and sides and by the tumbler plate on the bottom. The tumbler plate is machined out of Teflon to discourage the larvae from sticking during the tumbling action. A stepper motor drive rotates the pivot axis back and forth three times so that the tumbler plate sweeps about 90 degrees (45 degrees in each direction.) During this tumbling action, the boll weevil larvae fall from side to side

Figure 19. Tumbling to Distribute the Larvae

across the depressions in the tumbler plate. A hole is drilled in each depression to the vacuum cavity inside the tumbler plate. As the holes fill with larvae, the vacuum holds them securely in place. The three tumbling cycles end up filling about 95 percent of the holes. Once the three rocking cycles are complete, the tumbler plate turns upside down, and the boll weevil larvae are ready for dispensing into the Parafilm® pockets.

Dropping Boll Weevil Larvae Into the Pockets

After the tumbler plate rocks to distribute the boll weevil larvae into the depressions in the Teflon, the tumbler plate is turned upside down with the vacuum holding one larva in each depression. The array of depressions is spaced precisely as the array of pockets is spaced.

In order to position the pockets under the larvae, the bug box must be moved out of the way. This is accomplished by attaching pneumatic cylinders to the bug box and firing the cylinders when the tumbler plate is horizontal. These pneumatics then pull the spring-loaded bug box down out of the way so that the slider plate can move between the bug box and the tumbler plate.

With the bug box out of the way, the slider plate is driven with a stepper motor into position so that the Parafilm® pockets precisely match up with the depressions in the Teflon tumbler plate. (See Figure 20.) At this time the vacuum in the tumbler plate is released and an array of small pins pushes down through the holes in the tumbler plate depressions to clear out any boll weevil larvae that are clinging to the tumbler plate.

Figure 20. Preparing to Drop Larvae Into Pockets

Pulling a Parafilm® Cover Sheet

Once the larvae are deposited into the individual pockets in the Parafilm®, the stepper motor drives the slider plate out from under the tumbler plate and back to the Parafilm® feeders as shown in Figure 21. The grippers again close to grip the Parafilm® and the slider plate moves to pull the Parafilm® sheet off the roll. This sequence is nearly identical to the sequence used to pull the original sheet of Parafilm® from the roll.

Figure 21. Getting a Cover Sheet

Sealing the Parafilm® "Bubble Pack"

In order to seal the two sheets of Parafilm® to each other, approximately 250 psi of force is necessary. This force is supplied by the hydraulic unit which forces the press down on top of the slider plate (see Figure 18.) This pressure seals the two pieces of Parafilm® into one Parafilm® sheet or bubblepack. After the hydraulic sealing, each larvae is individually packaged into an air pocket inside a Parafilm® bubble. At the same time the bubblepack is sealed, the hot wire is used to cut the Parafilm® sheet from the roll.

Removing the Sheet From the Slider Plate

With the Parafilm® bubblepack sheet complete, the sheet needs to be removed from the slider plate. This step in the process proved to be most troublesome since the finished sheet would not always wind up in the same place when the hydraulic press would rise back up. Due to static electricity, material adhesion, and/or other forces, sometimes the finished sheet would remain on the slider plate, sometimes it would rise up and stick to the press, and still other times one end would stick to the press while the other end stayed on the slider plate.

In order to overcome this problem, a stripper mechanism was developed as shown in Figure 22. The stripper is a two-stage pneumatic device which utilizes silicone-backed aluminum disks to grip the Parafilm® sheet in much the same way as the grippers do. The sheet is held onto the slider plate by the grippers when the hydraulic press is raised. Then the slider plate moves underneath the tumbler plate in the same way it does for the larva drop.

Figure 22. Stripper Mechanism

Once the slider plate is in place, the stripper mechanism activates and drops down into a hollowed out region in the slider plate. Then the slider backs up slightly so that the back edge of the bubblepack is between disk and the plate of stage 2, and the stage 2 cylinder closes to grip the Parafilm® sheet as shown in Figure 23.

Figure 23. Stripper Grabbing Parafilm® Sheet

With the bubblepack sheet firmly held, the slider plate moves back slightly further to avoid stretching the sheet, and then the stage 1 cylinder closes to pull the stripper mechanism completely out of the way of the slider plate and gripper mechanism as shown in Figure 24. To complete the stripping process, the slider plate moves back to the Parafilm® feeder mechanism to start the cycle over again while the stripper peels the sheet off the slider as it goes by. Once the tumbler plate starts its tumbling for the next sheet, the strippers open up again and the tumbling action helps gravity pull the sheet free from the strippers. By placing a box or pan underneath the tumbler plate and stripper mechanism, the finished sheets can easily be collected.

Figure 24. Stripper Peeling Sheet From Slider Plate

Required Maintenance of the Encapsulating System

The encapsulating system will require routine maintenance.

The Parafilm® rolls will need to be replaced as they become empty. Operating the encapsulating system without Parafilm® can deposit boll weevil larvae into the slider plate vacuum area and could contaminate the system.

The slider plate rests on square rails with linear ball bearings. The bearings may become worn with use and require lubrication or replacement.

The hydraulic unit may leak hydraulic fluid. The fluid level should be checked and topped off monthly.

The pneumatic cylinders may bind or stick from time to time. Cleaning any grit from them may unbind them. If this fails, lubricate the shafts or replace them.

Sensors may become misaligned with the pneumatic cylinders due to vibrations caused by use of the encapsulating system. If this happens, the system may hang up during a pneumatic process step. To fix the problem, reposition the sensors and tighten the screws.

The Teflon tumbler plate and the stainless steel bug boxes are in intimate contact with the boll weevil larvae. Cleaning these surfaces daily will help prevent microbial contamination.

Safety Features of the Encapsulating System

The encapsulating system is designed to provide a safe work place for the operator. These safety mechanisms should never be defeated.

The encapsulating system is enclosed in a Lexan safety enclosure. Access doors are provided at the two ends and on one side of the system. These doors are equipped with dual safety interlocks. Any open door will immediately terminate the operation of the system.

An emergency stop button is built into the control panel so that the machine can be stopped by the user at any time.

Warning labels are placed on the equipment to warn the user of the hazardous areas.

Industrial Controller Design

Instructions for using the washing system are in Appendix A, and instructions for using the encapsulating system are in Appendix B. Appendix C contains the Encapsulating System Program Sequence Table.

Accomplishments

Design, assembly, prove-in, and performance of prototype equipment were successfully completed for the Wasp Project. Activities for this prototype included mechanical design and assembly, industrial controller design and assembly, industrial controller programming, and three-dimensional modeling using Pro/Engineer. Design and assembly of the prototype led to some new FM&T processes and technologies and exercised many others.

Future Work

The encapsulation equipment is only one of eight systems that will be required if augmentation of natural pests is to become a widespread option for the cotton producer. In addition, the current encapsulation equipment may need retrofitting to take advantage of recent breakthroughs in artificial diet technologies. The artificial diet will replace live boll weevil larvae, the medium on which *Catolaccus grandis* larvae must feed.

As larger field trials are undertaken by USDA, other mass propagation "choke points" must be identified and automated. U.S. industry will eventually take the lead in this effort "...on reducing overall risks from the use of pesticides through integrated pest management programs which lead to more

sustainable agricultural production strategies and reductions in the use of pesticides." (quote in June 1993, Administrators of the EPA, USDA, and FDA). USDA has the charter to develop new technologies for sustainable agriculture, and the DOE can participate, where appropriate, as encouraged by the Memorandum of Understanding signed by the Secretaries of Agriculture and Energy on November 5, 1995. .

Appendix A

Instructions for Using the Washing System

Instructions for Using the Washing System

- Ensure that the switch handle on the controller Hoffman enclosure located on the left side of the washer is set to ON.
- Ensure that the controller Hoffman enclosure is plugged into a 120V/30A twistlock GFCI protected outlet. A safety hazard can exist without the use of a GFCI outlet.
- Ensure that both the top and bottom controller Hoffman enclosure latches are screwed tightly down. This will seal the Hoffman enclosure and prevent any potential water leakage into the controller electronics.
- Ensure that all required power switches are on and all required air valves are open.
- Perform desired operation:

Wash Mode

This procedure turns on air bubbles as the sink is filled with water, rotates the basket for five minutes with air bubbles on, moves the basket to a 270-degree position with air bubbles shut off for one minute, and finally rotates the basket into the home position, allowing the basket to be unloaded.

1. Press the console STOP button.
2. The grate may be removed so that the sink can more easily be filled with water, and salt and diet added.
3. Turn the console leftmost three-position switch to WASH.
4. Press the console ENTER button. The air solenoid will activate.
5. Fill the sink with water and add salt and diet as desired.
6. Note: Air can be turned off by turning the console leftmost three-position switch to a position other than WASH. Air is then turned back on by turning the leftmost three-position switch back to WASH and pressing the ENTER button.
7. Place the grate over the sink, ensuring that the two grate pins insert through the interlock switch holes.
8. Turn the console leftmost three-position switch to WASH.
9. Press the console START button.
10. Press the console ENTER button.
11. The basket will rotate with air bubbles for five minutes. It will then move to the 270-degree position for a one-minute dwell with no air bubbles. Then the basket will move to the home position and stop for unloading, and the operation will have been completed.

12. The wash mode can be repeated by pressing the console ENTER button once for air bubbles alone and then pressing the console ENTER button again for the rest of the wash routine.
13. Press the console STOP button before removing the sink grate.
14. The wash mode can be stopped prematurely by pushing the console STOP button.

Tumble Mode

This procedure rotates the basket for five minutes with air bubbles on. The rotation is then slowed and finally stopped in a position allowing the basket to be unloaded.

1. Place the grate over the sink, ensuring that the two grate pins insert through the interlock switch holes.
2. Turn the console leftmost three-position switch to TUMBLE.
3. Press the console START button.
4. Press the console ENTER button.
5. When the basket rotation has stopped, the operation has completed.
6. The wash mode can be repeated by pressing the console ENTER button again.
7. Press the console STOP button before removing the sink grate.
8. The tumble mode can be stopped prematurely by pushing the console STOP button.

Index Mode

This procedure rotates the basket in 90-degree increments. Air bubbles are off in this mode.

1. Place the grate over the sink, ensuring that the two grate pins insert through the interlock switch holes.
2. Turn the console leftmost three-position switch to INDEX.
3. Press the console START button.
4. Press the console ENTER button.
5. When the basket rotation has stopped, the operation has completed.
6. Press the console ENTER button successively for each 90-degree rotation desired.
7. Press the console STOP button before removing the sink grate.
8. The index mode can be stopped prematurely by pushing the console STOP button.

Drain

The drain, alone, is activated immediately when the console rightmost three-position switch is turned to DRAIN. Turn the console rightmost three-position switch to OFF to turn off the drain.

Disposal and Drain

Both the disposal and drain are activated immediately when the console rightmost three-position switch is turned to DRAIN & DISPOSAL. Turn the console rightmost three-position switch to OFF to turn off the disposal and drain.

Off

The disposal and drain are both turned off when the console rightmost three-position switch is turned to OFF.

Interlocks Check

This procedure verifies that neither of the two sink grate interlock switches are sticking when the grate is removed. This operation should be performed once a week to ensure safe operation of the interlocks.

1. Press the console STOP button.
2. Remove the grate from the sink.
3. Turn the console leftmost three-position switch to WASH.
4. Turn the console leftmost three-position switch to TUMBLE.
5. Press the console ENTER button.
6. Place the grate over the sink, ensuring that the two grate pins insert through the interlock switch holes.
7. While watching the basket or basket arm inside the sink, press the console START button.
8. If the basket or basket arm moves for about five seconds and then stops, the interlocks are operating properly. Otherwise there is a problem with at least one interlock sticking closed. In the latter case, the system must not be used until the interlock is repaired, since a safety hazard exists.

Stop

The console STOP button can be used to prematurely stop the wash, tumble, or index mode operations. Push the STOP button firmly to operate. Too quick a push may not shut off the system. As a matter of practice, the console STOP button should always be pushed before removing the sink grate rather than letting the interlock switches shut off the system. Note that the STOP button has no effect on the drain or disposal operation.

Emergency Stop

The console EMERGENCY STOP button is functionally identical to the STOP button but as a matter of practice should only be used in an emergency situation. Its purpose is to provide a redundant safety feature. Push the EMERGENCY STOP button firmly to operate. Too quick a push may not shut off the system. Like the STOP button, the EMERGENCY STOP button has no effect on the drain or disposal operation.

Interlocks

The two interlocks are closed when the sink grate is placed over the sink so that the two grate pins insert into the two interlock holes. When the grate is removed, the two interlocks are opened and the basket and basket arm cannot be rotated under automatic motor control. Like the console STOP and the EMERGENCY STOP buttons, the interlocks have no effect on the drain or the disposal operation.

Controller Hoffman Enclosure Switch Handle

The switch handle on the controller Hoffman enclosure located on the left side of the washer turns power on and off to the entire washer system. There is no power to the motor that rotates the basket and basket arm, to the controller itself, to the drain, and to the disposal when this switch is in the OFF position.

Appendix B

Instructions for Using the Encapsulating System

Instructions for Using the Encapsulating System

- Ensure that the switch handle on the controller Hoffman enclosure mounted on the encapsulating system is set to ON.
- Ensure that the controller Hoffman enclosure is plugged into a 120V/30A twistlock outlet.
- Ensure that both the top and bottom controller Hoffman enclosure latches are screwed tightly down. This will ensure that the Hoffman enclosure provides resistance to any potential contamination of the controller electronics from dirt, debris, or liquids in the operating environment.
- For safety purposes, ensure that both the slider plate and the tumbler stepper motor drivers, and also the Hydraulic Interface box, are all plugged into an outlet strip which is in turn plugged into the Hoffman enclosure 120V/15A outlet located at the bottom of the enclosure. This will ensure that power is removed from the stepper motors when the console STOP or EMERGENCY STOP buttons are pushed or if any of the interlock switches are opened. The compressed air line AC solenoid should also be plugged into this outlet strip so that the compressed air is shut off when the system is not being used.
- Ensure that all required power switches are on and all required air valves are open.
- Ensure that the console EMERGENCY STOP button is pulled out.
- Perform desired operation(s):

Run Mode ("00")

This is the normal encapsulating system operation.

- 1.. Firmly press the console STOP button.
2. Dial "00" on the console MODE thumbwheels.
3. Dial the number of encapsulation cycles desired on the console INPUT thumbwheels. The maximum number of cycles allowed is 999. If a number greater than 999 is entered, the number of cycles will be set to 999. There must be sufficient Parafilm® and larvae for the number of cycles entered.
4. Press the console ENTER button.
5. Ensure that all four encapsulating system doors are latched shut.
6. Press the console START button.

7. The process stops when the number of cycles run equals that entered on the INPUT thumbwheels in the previous step. The current cycle number is displayed on the console VALUE display.
8. When all cycles have been completed and the encapsulating system has ceased movement, (and VALUE display of cycle number goes blank), press the console STOP button.
9. The "Run" mode can be stopped prematurely, immediately, by pressing the console STOP button. The system will be stopped in its current state. This is not the desirable manner to cease operation prematurely and should only be used if a major problem has developed and all movement must be stopped immediately.
10. Operation can be frozen by pressing and holding in the console ENTER button. Operation will resume when the ENTER button is released.
11. Operation can be ceased prematurely at the end of the current cycle and the system properly homed by entering "55" on the console MODE thumbwheels and pressing ENTER at any time during the "Run" mode operation. This is the preferred method of stopping operation before all the cycles originally entered have been run.
12. If "30," "40," or "41" are dialed on the MODE thumbwheels, the VALUE display will display timer preset times (with the desired timer number on the INPUT thumbwheels), last completed program step, or Allen-Bradley input/output state (with the desired slot and bit numbers on the INPUT thumbwheels) respectively, rather than the cycle number. If MODE thumbwheels are changed to a number other than "30," "40," or "41," VALUE will resume displaying the current cycle number upon the start of the next cycle.
13. Always press the console STOP button before opening any encapsulating system door.
14. When completed with the "Run" mode, after pressing the STOP button, dial "75" on the console MODE thumbwheels and press the ENTER button to prevent the "Run" mode from being unintentionally reactivated by the START button being pressed.

Step Mode ("01")

This allows step-by-step advancement through the encapsulating system process by repeated pressing of the console ENTER button. This can be used for troubleshooting.

1. Press the console STOP button.
2. Dial "01" on the console MODE thumbwheels.
3. Dial the number of encapsulation cycles desired on the console INPUT thumbwheels. The maximum number of cycles allowed is 999. If a number greater than 999 is entered, the number of cycles will be set to 999.
4. Press the console ENTER button.
5. Ensure that all four encapsulating system doors are latched shut.

6. Press the console START button.
7. Press the console ENTER button successively to advance sequentially through each step of the encapsulating system operation.
8. The process stops when the number of cycles run equals that entered on the INPUT thumbwheels in the previous step. The current cycle is displayed on the console VALUE display.
9. When all cycles have been completed and the encapsulating system has ceased movement, (and VALUE display of cycle number goes blank), press the console STOP button.
10. The "Step" mode can be stopped prematurely, immediately, by pressing the console STOP button. The system will be stopped in its current state. This is not the desirable manner to cease operation prematurely and should only be used if a major problem has developed and all movement must be stopped immediately.
11. Operation can be ceased prematurely at the end of the current cycle and the system properly homed by entering "55" on the console MODE thumbwheels and pressing ENTER at any time during the "Step" mode operation. This is the preferred method of stopping operation before all the cycles originally entered have been run.
12. If "30," "40," or "41" are dialed on the MODE thumbwheels, the VALUE display will display timer preset times (with the desired timer number on the INPUT thumbwheels), last completed program step, or Allen-Bradley input/output state (with the desired slot and bit numbers on the INPUT thumbwheels) respectively, rather than the cycle number. If MODE thumbwheels are changed to a number other than "30," "40," or "41," VALUE will resume displaying the current cycle number upon the start of the next cycle.
13. Always press the console STOP button before opening any encapsulating system door.
14. When completed with the "Step" mode, after pressing the STOP button, dial "75" on the console MODE thumbwheels and press the ENTER button to prevent the "Step" mode from being unintentionally reactivated by the START button being pressed.

End of Cycle Stop ("55")

During the "Run" or "Step" mode, operation can be ceased prematurely at the end of the current cycle and the system properly homed by entering "55" on the console MODE thumbwheels and pressing ENTER at any time during the operation. This is the preferred method of stopping operation before all the cycles originally entered have been run.

Display Step Mode ("40")

This allows the number of the program step last completed to be displayed rather than the cycle number during the "Run" mode or the "Step" mode. (This mode will run concurrently with the "Run" or "Step" mode.) If the program should hang up, this can be used to determine the cause. When the program is hung, this mode would display the last step completed. The program is then hung on the subsequent step. The "Program Sequence Table" shows the

inputs and their states for which that step is waiting. The states of each of those inputs can then be checked with the "Display Input/Output State" mode ("41") to find the sensor, etc., which is not functioning. This mode will only display steps while in the "Run" mode or the "Step" mode after the START button has been pressed.

1. While in the "Run" mode or the "Step" mode, dial "40" on the MODE thumbwheels.
2. The last completed program step is displayed on the console VALUE display rather than the current cycle number. Refer to the "Program Sequence Table" for information on the program steps and their respective inputs and outputs. When the "Run" or "Step" mode has completed all cycles and the final cycle cleanup, the VALUE display will go blank.
3. Enter "42" (or any number other than "30," "40," or "41") on the MODE thumbwheels to turn off the "Display Step" mode and resume display of cycle numbers when the next cycle begins.

Display Input/Output State Mode ("41")

This allows the current status of any Allen-Bradley input or output to be displayed. (This mode can run concurrently with the "Run" or "Step" modes, if desired.) During the "Run" mode or the "Step" mode the input/output state will be displayed rather than the cycle number. If the program should hang up, this can be used to determine the cause. When the program is hung, use the "Display Step" mode ("40") to display the last step completed. The program is then hung on the subsequent step. The "Program Sequence Table" shows the Allen-Bradley inputs and their states for which that step is waiting. The states of each of those inputs can then be checked with this mode to find the sensor, etc., which is not functioning. This mode will display brightly when the START button has been pressed. This mode will display dimly when the STOP button has been pressed and thus can still be used to check inputs even when the interlocks are open. In this latter situation any output displayed only shows the Allen-Bradley relay state: Since 24 volts is off, there is no actual Allen-Bradley output.

1. Dial "41" on the MODE thumbwheels.
2. Dial the Allen-Bradley slot number and bit number of the Allen-Bradley input or output desired on the INPUT thumbwheels. For instance, dial "0010" for i1/0, dial "0032" for i3/2, dial "0312" for i3/12, dial "0079" for o7/9, dial "0511" for o5/11, etc. (Since each slot is unique, "o" and "i" output/input designation is not required.)
3. The Allen-Bradley controller input or output slot/bit status is displayed on the console VALUE display. (This is displayed rather than the current cycle number during the "Run" or "Step" modes.) "000" indicates a low state and "001" indicates a high state. A blank will be displayed if the slot/bit entered on the INPUT thumbwheels is invalid. Refer to the "Program Sequence Table" for information on the program steps and their respective inputs and outputs.

4. If the console START button had not previously been activated, the display will be dim. Press START, if desired, for a bright display.
5. To display the status of a different Allen-Bradley input or output, simply dial the slot and bit number desired on the INPUT thumbwheels. There is no need to press the ENTER button. The status of whatever slot/bit currently dialed on the INPUT thumbwheels is displayed.
6. Enter "42" (or any number other than "30," "40," or "41") on the MODE thumbwheels to turn off the "Display Input/Output State" mode (and resume display of cycle numbers when the next cycle begins if the "Display Input/Output State" mode was activated during the "Run" or "Step" modes).

Display Timer Value Mode ("30")

This allows the display of timer preset times in hundredths of seconds. This mode will display brightly when the START button has been pressed. (This mode can run concurrently with the "Run" or "Step" modes, if desired.) This mode will display dimly when the STOP button has been pressed and thus can still be used to check timer settings even when the interlocks are open. This mode is only valid for timers set to 9.99 seconds or less.

1. Enter "30" on the MODE thumbwheels.
2. Dial the timer number desired on the INPUT thumbwheels. For instance, dial "0002" for T2.
3. The preset time in hundredths of seconds of the timer dialed on the INPUT thumbwheels is displayed on the VALUE display. For instance, "020" is displayed if the timer preset value is 0.20 seconds. If, however, the timer had been set to a value greater than 9.99 seconds, the timer value displayed in the "Display Timer Value" mode is not valid: Only the three least significant digits are then displayed.
4. If the console START button had not previously been activated, the display will be dim. Press START, if desired, for a bright display.
5. For a different timer, simply dial the desired timer number on the INPUT thumbwheels and its preset value will be displayed. There is no need to press the ENTER button.
6. Enter "42" (or any number other than "30," "40," or "41") on the MODE thumbwheels to turn off the "Display Timer Value" mode (and resume display of cycle numbers when the next cycle begins if the "Display Timer Value" mode was activated during the "Run" or "Step" modes).

Check Interlock Mode ("02")

This verifies that none of the interlock switches are sticking shut when they should be open. This procedure should be performed once a week to ensure safe operation of the interlocks. There are eight interlock switches, two for each of the four encapsulating system doors.

1. Press the console STOP button.
2. Dial "02" on the console MODE thumbwheels.

3. Press the console ENTER button.
4. Close and latch all four encapsulating system doors.
5. Press the console START button.
6. Press the console ENTER button.
7. Verify that "1" appears on the console VALUE display. There is an interlock problem if "1" is not displayed.
8. Press STOP.
9. Completely open all four encapsulating system doors.
10. Press the console ENTER button.
11. Close and latch all four encapsulating system doors.
12. Press the console START button.
13. Verify that "2" appears on the console VALUE display. There is an interlock problem if "2" is not displayed. If "3" is displayed, one or more of the interlock switches are sticking shut when they should open.
14. Press the console STOP button.
15. If an interlock problem is indicated, the encapsulating system must not be used until the interlock is repaired, since a safety hazard exists.

Load Parafilm® Mode ("03")

This moves the encapsulating system into position for loading the Parafilm®.

1. Press the console STOP button.
2. Dial "03" on the console MODE thumbwheels.
3. Press the console ENTER button.
4. Ensure that all four encapsulating system doors are latched shut.
5. Press the console START button.
6. When movement has completed and the system is ready for loading Parafilm®, press the console STOP button.
7. The load Parafilm® mode can be stopped prematurely by pressing the console STOP button.
8. Always press the console STOP button before opening any encapsulating system door.

Cycles Check Mode ("04")

This allows the cycle number on the display to be incremented with the console ENTER button. Encapsulating system process steps are skipped. This is for cycle counter and display troubleshooting only.

1. Press the console STOP button.
2. Dial "04" on the console MODE thumbwheels.
3. Press the console ENTER button.
4. Ensure that all four encapsulating system doors are latched shut.
5. Press the console START button.
6. Press the console ENTER button successively to advance the cycle number.
7. The current cycle is displayed on the console VALUE display. When the cycle count reaches 999, the cycle number is reset and the count starts again from 1.
8. When completed with the cycles check mode, press the console STOP button.

Input Timer Modes ("1x")

This allows the operator to change timer preset settings from the default settings. This value is retained by the controller even if power to the controller is removed. However, the value will be lost by the controller if power remains off for about two years or more or if the processor battery goes bad and the controller power is turned off. (A processor battery maintains DC to the processor memory for about two years.) The program default setting is then restored. Should power to the controller have been off for more than a year and if a timer setting different from the default is important, as a matter of caution, the timer value desired should be checked with the "Display Timer Value" mode ("30"), and, if incorrect, be re-entered. Note that power to the controller is removed if either the AC input cable to the controller Hoffman enclosure is disconnected, AC at the wall outlet to this cable is turned off, or if the Hoffman enclosure switch handle is in the OFF position.

1. Press console STOP button.
2. Dial the number indicated in the table below on the console MODE thumbwheels for the timer desired.
3. Dial the desired timer time in hundredths of seconds on the console INPUT thumbwheels. For instance, "2354" on the INPUT thumbwheels represents 23.54 seconds and "6000" on the INPUT thumbwheels represents one minute.
4. Press the console ENTER button to enter the timer value dialed in on the INPUT thumbwheels.
5. Dial "75" on the console MODE thumbwheels to prevent an erroneous time from accidentally being entered later.

Timer	Description	Default Time (sec)	MODE thumbwheels setting
T0	Time to close sheet gripper and drop	0.5	"10"
T1	Time to press pockets	1.75	"11"
T2	Time to drop larvae	5.00	"12"
T3	Time to press sheets together	0.8	"13"
T4	Time to evacuate dies	1	"14"
T5	3-second wait	3	not allowed
T6	0.30-second wait	0.3	not allowed
T7	Lower strip mechanism time	0.2	"17"
T8	Hot wire knife on time	6.00	"18"
T10	2-second wait	2	not allowed
T12	0.30-second wait	0.3	not allowed

Troubleshooting Mode (63")

This allows control of individual Allen-Bradley controller output lines and must only be used by qualified individuals with full understanding of the system since severe damage to the system can easily occur. Always be ready to push the EMERGENCY STOP button while in this mode.

1. Press the console STOP button.
2. Dial "63" on the console MODE thumbwheels.
3. Press the console ENTER button.
4. Press the console START button.
5. Dial the desired action on the INPUT thumbwheels as indicated below. Press the console ENTER button. Repeat this step as desired.
6. Actions corresponding to the number set on the INPUT thumbwheels:

<u>INPUT</u>	<u>ACTION</u>
1000	Slider plate move "0" (1111 AB output to I4,I3,I2,I1).
1001	Slider plate move "1" (1110 AB output to I4,I3,I2,I1).
1002	Slider plate move "2" (1101 AB output to I4,I3,I2,I1).
1003	Slider plate move "3" (1100 AB output to I4,I3,I2,I1).
1004	Slider plate move "4" (1011 AB output to I4,I3,I2,I1).
1005	Slider plate move "5" (1010 AB output to I4,I3,I2,I1).
1006	Slider plate move "6" (1001 AB output to I4,I3,I2,I1).
1007	Slider plate move "7" (1000 AB output to I4,I3,I2,I1).
1008	Slider plate move "8" (0111 AB output to I4,I3,I2,I1).
1009	Slider plate move "9" (0110 AB output to I4,I3,I2,I1).

2000	Tumbler move "0" (11 AB output to I2,I1).
2001	Tumbler move "1" (10 AB output to I2,I1).
2002	Tumbler move "2" (01 AB output to I2,I1).
3000	Gripper cylinder (o5/8) OFF
3001	Slider plate vacuum (o5/9) OFF
3002	Slider plate air (o5/10) OFF
3003	Press die vacuum (o5/11) OFF
3004	Press die air (o5/12) OFF
3005	Press hydraulic cylinders up (on/off) (o5/13) OFF
3006	Press hydraulic cylinders down (on/off) (o5/14) OFF
3007	Press air cylinders down (o5/15) OFF
3008	Tumbler air (on/off) (o7/7) OFF
3009	Tumbler cylinders (on/off) (o7/8) OFF
3010	Hot wire knife (on/off) (o7/9) OFF
3011	Stripper cylinder (o7/10) OFF
3012	Stripper gripper (on/off) (o7/11) OFF
3013	Push pins (on/off) (o7/12) OFF
3014	Parafilm® roll air (o7/13) OFF
3100	Gripper cylinder (o5/8) ON
3101	Slider plate vacuum (o5/9) ON
3102	Slider plate air (o5/10) ON
3103	Press die vacuum (o5/11) ON
3104	Press die air (o5/12) ON
3105	Press hydraulic cylinders up (on/off) (o5/13) ON
3106	Press hydraulic cylinders down (on/off) (o5/14) ON
3107	Press air cylinders down (o5/15) ON
3108	Tumbler air (on/off) (o7/7) ON
3109	Tumbler cylinders (on/off) (o7/8) ON
3110	Hot wire knife (on/off) (o7/9) ON
3111	Stripper cylinder (o7/10) ON
3112	Stripper gripper (on/off) (o7/11) ON
3113	Push pins (on/off) (o7/12) ON
3114	Parafilm® roll air (o7/13) ON

Note: Move "0" should be issued after some slider plate or tumbler moves are issued or movement will repeat. Press hydraulic cylinders up or down ON actions should be followed by the corresponding OFF action particularly before an opposite direction action is issued.

7. When finished, press the console STOP button, dial "75" on the console MODE thumbwheels, and press ENTER to clear out the troubleshooting mode so that it is not accidentally reactivated.

Stop

As a matter of practice, for safety purposes, always press the console STOP button before unlatching or opening any of the four encapsulating system doors rather than depending upon the interlock switches to shut off the system. Also, as a matter of practice, always press the console STOP button when the encapsulating system has completed a process. The console STOP button can also be used to prematurely stop the encapsulating system operation. Press the STOP button firmly to operate. Too quick a press may not shut off the system. The STOP button removes DC voltage from all solenoid and stepper motor control lines and removes AC voltage from the AC strip plugged into the controller Hoffman box. For safety purposes the two stepper motors and the Hydraulic Cylinders Interface box AC inputs must be plugged into this AC strip. AC power will then be removed from them when the console STOP or EMERGENCY STOP buttons are pressed or when any of the door interlock switches are opened. The compressed air line AC solenoid should also be plugged into this outlet strip so that the compressed air is shut off when the system is not being used.

Emergency Stop

The console EMERGENCY STOP push/pull button is functionally identical to the STOP button, but as a matter of practice should only be used in an emergency situation. Its purpose is to provide a redundant safety feature. To run the encapsulating system, ensure that the EMERGENCY STOP button is pulled out.

Interlocks

The eight interlock switches are closed when the four encapsulating system doors are closed and latched. When any door is unlatched or opened, DC voltage is removed from all solenoid and stepper motor control lines and AC voltage is removed from the AC strip plugged into the controller Hoffman box. The two stepper motors and the Hydraulic Cylinders Interface box AC inputs should be plugged into this AC strip. Opening any of the interlocks has the same effect as pressing the console STOP or EMERGENCY STOP buttons.

Controller Hoffman Enclosure Switch Handle

The switch handle on the controller Hoffman enclosure located on the encapsulating system turns power on and off to the controller. DC voltage is removed from all solenoid and stepper motor control lines and AC voltage is removed from the AC strip plugged into the controller Hoffman enclosure when this switch is in the OFF position. The two stepper motors and the Hydraulic Cylinders Interface box AC inputs should be plugged into the AC strip which is plugged into the Hoffman box 120V/15A outlet. This will remove AC power to the stepper motors and the Hydraulic Cylinders Interface box when the Hoffman enclosure switch is in the OFF position.

Appendix C
Encapsulating System Program Sequence Table

Encapsulating System Program Sequence Table

		INPUTS									T	OUTPUTS																
step		rd sw	sp bits 3,2,1,0	tm bits 1,0	pf r1	pf r2	tm bx	bs hc 1-2	ts hc 1-2	str rd sw	I M E R S	hot wr	str cyl	str grp	psh pin	pf air	sp bits 3,2,1,0	tm bits 3,2,1,0	grp cyl	sp vac	sp air	pr die vac	pr die air	pr hc up	pr hc dn	pr air dn	tm air on	tm cyl dn
description		#	i3/ 0	i1/ 3,2,1,0	i1/ 5,4	i3/ 1	i3/ 2	i3/ 3	i3/ 4-5	i3/ 6-7	i3/ 11-12	o7/ 9	o7/ 10	o7/ 11	o7/ 12	o7/ 13	o5/ 3,2,1,0	o5/ 7,6,5,4	o5/ 8	o5/ 9	o5/ 10	o5/ 11	o5/ 12	o5/ 13	o5/ 14	o5/ 15	o7/ 7	o7/ 8
SAFE STARTUP																												
	80																											
safe startup	81											U	U	U	U	U	LLLL	LLLL	U	U	U	U	U	U	U	U	U	U
	82																											
tumbler sensor on	83																											
	84																											
open tumbler	85										T5													L				L
	86																											
home slider	87								1	1	E5 T6						xUxU							U				
timer	88										E6						xLxL											
close tumbler	89		1010																									U
	90																											
home tumbler	91										T6							xxxU										
timer	92										E6							xxxL										
safe startup done	93			10																								
	94																											
LOAD PARAFILM																												
check tumbler & open	95						1																					L
move to parafilm load	96						0		1	1							xUUx											
NORMAL CYCLE FIRST STEP																												
check if cycles done	1																											
FINAL CYCLE CLEANUP																												
This sequence run only if cycles finished or if smooth stop has been entered as determined at step 1. Otherwise program skips and resumes with step 2. Step 108 turns off run or step modes. Step 110 calls the clean-out routine.	101		0110 or 1010						1	1		U	U	U	U	U	LLLU	LLLL	L	U	U	U	U	U	U	U	U	L
	102		1110						1	1	T6		L	L			xLUL											
	103										E6						xxLx											
	104										T10																	U
	105										E10 T12							xxUL										
	106										E12							xxLx										
	107			01 or 10							T2				L												L	
	108										E2 T10				U												U	

step	INPUTS										T	OUTPUTS																
	rd sw	sp bits 3,2,1,0	tm bits 1,0	pf r1	pf r2	tm bx	bs hc 1-2	ts hc 1-2	str rd sw		hot wr	str cyl	str grp	psh pin	pf air	sp bits 3,2,1,0	tm bits 3,2,1,0	grp cyl	sp vac	sp air	pr die vac	pr die air	pr hc up	pr hc dn	pr air dn	tm air on	tm cyl dn	
description	#	13/0	11/ 3,2,1,0	13/ 1	13/ 2	13/ 3	13/ 4-5	13/ 6-7	11-12		07/ 9	07/ 10	07/ 11	07/ 12	07/ 13	05/ 3,2,1,0	05/ 7,6,5,4	05/ 8	05/ 9	05/ 10	05/ 11	05/ 12	05/ 13	05/ 14	05/ 15	07/ 17	07/ 18	
FINAL CYCLE CLEANUP CONTINUED																												
	109																											
	110																											
NORMAL CYCLE CONTINUED																												
inc & display cycle	2																											
clean-out count	3																											
call clean-out	4																											
move slider to drop sheet & get new	5		0110 or 1010					1	1		U	U	U	U	U	LLLL	LLLL	L	U	U	U	U	U	U	U	U		
drop sheet & close grippers	6																											
	9		1110								L	L						U			U						U	
Sequence run currently with rest of program (10, 11, 12, etc.)	201																											
Initiated by step 9.	202																											
	203																											
	204																											
	10																											
move slider under press	11							1							L	xxUL						U						
	12															xxLx												
hyd cylinders down	13										L												L					
press pockets	17														U								U	L				
slider vacuum on	18																		L									
raise pins	19																											
	20																											
raise hyd cylinders	21	1																										
open tumbler box	23										U	U										L					L	
slider to tumbler	25																											
drop larvae	27		1100											L		xxUU							U				L	
move slider to zero	28												U			ULLU											U	
move slider to get top parafilm sheet	31		0110													LxLx		L										
	32																											

		INPUTS									T	OUTPUTS																
step		rd sw	sp bits 3,2,1,0	tm bits 1,0	pf r1	pf r2	tm bx	bs hc 1-2	ts hc 1-2	str rd sw	I M E R S	hot wr	str cyl	str grp	psh pin	pf air	sp bits 3,2,1,0	tm bits 3,2,1,0	grp cyl	sp vac	sp air	pr die vac	pr die air	pr hc up	pr hc dn	pr air dn	tm air on	tm cyl dn
description	#	i3/ 0	i1/ 3,2,1,0	i1/ 5,4	i3/ 1	i3/ 2	i3/ 3	i3/ 4-5	i3/ 6-7	i3/ 11-12		o7/ 9	o7/ 10	o7/ 11	o7/ 12	o7/ 13	o5/ 3,2,1,0	o5/ 7,6,5,4	o5/ 8	o5/ 9	o5/ 10	o5/ 11	o5/ 12	o5/ 13	o5/ 14	o5/ 15	o7/ 7	o7/ 8
close grippers	33		1110								T0								U									
	34																											
move slider under press	35								1	1	E0 T6					L	xxUL											
timer	36										E6 T8	L					xxLx											
hyd cyl down	37		1101								T8	L				U										L		
	38																											
hold hyd cyl down	41							1			T3															U		
	42																											
vac above sheet	43								0		E3 T4							xxxL				L						
	44										E4 T4																	
raise hyd cyl	45								0		E4											U			L			
slider to tumbler to strip sheet	46						0		1	1							xxUU											
lower strip mech	47		1100								T7		L	L														
move slider to strip sheet	48								1		E7						xUUU											
close strip grippers	49		1000								T0			U														
	50								1		E0						ULLL											
	51																											
raise strip mech	52		0111										U															
slider to zero	53								1	1							ULLU											
	54																											

NOTES

- 1) Under INPUTS, "0" indicates zero volts at that Allen-Bradley input. "1" indicates 24 volts at that input. A blank indicates a "don't care" condition. Under i3/4-5, i3/6-7, and i3/11-12, a "1" or "0" applies to both corresponding input lines.
- 2) The "TIMERS" column indicates timer set or elapsed conditions. "Tn" indicates that timer "n" is set. "En" indicates that the previously set timer "n" must have elapsed. When T8 elapses, the hot wire knife output, o7/9, is automatically unlatched, independent of the program steps listed. Timer information is provided in the table below. Unless times have been changed using the encapsulating system console thumbwheel switches, the default times listed apply.

Timer	Description	Default Time (sec)
T0	Time to close sheet gripper and drop	0.5
T1	Time to press pockets	1.75
T2	Time to drop larvae	5.00
T3	Time to press sheets together	0.8
T4	Time to evacuate dies	1
T5	3 second wait	3
T6	0.30 second wait	0.3
T7	Lower strip mechanism time	0.2
T8	Hot wire knife on time	6.00
T10	2 second wait	2
T12	0.30 second wait	0.3

- 3) Under OUTPUTS, "L" indicates that the Allen-Bradley output is latched high, 24 volts. "U" indicates that the output is unlatched, voltage removed. An output latched high remains so until it is unlatched, and vice versa. A blank indicates that the output is left unchanged from its previous condition. Under o5/3,2,1,0 and o5/7,6,5,4, "x" is a place holder only, the corresponding bit being unchanged.
- 4) All input and timer elapsed conditions must be as indicated, "0", "1", and "En", before outputs and timers are set as indicated, "L", "U", and "Tn".
- 5) In the "run" and "step" modes the "SAFE STARTUP" steps (80 through 94) are performed first, then the "NORMAL CYCLE" steps (1 through 54) are repeated for the desired number of cycles, and finally, after the last cycle, the "FINAL CYCLE CLEANUP" steps (101 through 108) are performed. Steps 201 through 204 start after step 9 and run concurrently with steps 10, 11, 12 etc..
- 6) In the "step" mode, bold step numbers are performed when the ENTER button is pressed and *italicized* step numbers are performed when the ENTER button is released. Step numbers neither bold nor italicized are not conditioned on the ENTER button state.
- 7) In the "load Parafilm" mode the "SAFE STARTUP" steps (80 through 94) are performed and then the "LOAD PARAFILM" steps (95 and 96) are performed.
- 8) Steps are performed in strict sequential order as listed (not necessarily numerical order): A subsequent step cannot be performed until the immediately previous step has completed. That is, the previous step's required input and timer elapsed conditions must have been true (and its required outputs and timer then set). Also, the previous step must have been the last step performed before the subsequent step can be performed. The exception is that sequential steps 201 to 204 run concurrently with the rest of the program after step 9.

9) Out and in two times. This clean-out routine is called at step 4 once every "n" cycles as set in the step 3 counter. The clean-out routine is also called at the end of the Final Cycle Cleanup sequence at step 110.

10) INPUTS/OUTPUTS key:

ABBREVIATION	ALLEN-BRADLEY SLOT/BIT	DESCRIPTION
INPUTS		
rd sw	i3/0	reed switch on press air cylinders
sp bits	i1/3,2,1,0	slider plate motor drive output
tm bits	i1/5,4	tumbler motor drive output (4 bits, i1/7 & i1/6 always "1", not checked)
pf r1	i3/1	Omron sensor Parafilm [®] roll 1
pf r2	i3/2	Omron sensor Parafilm [®] roll 2
tm bx	i3/3	Omron sensor tumbler box
bs hc 1-2	i3/4,5	bottom of stroke pressure sensor hydraulic cylinder 1 & 2
ts hc 1-2	i3/6,7	Omron top of stroke sensor hydraulic cylinder 1 & 2
str rd sw	i3/11-12	stripper reed switch cylinders 1 & 2
OUTPUTS		
hot wr	o7/9	hot wire knife
str cyl	o7/10	stripper cylinder
str grp	o7/11	stripper gripper
psh pin	o7/12	push pins
pf air	o7/13	Parafilm [®] roll air
sp bits	o5/3,2,1,0	slider plate motor drive
tm bits	o5/7,6,5,4	tumbler motor drive (o5/7 & o5/6 always "L")
grp cyl	o5/8	gripper cylinders
sp vac	o5/9	slider plate vacuum
sp air	o5/10	slider plate air
pr die vac	o5/11	press die vacuum
pr die air	o5/12	press die air
pr hc up	o5/13	press hydraulic cylinders up
pr hc dn	o5/14	press hydraulic cylinders down
pr air dn	o5/15	press air cylinders down
tm air on	o7/7	tumbler air on/(off vacuum)
tm cyl dn	o7/8	tumbler cylinders on (down)