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Assembly cell design for the canister control valve

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ASSEMBLY CELL DESIGN FOR THE CANISTER CONTROL VALVE

by

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Abstract

This thesis involved the design and testing of a robotic assembly cell for a canister control valve. The valve regulates the air flow to a carburetor of an automobile and is presently hand assembled at Rochester Products Division of General Motors. It consists of a body, a spring, a diaphragm and a cap. Each part required special handling by the robot.

A simulated canister control valve assembly cell has been built in a laboratory using an Adept One robot. This report covers the design process of the cell along with the test of the cell. The report also includes pertinent background information including available feeding devices and parts pickup material.

Acknowledgments

I would like to express my sincere thanks to the following people who made this work possible.

To Greg Weilnau, Dale Gnage and Wayne Walter for their guidance and suggestions.

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Most of all to my mother, Mary B. Gates, who always supported me through the good and bad moments of my education.

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INTRODUCTION

The objective of this thesis is to investigate assembly techniques using parts-feeding devices, robotics, and end-effector design for assembling a canister control valve at the Rochester Products Division of General Motors in Rochester, New York. The present method of assembling a canister control valve is by hand. Four parts bins are located around a seated operator. A parts nest for the valve is in front of the operator. The operator places the body, diaphragm and spring into the weld nest. A cap is placed in the ultrasonic weld head which is directly above the parts nest. The operator then presses a button and the ultrasonic weld head comes down and welds the cap and body together with the spring and diaphragm inside. This process works well and it is cost effective for infrequent operation. Rochester Products Division, however, has received orders that will keep an assembly cell in operation for over five years. Instead of using an operator to assemble the canister control valve, a robotic assembly cell will be researched to determine feasibility and cost effectiveness. This report will cover the design techniques used for the assembly cell along with the testing procedures.

Chapter I describes the canister control valve. Chapter II, Feeding Devices, reviews and analyzes bowl feeders, matrix tray feeders, and belt feeders with vision. In

Chapter III, the best feeding method is selected for each part along with the cell layout and design. After the cell layout is complete, a robot can be selected for the assembly process. This is covered in Chapter IV. The report then covers the many pickup techniques and compliance devices in Chapter V. Methods of pick up specific to each part are reviewed in Chapter VI. The design techniques of the actual end-effector are discussed in Chapters VII and VIII.

Chapter IX covers end-effector controls, simulated parts-presenting devices, and simulated weld stations. The simulated assembly cell and end-effector was constructed according to the design techniques used in this report. The cell was tested for dependability and design errors. The test objectives, procedure, results and design recommendations are included in Chapter X. In the summary, recommendations are made on the feasibility of the robotic assembly cell project.

The design of the automated assembly cell for the canister control valve will be considered if the order for the canister control valves is increased at Rochester Products.

CHAPTER I

Description of the Canister Control Valve

A canister control valve consists of four parts: body, cap, diaphragm and spring. The valve can easily be held in one hand and weighs about .75 ounces. The body and cap are made of a hard plastic. The body has two air tubes located at the base. The cap also has one air tube which is called the stem (see Fig. 1a on the next page). The diaphragm is a rubber lined part which bends under its own weight. The spring is about 1.5 inches long and has a diameter of .375 inches. The cap is ultrasonicly welded to the body. Enclosed between the cap and body are the spring and diaphragm. The diaphragm rests on the inside of the body with the spring pressing against it (see Fig. 1b).

One of the objectives of this report is to select the fastest and most accurate method for assembling the four parts and inserting them in the ultrasonic weld nest. The canister control valve is connected to the carburetor of an engine and a canister by an air hose. When the conditions of a running engine are right the canister control valve opens and allows fumes from the canister to enter the carburetor.

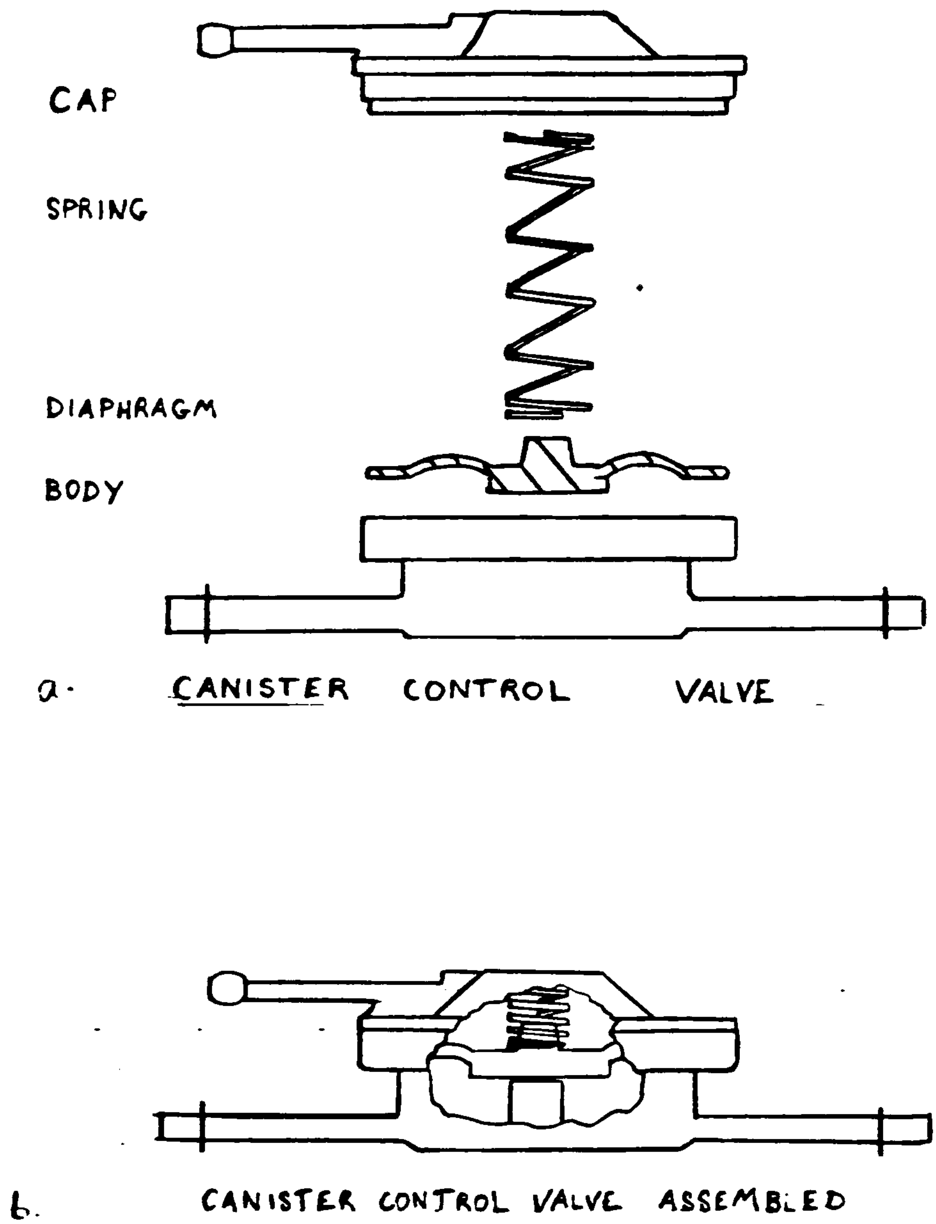


Figure 1. Canister Control Valve.

CHAPTER II

Feeding Devices

The design of the assembly cell must use existing parts presenting devices. The parts feeding devices for this project were selected based on their dependability and performance.

The parts can be presented on a matrix tray, on a conveyor located by vision, by bowl feeding, or by hand. Bowl feeding is the simplest and least expensive method for feeding parts. In the procedure for bowl feeding, an operator empties a box of parts into a bin over the vibrating bowl feeder. The vibration of the bowl causes the parts to travel around the inside of the bowl. Some of the parts eventually become properly oriented and stop at the end of a ramp after travelling around the inside of the bowl several times. The remaining parts are pushed back into the bowl by an obstruction that only allows properly oriented parts to pass (see Fig. 2 on the next page). Bowl feeders must be custom made and tested for each part, resulting in high unit costs of from $5,000 to $10,000 each.[1] Bowl feeders are inflexible. Should the part being fed change, a new bowl feeder would be required.

Some parts cannot be bowl fed due to the parts being too flexible. In other cases, parts tend to stick together. Matrix trays solve these problems. A matrix tray has a series of holes or slots in the shape of the part. These holes or slots are on a Cartesian plane, equidistant from each other (see Fig. 3). The holes or slots insure that

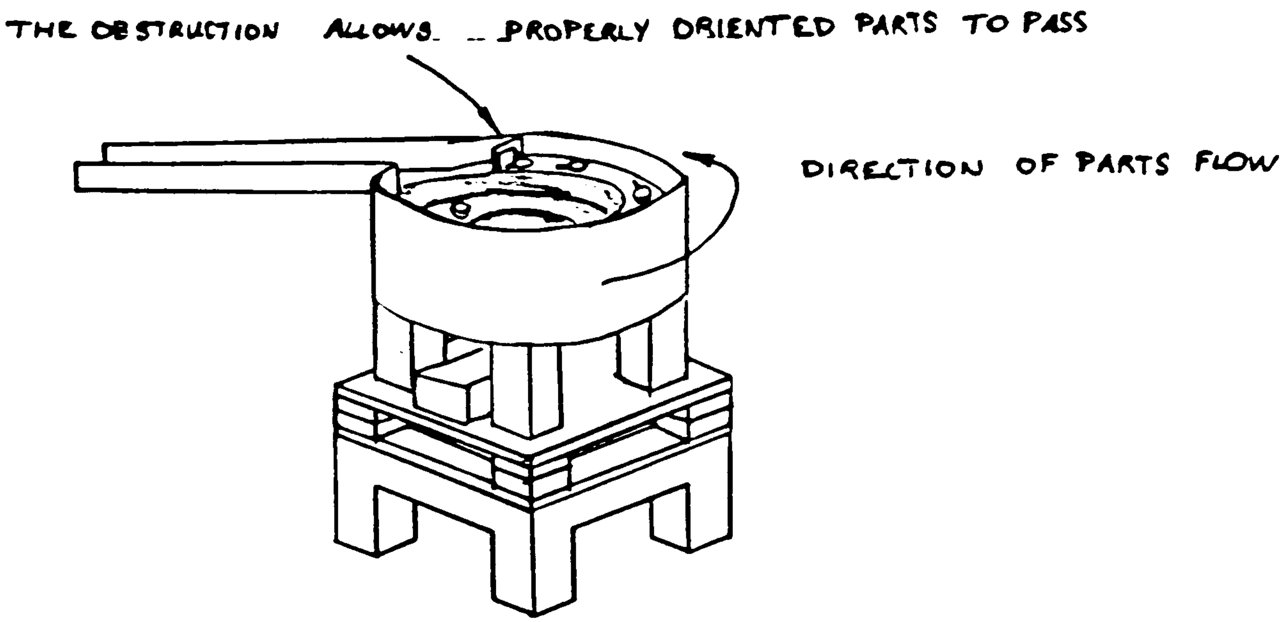


Figure 2. Vibrating Bowl Feeder.

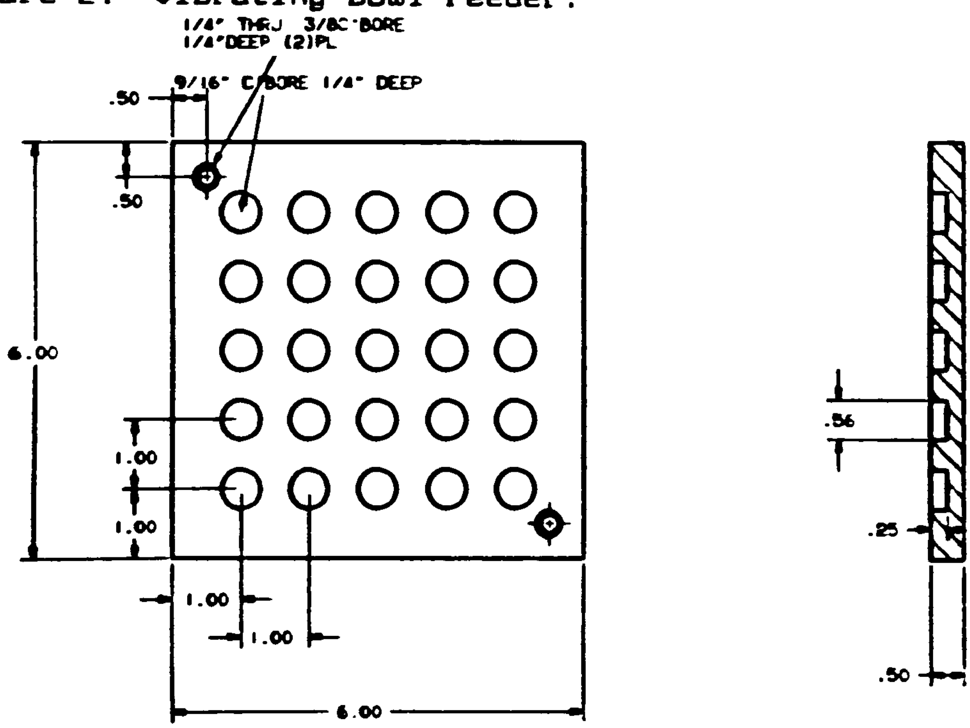


Figure 3. Matrix Tray.

the parts are properly oriented and that the parts do not stick together. Using matrix trays requires a tray feeding device which replaces empty trays with ones full of parts. The tray feeder and trays can cost more than $10,000.[2] Again, this high cost results from the system being custom made for the part being fed. Also the cost per part can possibly be greater since each part must be placed into the matrix trays.

Feeding parts on a conveyor with vision has not been developed enough to be implemented. Machine vision can locate parts on a horizontal plane, but it is difficult to locate the parts in a vertical plane. For example, if two parts overlap, a vision package would not recognize that one part was higher than the other.[3]

Feeding parts by hand is initially the least expensive method. However, over a long period of time, it can easily be shown that parts-feeding by hand would be the most costly and troublesome.

CHAPTER III

Cell Layout and Design

The canister control valve consists of four parts: cap, body, spring, and diaphragm. The parts are assembled and placed in a nest where they are ultrasonicly welded together. The ultrasonic welder has two nests (see Fig. 4). The lower nest holds the body diaphragm and spring. The upper nest is for the cap.

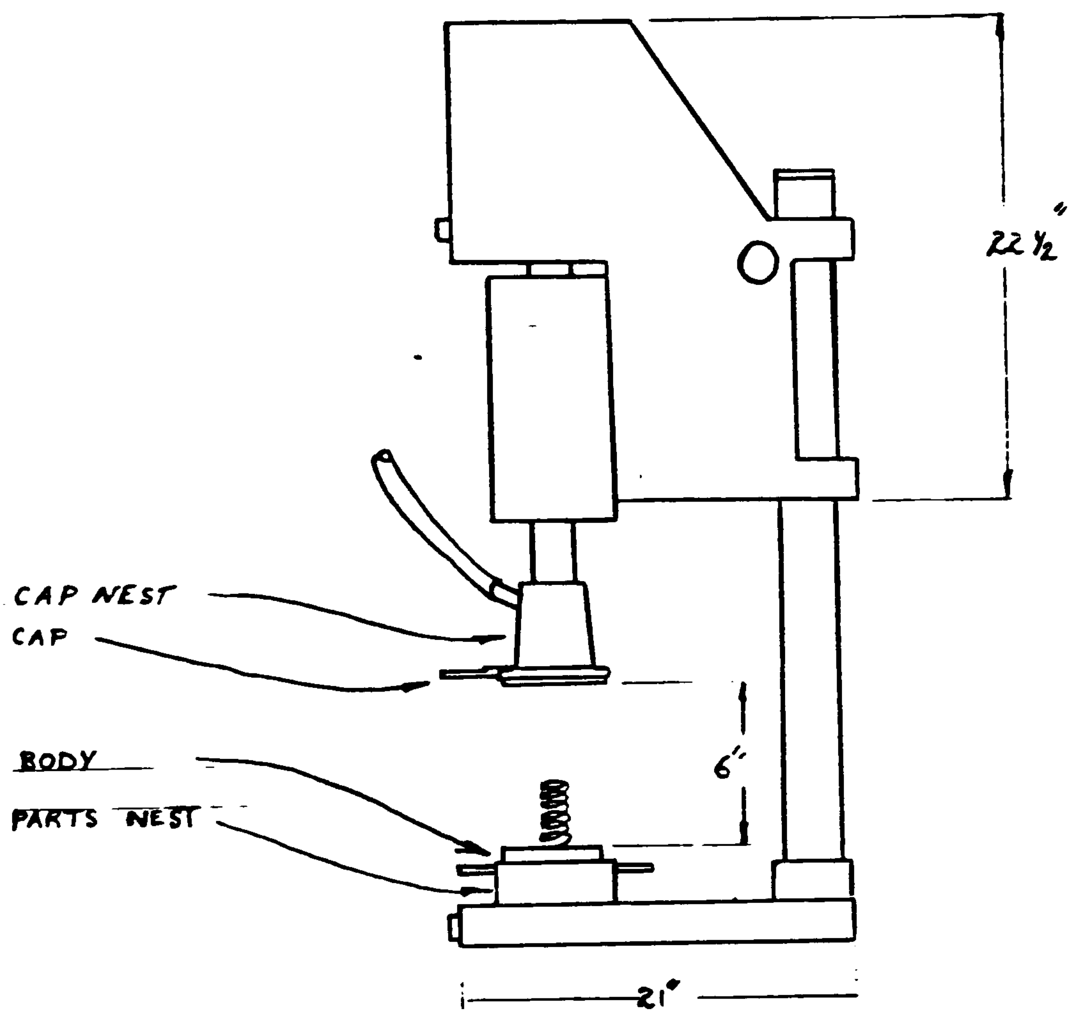


Figure 4. Ultrasonic Welder.

The objective of the assembly layout is to select the best feeding device for each part and to arrange the feeding devices in the order that minimizes cycle time. The constraints of the assembly cell are the work envelope and speed of the robot used. In addition, the cell should be designed so that reloading parts is easy. For the fastest cycle time the cell should be arranged in the order that the parts are assembled. The assembly process is as follows: pick up the spring, place the spring in the diaphragm, place the spring and diaphragm into the body, pick up the body and cap, place the body into the weld nest and the cap into the weld head (see Fig. 5 on next page).

Bowl feeders were selected for the cap and body since the parts do not stick together and are not flimsy. The cap and body could be presented in matrix trays, but the bowl feeders are easier to use and less expensive.

The spring and diaphragm cannot be bowl fed. The springs would eventually get tangled, requiring the attention of an operator to remove the tangled portions. The diaphragms bend by their own weight and stick to each other. Both the spring and diaphragm should be matrix packed and fed.

The matrix trays, ramps, and sonic welder must be arranged in the robot work envelope to minimize cycle time. This is done by arranging the presenting devices in the order that the parts should be assembled. Starting from

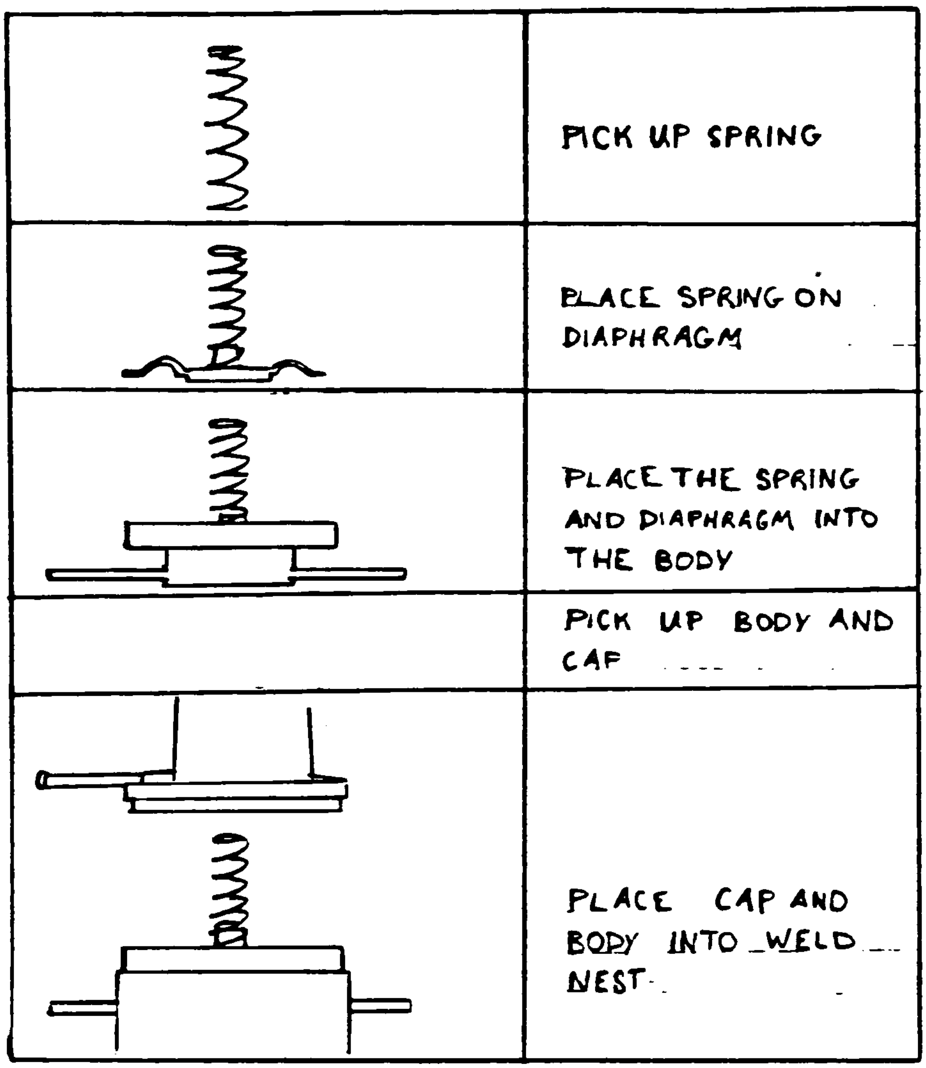


Figure 5. Assembly Process.

one side and going to the other side, the presenting devices were placed in the following order: spring tray, diaphragm tray, body bowl feeder, cap bowl feeder, and sonic weld station (see Fig. 6).

This order of feeders will allow the parts to be assembled in the order presented in figure 5. Also needed to accommodate this is an end-effector that can pick up the spring diaphragm and body in one set of jaws, and the cap in a different set of jaws.

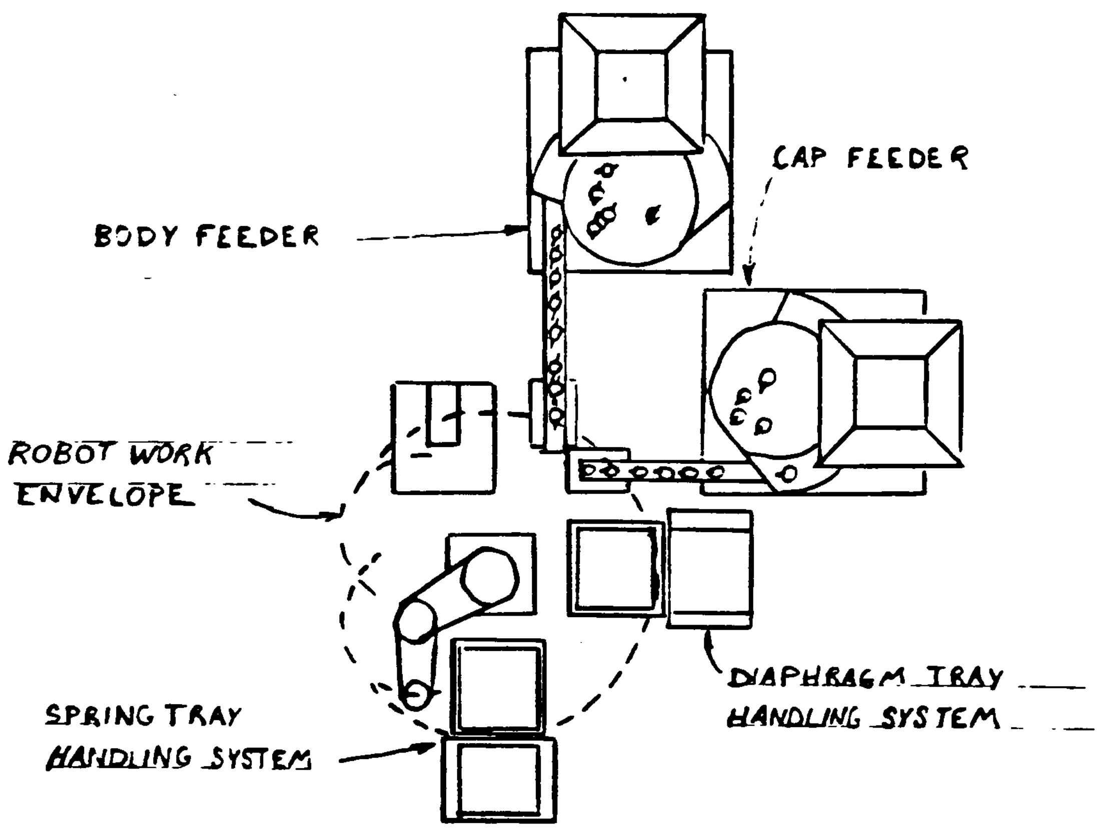


Figure 6. Canister Control Valve Assembly Cell.

CHAPTER IV

Robot Selection

The method of robot selection was based on a five step process. The first step was to gather comprehensive information about robots from the General Motors Technical Center and Robonet. Robonet is a resource which consists of present users of robots in manufacturing. From these sources, five robots were recommended.

The second step was to list the parameters that would effect the assembly cell performance. These are listed in Table 1.

Table 1. Considerations for Application

Speed
Repeatability
Size (Work Envelope)
Payload Capacity
Programmability/Usability
Interface Capability

In step three, a primary list of five robots was made based on the criterion listed in the considerations for application. The names of these robots are listed in Table 2.

Table 2. Preliminary Robot List

Accusembler
Adept One
GMF A-200
Intelledex 405
Unimate Series 100

The fourth step involved a meeting between company representatives and this investigator. The criteria for robot selection for the assembly cell was discussed, along with a review of cost and repair procedures. It was found that the GMF A-200 Robot was not designed for high speed assembly[4].

The Accusembler is produced by a new company in the United States. It has not developed a reputation for the dependability of their robot and repair service.[5] The Unimate series[6] was found to be slower than the Adept-One[7] and Intelledex 405 robots.[8] After meeting with the company representatives, it was found that the robots best suited for this application are the Intelledex 405 and the Adept-One.

The fifth step involved reevaluating both robots using the information and literature gathered from the robot manufacturers and users.

The Adept-One robot was finally selected for the canister control valve assembly cell. It was found that the Adept-One's maximum velocity was six times the maximum velocity of the Intelledex 405. The Adept-One Robot has direct drive for all axis of movement unlike the other robots that are either gear or chain driven. The direct drive reduces hysteresis error which occurs with chain or gear driven systems. Also the Adept controller is simple to operate with the Val II language. The Adept controller is easy to repair. If something does go wrong with the controller, the boards can be checked by rearranging them and testing the robot. This process will locate the faulty chip board. The board can then be easily replaced to allow the robot to function properly.

CHAPTER V

Literature Survey of End-Effector Concepts and Compliance Devices

A. End-Effector Concepts

Each part must be analyzed to find the best method of picking it up. Possible methods of picking up parts are discussed in this chapter.

A1. Air or Hydraulic Gripper

An air or hydraulic gripper is operated by a double acting piston connected to a central pivot by a connecting rod. Each jaw has a lever with a pivot pin passing through the central pivot (see Fig. 7). The lever is forced to rotate around a pivot pin when air pressure is applied. A

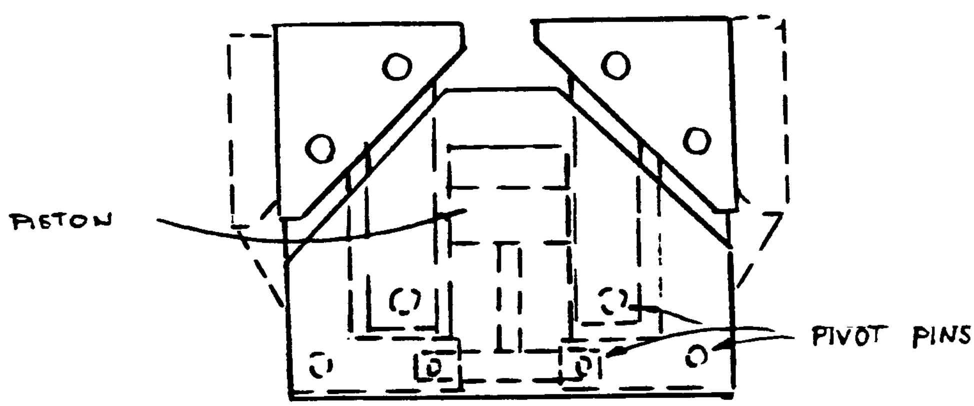


Figure 7. Air or Hydraulic Gripper.

second lever is required to keep the gripper jaws moving parallel to each other. The second lever is attached to the gripper jaw and body of the gripper. Fingers that attach to the jaws are built to fit the part to be picked up.[9] When using the grippers some considerations must be made:[10]

1) The largest surface of the part should be grasped if there is a choice. This assures better control in positioning the part.

2) Fingers of the gripper should have a high friction surface and both fingers should at least contact the part at three points. If the fingers of the gripper contact the part at two points the part will have a higher possibility of rotating around the points.

3) The maximum gripping force a part can handle without damaging the part should be determined.

4) The gripper fingers must be designed to avoid hitting parts or devices while grasping or dropping parts.

5) The gripping force should be strong enough to hold a part during the end-effector acceleration. The amount of force that is required to hold a part depends on the maximum acceleration of the end-effector, and the friction between the gripper fingers and part. From the book, Robotics In Practice by Joseph F. Engelberger, some typical relationships are of interest:

A: A part transferred by a robot in the horizontal plane will exert a force on the fingers of twice the weight of the part.

B: If the part is lifted vertically it will exert a force on the fingers three times its weight: 1mg due to gravity and 2mg due to the acceleration of the part upwards.

A2. Compression Expansion Device

The compression expansion device operates by a single acting piston. A rod is connected to the piston and passes through the piston housing (see Fig.8). The opposite end of the rod has a flat plate either welded or bolted to it. A rubber body is between the flat plate and piston housing

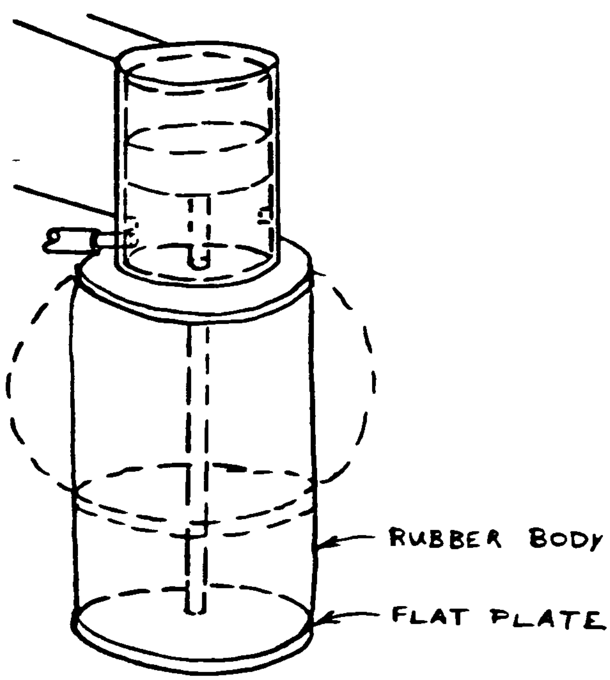


Figure 8. Compression Expansion Device.

with the rod running through it. The rubber body is in the form of the inside of the part to be picked up. Pressurized air moves the piston upward which compresses the rubber material enabling the part to be picked up. When using the compression expansion device, some considerations must be made:[11]

1) A rubber material with a high Poisson's ratio should be selected. The rubber must be able to be cycled many times before cracking.

2) The force required to pick up the part depends on the weight of the part, friction between the part and rubber, and the acceleration of the robot.

3) Determine the maximum pressure that a part can handle without damage.

A3. Bellows

A bellows is an air activated expanding device. Air is forced into a hollow rubber body which is in the form of the part. The rubber expands and contacts the inside of the part enabling the part to be picked up (see Fig. 9 on the next page). The bellows can be modified to pick up parts by their outside surfaces by using more than one bellows or a bellows and a solid surface to press the part against[12] (see Fig.10).

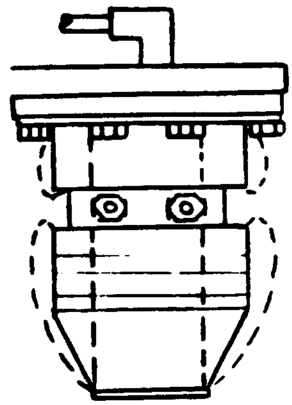


Figure 9. Bellows.

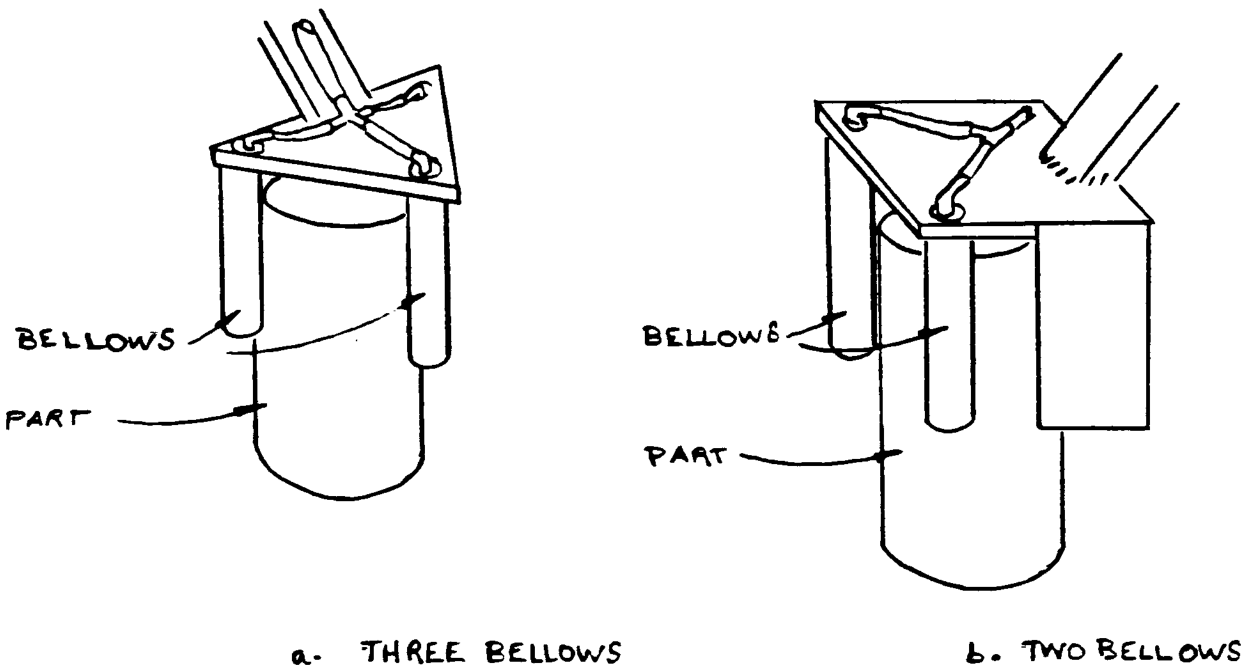


Figure 10. Different Applications of the Bellows.

When using a bellows, several considerations must be made:

1) Select a rubber material that can be cycled many times before cracking.

2) The pressure required to pick up the part depends on

the weight of the part, acceleration of the robot, friction between part and bellows, and the force required to expand the bellows.

<u>A4. Suction Pickups</u>

For hard solid parts with a large flat surface vacuum cups with suction can be used. Vacuum cups are made of an elastic material that forms a seal with the surface of the part in contact (See Fig 11). For rubber parts a hard

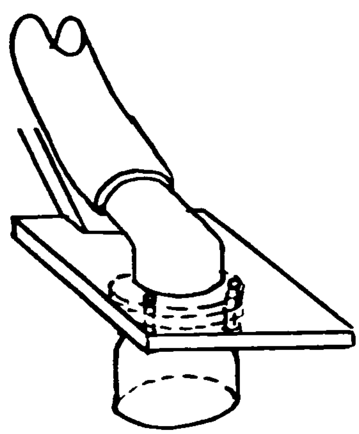


Figure 11. Vacuum Cup.

rubber vacuum tube can be used since the rubber of the part will form a seal with the vacuum tube. The material of the part to be picked up will determine the type of suction device to be used.[13] For example, a very porous material such as a brick would require many small vacuum cups to pick it up. A nonporous material like an an aluminum plate could be picked up with many small vacuum cups or a few large vacuum cups[14].

The holding force of a vacuum is the effective area times the pressure difference between the inside and outside pressure. Naturally, a strong vacuum is required to insure a high pressure difference. A part can only be picked up when a vacuum is formed on the part. The process of forming a vacuum on the part to be picked up takes a longer time than if the part was grasped by a different method. To allow time for this, the vacuum cup or cups should be mounted on a vertically guided spring. The spring will allow time for the cups to form a vacuum on the material during the downward motion of the robot arm[10]. The best material to use for a vacuum cup is polyurethane, due to its long life span compared to other rubber-like materials. When designing a suction pickup method, the weight, acceleration of the robot, and size of the part must be considered.

To create a vacuum, a pump or venturi can be used. Joseph F. Engelberger cites a list of advantages and disadvantages of "vacuum pumps versus venturis" in Chapter Three, "End-Effectors", of his book <u>Robotics in Practice</u>[10] (see Table 3).

Table 3. Advantages and disadvantages of vacuum devices.

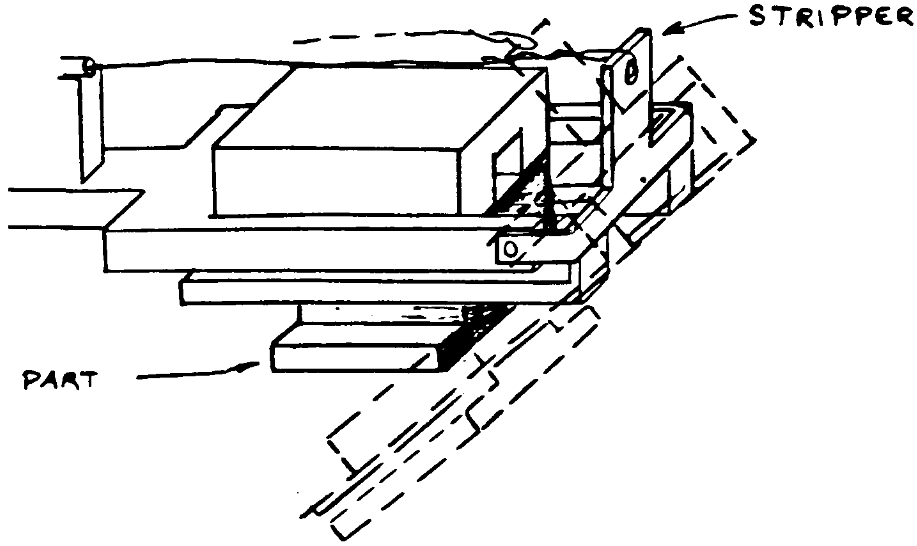
Vacuum pump advantages	Venturi advantages
-Able to create a high vacuum -Low cost of operation -Relatively silent	- Low initial cost - Does not normally need a blow-off valve on the vacuum tank
Vacuum pump disadvantages	**Venturi disadvantages**
-High initial cost -Requires a more complex system	- Very Noisy - High cost of operation

A5. Magnetic Pickup

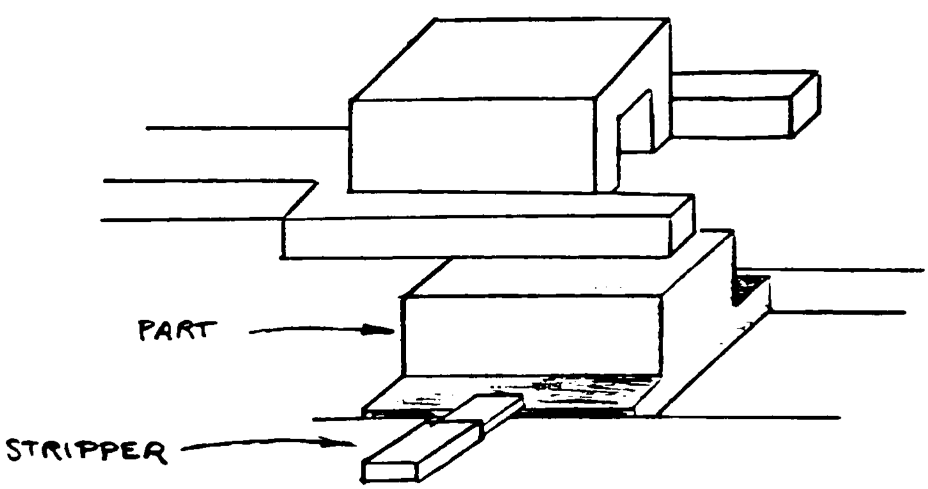
An effective method used to pick up ferrous material is using either a permanent magnet or an electromagnet. Either type of magnetic pickup can be used to handle many shapes with the same magnet. Direct current along with an activator is required to operate an electromagnet. The activator can either shut the electromagnet off or reverse the polarity which will force the part off. It is necessary to reverse the polarity when there is a possibility of the part getting stuck on the electromagnet.

Permanent magnets can be used in "hazardous environments that require explosion-proof electrical equipment."[10] A permanent magnet requires a stripper to remove the part from the magnet. A stripper is a mechanical device that removes the part from the face of the magnet. The stripper can be located either on the end-effector or at the location where the part is being placed. The stripper on the end-effector will push or pull the part off the magnet when the end-effector is in the position to drop off the part (see

Fig. 12a). The stripper at the drop off point holds the part down while the end-effector moves away. The part is held in position by a pin or blocking device in the shape of the part (see Fig. 12b). Magnets grasp flat surfaces better



a. STRIPPER ON MAGNET



b. STRIPPER ON PARTS TRAY OR NEST

Figure 12. Use of Parts Strippers.

since curved surfaces would wobble on the magnet unless the magnet were rounded to a shape similar to the surface of the part. The surface that contacts the magnet should be smooth and free of oil film and debris. Also the magnet must be in an environment that is free of metal chips. The best position of the magnet face is parallel with the horizontal plane.[10] If the magnet face is in the vertical plane the part being picked up will tend to slide pff the magnet. The moment of the center of gravity could also cause the part to break away from the magnet face (see Fig. 13). If the magnet force must be in the vertical plane, the force

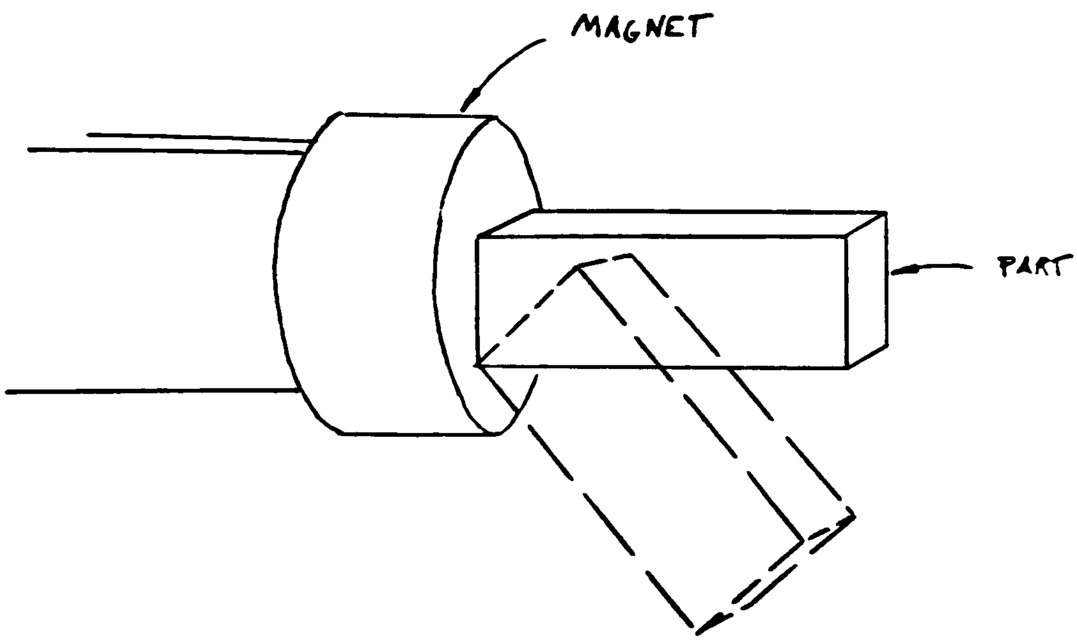


Figure 13. Part Breaking Away From the Face of the Magnet.

required would be four times that required if the magnet force were in the horizontal plane. The reason for this is that the part can slide off the face of the magnet and to stop this it has been found that four times the force is required.[13]

B. Compliance Devices

A compliance device allows part movement for the purpose of alignment between mating parts. There are three types of movement allowed with a compliance device. These are lateral, axial, and rotational movement.[13] Lateral compliance allows for part mating due to chamfers (see Fig. 14a). Rotational compliance allows one part to be inserted into another (see Fig.14b). Axial compliance prevents too much force from being applied to the parts (see Fig. 14c).

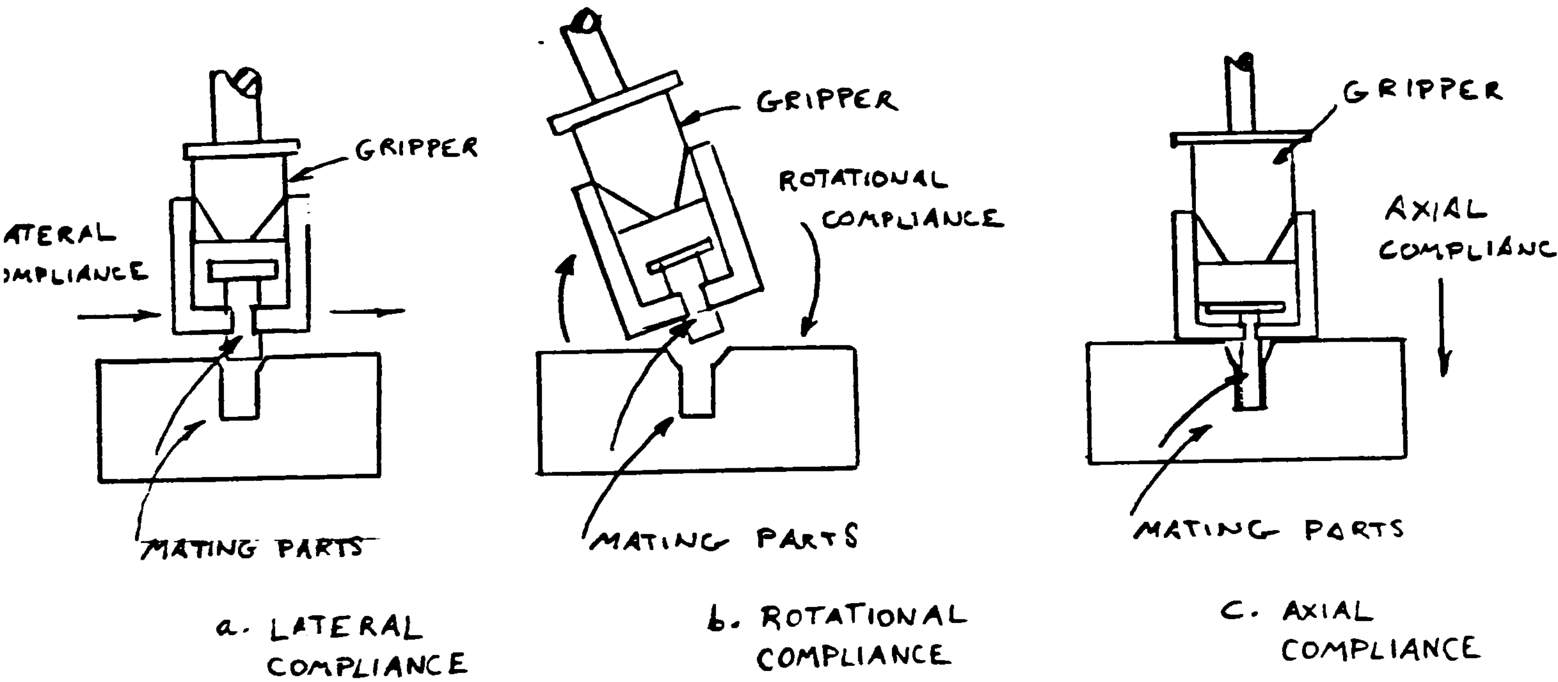


Figure 14. Three Types of Compliance.

A compliance device also protects the end-effector. If the end-effector hits an object blocking its path, the compliance device will absorb the energy due to impact. A over-travel switch could be located on the compliance device which would shut down the robot after impact. The obstruction could then be removed from the path of the end-effector. The end-effector would then be ready to be used again.

If a compliance device were not connected between the robot arm and end-effector, the robot would continue it's motion into an obstruction until either the reaction from the obstruction stopped the robot or the obstruction was moved out of the way. In either case, the end-effector would be damaged.

Three types of compliance devices are discussed in this paper. They are: 1) air operated, 2) spring absorbing, and 3) rubber absorbing compliance devices.

B1. The Air Operated Compliance Device

The air operated compliance device uses air pressure to absorb shock and to keep it together in normal operating conditions (see Fig. 15 on the next page). The end-effector has some freedom to move when inserting or mating parts, by allowing movement of the raised surfaces on the compliance device.[11] The amount of movement depends on the air pressure and the size of the raised surfaces. This type of compliance device also requires a pressure adjustment. This air compliance device absorbs vertical forces by the

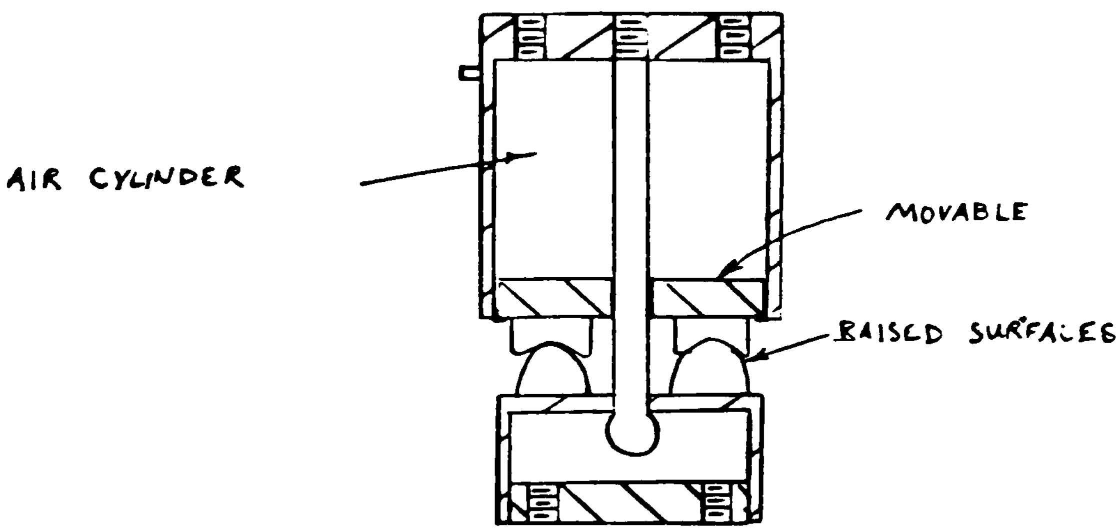


Figure 15. Air Operated Compliance Device.

location of the piston head (see Fig. 16 for examples of absorption of vertical forces).

B2. The Spring Absorbing Compliance Device

The spring absorbing compliance device uses springs to allow for part insertion mating and absorption of the energy of the end-effector hitting an object.[13] The amount of movement allowed depends on the distance (y) and the difference between the diameter of bolt A and the diameter of the hole it is passing through (Fig. 17). The compliance device absorbs vertical force by compressing the springs.

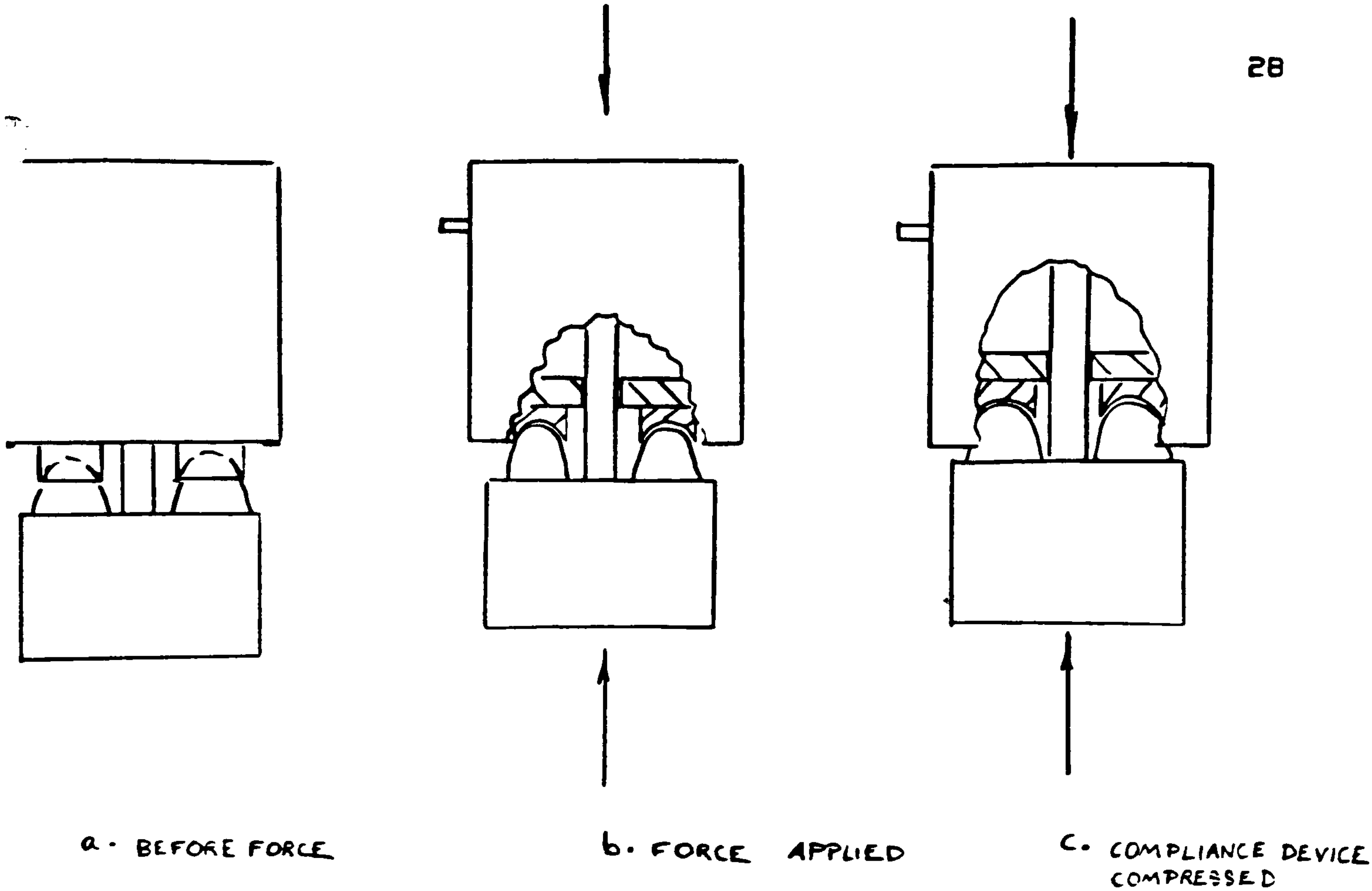


Figure 16. Air Operated Compliance Device Absorbing a Vertical Force.

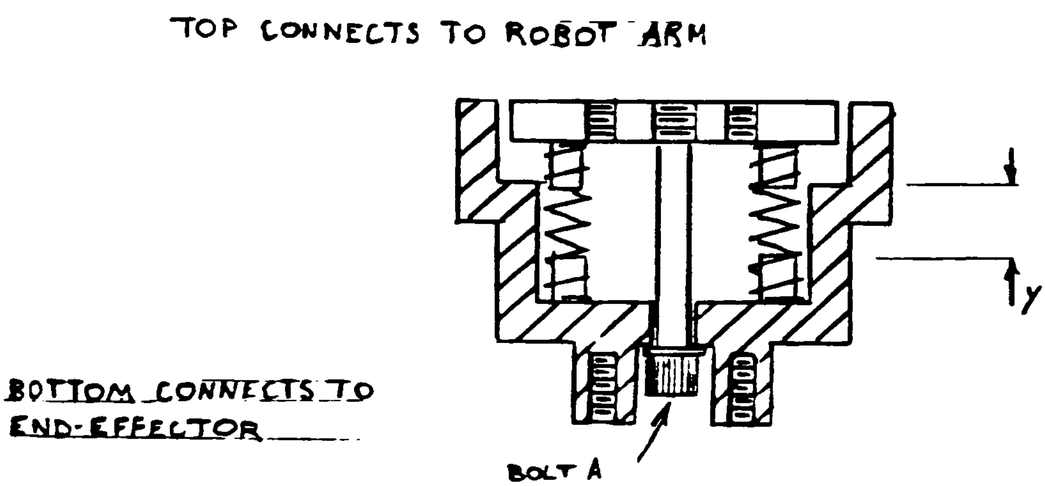


Figure 17. Spring Absorbing Compliance Device.

B3. The Rubber Absorbing Compliance Device

Part insertion and mating are done by the deflection of the rubber cylinder between the two plates (Fig. 18). A vinyl rubber is recommended to be used because of its stiffness and long life. This type of compliance device also

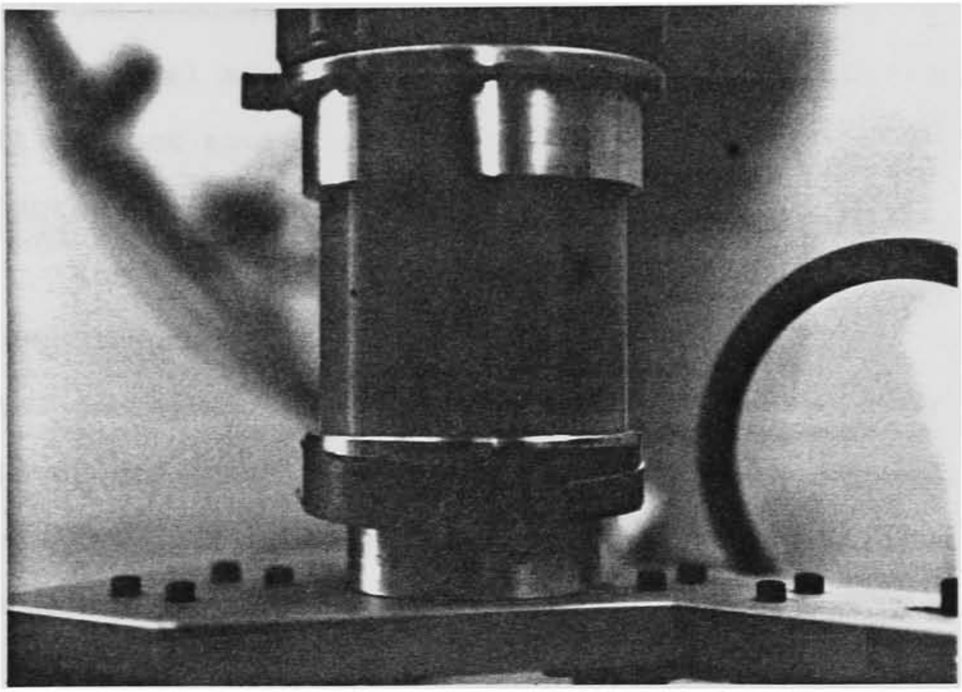


Figure 18. Rubber Absorbing Compliance Device.

absorbs vertical force by the compression of the rubber cylinder. The rubber absorbing compliance device has one unique advantage over the other two types. The spring and air compliance devices come apart if they receive too much torque. The springs pop off the dowel pins in the spring absorbing compliance device under excessive torque[1]. The raised surfaces pop out of the slots in the air pressure compliance device under excessive twisting action[1]. Rubber has the ability to absorb more rotation before it comes apart. This is a time-saver since spring and air compliance devices would require reassembly. Care must be taken when designing a rubber absorbing compliance device for a particular end-effector. The end-effector cannot be too heavy or cause unequal bending moments on the compliance device. Under unequal moments the rubber absorbing compliance device will deflect causing a change in the positioning of the end-effector when picking up parts.

The end-effector design for this project employs a rubber absorbing compliance device. Two factors influenced this decision. The design was simple and the rubber compliance device will not come apart under a large deflection. See compliance drawings in Appendix B for actual dimensioning.

CHAPTER VI

Pickup Methods Selected for each Part

This section describes the best methods for picking up each part. When possible more than one selection process was made. This allowed for greater freedom when the end-effector for the cell was designed. The selection of the pickup process was based on two criteria: simplicity and security in picking up a part.

A. Body

The body can be picked up by all the methods except the magnetic and suction pickup methods. Picking up the body by a gripper is the easiest method since a bellows and compression expansion device would have to be complex enough to pick up the body securely (see Fig. 19). Using a gripper

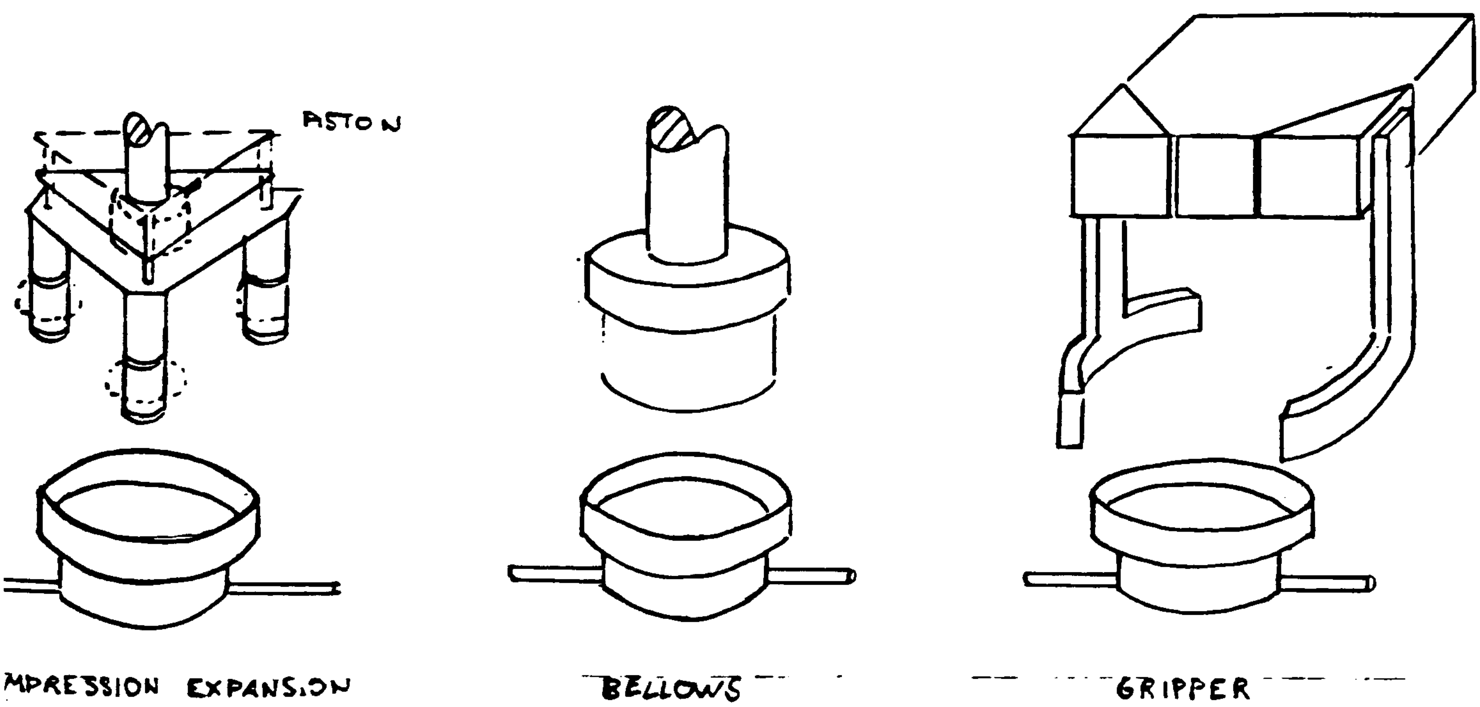
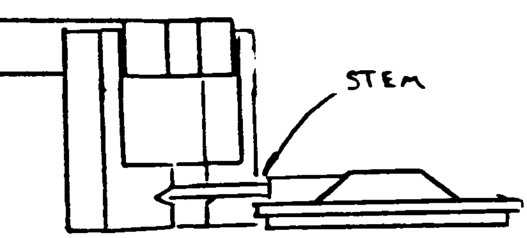


Figure 19. Body Pickup Methods.

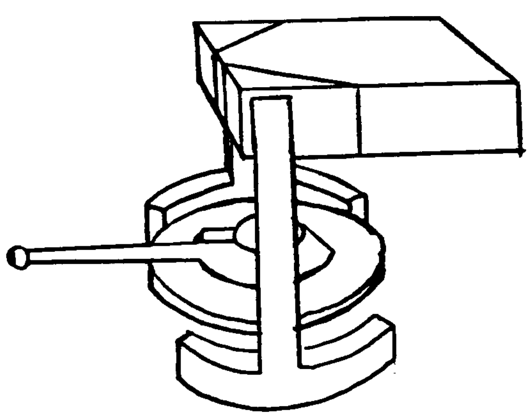
would hold the body more securely than a bellows since there is not much available surface area for the bellows to contact with the body. This is true for the compression expansion device.

B. Cap

The cap can be picked up by its stem or its sides. The compression expansion and bellows pickup method can be used, but they will again be more complex than using a gripper. Gripper fingers can either be designed to pick up the cap by the stem or the sides (see Fig. 20).



a. GRIPPER FROM STEM



b. GRIPPER FROM SIDES

Figure 20. Cap Pickup.

C. Diaphragm

Since the diaphragm is flat in some spots and made of rubber-like material, it can be picked up using suction (see Fig. 21). The diaphragm can also be picked up by using a pneumatic gripper. This is possible since the raised surface is made of hard rubber (see Fig. 21). Both methods are capable of securely picking up the diaphragm. Also both methods prevent the diaphragm from moving when being held. The choice between suction or gripper pickup will be made when designing the end-effector for the assembly cell.

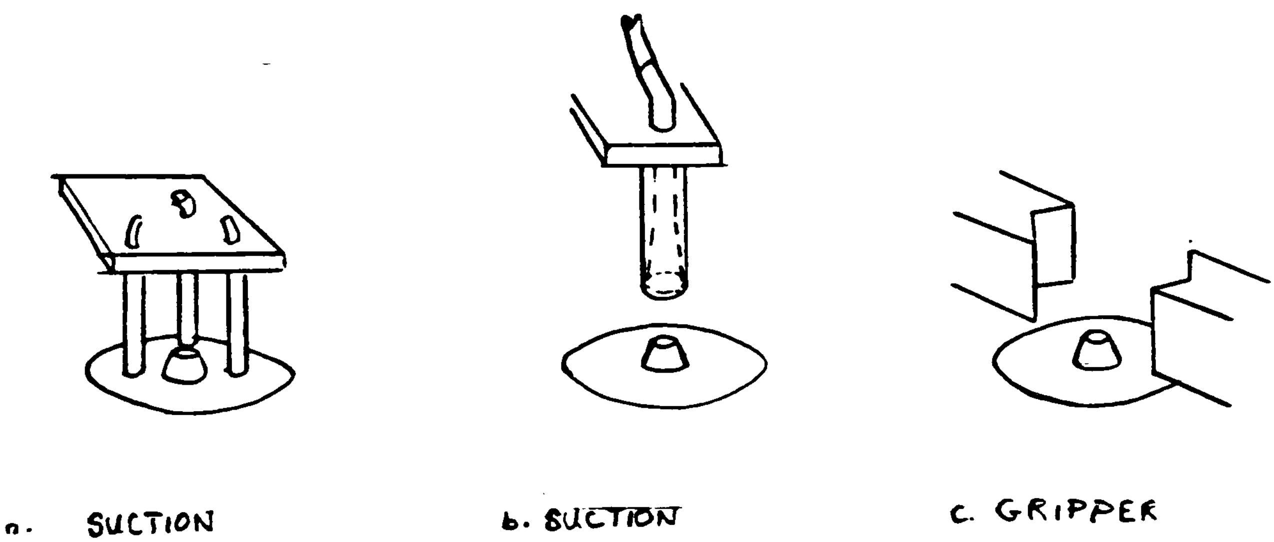


Figure 21. Methods for Pickup Up the Diaphragm.

D. Spring

The spring can be picked up by all the methods except by suction, using many configurations for each method (see Fig. 22). The method with the magnetic pick up is the most complex and most expensive. The other methods are all secure methods of picking up the spring and they do not allow the spring to move once picked up. The choice for the pickup method will be made when designing the end-effector for the assembly cell.

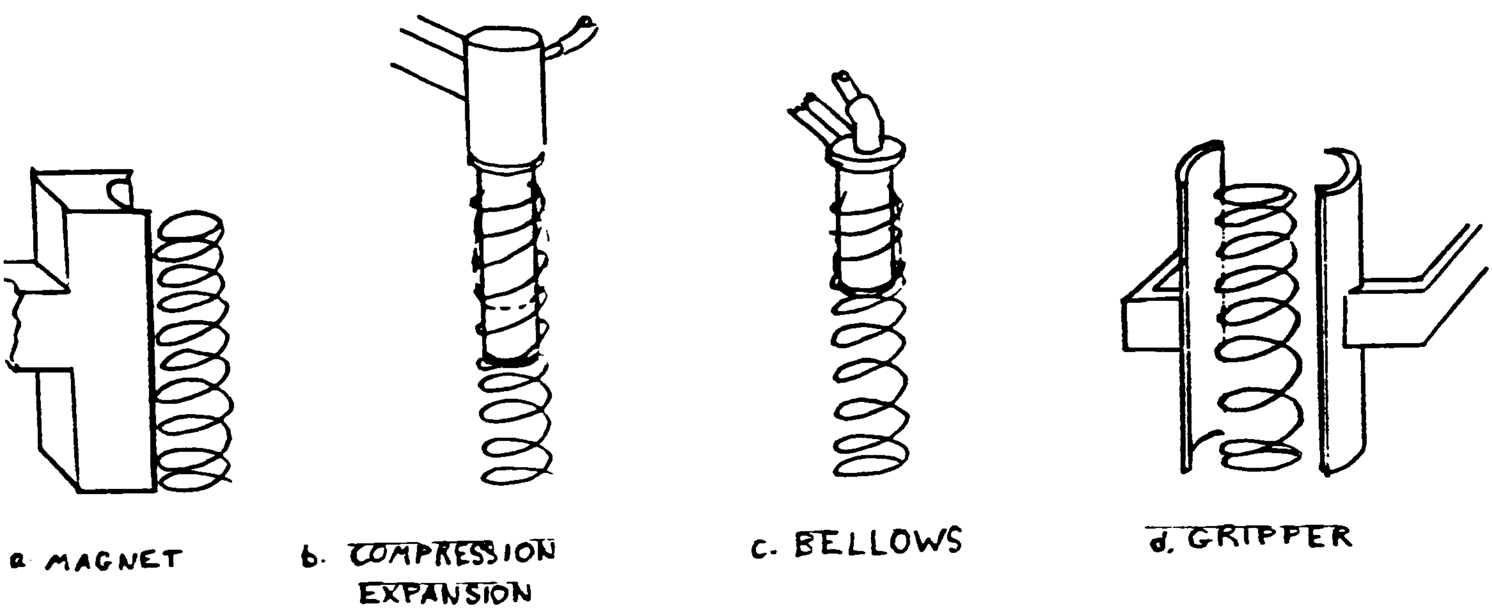


Figure 22. Spring Pickup

CHAPTER VII.

End-Effector Design.

Once the pick up methods for each part have been identified, the end-effector can be designed to accommodate the assembly cell layout. The end-effector will consist of a plate and pick up devices. The pick up devices on the end-effector, will be located so as not to interfere with the parts on the matrix trays, feeders and weld station.

A properly designed end-effector can reduce the cycle time by one third. This will be established by demonstrating the process flow for two different end-effector configurations. The first concept will consist of picking up each part separately and assembling them in the weld station nest (see Fig. 23). The second concept will consist of the parts being assembled while the end-effector picks up the parts (see Fig. 24). Then the end-effector will place the assembled parts in the weld nest. The approximate time required to move the robot from one point to another, to rotate the end-effector, or to close the jaws of a gripper or any other pick up action will be .5 seconds. By looking at the number of steps required it is clearly shown that the assembly process with the fewest steps will produce the fastest cycle time. Therefore an end-effector will be designed to produce a process flow similar to Figure 24 and to accommodate the

PICK UP SPRING
MOVE TO CLEAR SPRING TRAY
MOVE TO POSITION OVER THE DIAPHRAGM TRAY
LOWER TO A DIAPHRAGM
PICK UP A DIAPHRAGM
MOVE TO BODY FEEDER
LOWER TO PICK UP A BODY
CLOSE JAWS
MOVE TO CLEAR BODY FEEDER
MOVE TO CAP FEEDER
LOWER TO PICK UP A CAP
CLOSE JAWS
MOVE TO WELD STATION
POSITION BODY
OPEN BODY JAWS
LIFT END-EFFECTOR
ROTATE END-EFFECTOR
LOWER END EFFECTOR
DROP OFF DIAPHRAGM
LIFT END-EFFECTOR
ROTATE END-EFFECTOR
LOWER END-EFFECTOR
DROP OFF SPRING
LIFT END-EFFECTOR
ROTATE END-EFFECTOR
POSITION CAP
OPEN CAP JAWS
MOVE END-EFFECTOR TO SPRING TRAY
LOWER ONTO A SPRING

ESTIMATES TIME FOR EACH STEP IS .5 SECONDS

TOTAL ESTIMATED TIME FOR ONE CYCLE IS 14.5 SECONDS

Figure 23. Conceptual Process Flow without Modifications.

CONCEPTUAL PROCESS FLOW WITH END-EFFECTOR MODIFICATIONS

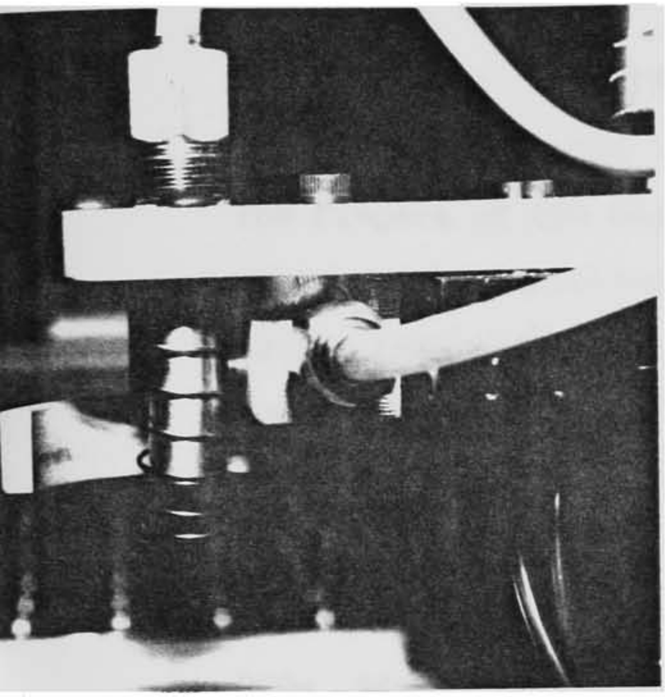
PICK UP SPRING
MOVE UP TO CLEAR SPRINGS
MOVE TO DIAPHRAGM TRAY
LOWER END-EFFECTOR
PICK UP DIAPHRAGM
MOVE TO CAP AND BODY PRESENTATION POINTS
LOWER END-EFFECTOR
CLOSE CAP AND BODY JAWS
MOVE TO CLEAR CAP AND BODY FEEDERS
MOVE TO WELD NEST
LOWER END-EFFECTOR INTO NEST
OPEN BODY JAWS
MOVE TO CLEAR NEST
ROTATE END-EFFECTOR
POSITION CAP
OPEN CAP JAWS
MOVE END-EFFECTOR TO SPRING TRAY
LOWER END-EFFECTOR ONTO SPRING TRAY

ESTIMATED TIME FOR EACH STEP IS .5 SECONDS

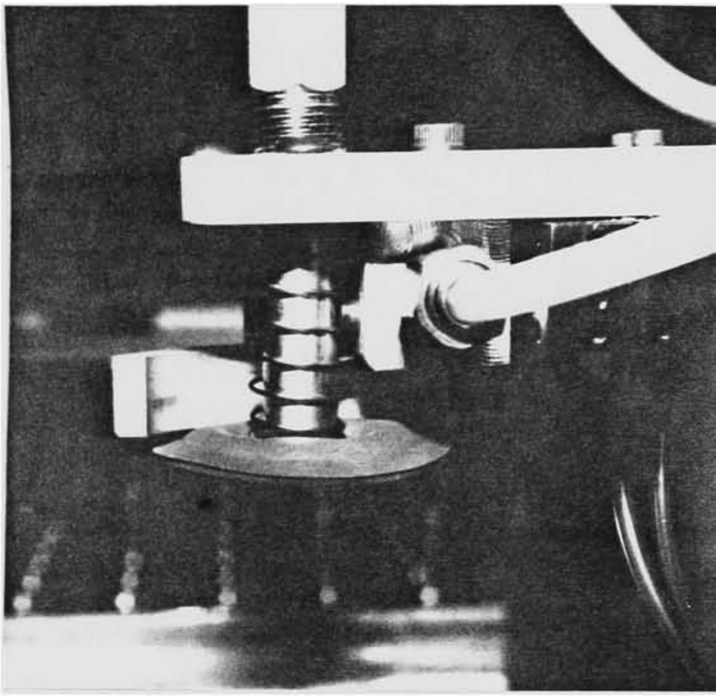
TOTAL ESTIMATED TIME FOR ONE CYCLE IS 9.0 SECONDS

Figure 24. Conceptual Process Flow with End-Effector Modifications

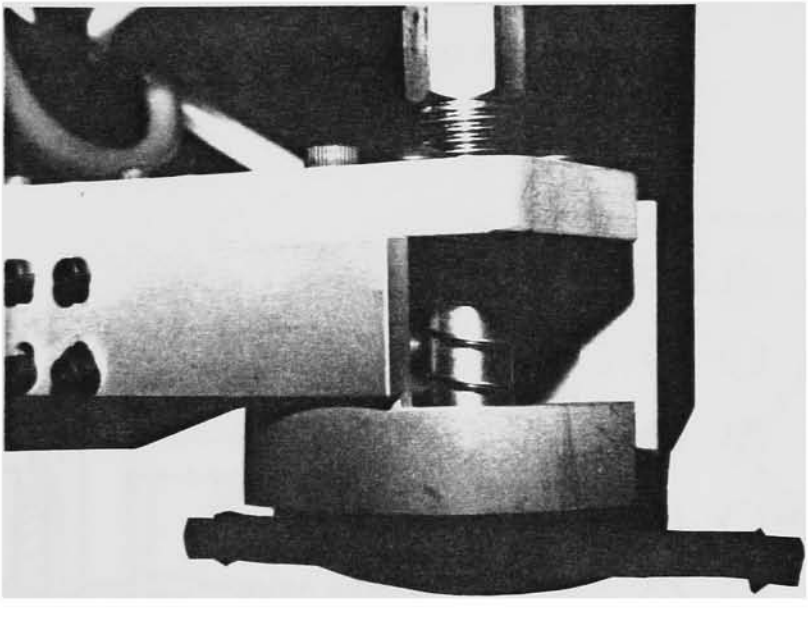
assembly cell feeding devices. To do this, the spring diaphragm and body must be picked up and assembled in one jaw and the cap picked up in the other jaw. This can be done by using a suction device to pick up the diaphragm as shown in Figure 21b. The outer diameter of the suction device must be less than the spring inner diameter by .15 inches. This tube will be used to pick up the spring by pinching the spring against the tube with a bellows (see Fig. 25a see next page). When air enters the block the bellows expands and pinches the spring against the tube. The diaphragm is then picked up by using the tube as a suction device (see Fig. 25b). The body is picked up with grippers by placing the diaphragm in the body and closing the grippers around the body (see Fig. 25c). The cap is picked up by a separate gripper mounted on the end-effector. Since the cap and body are bowl fed to the same point after each cycle, both parts can be picked up at the same time.



a. SPRING PICKUP



b. DIAPHRAGM PICKUP



C. BODY PICKUP

Figure 25. Parts Pickup.

The end-effector was then designed so as not to interfere with the trays, feeders and ultrasonic welder. The fingers of the body gripper were designed not to hit any springs while picking up a spring or moving to or from the spring tray. This was done by positioning the end-effector over the spring tray for minimal interference. The remaining interference is eliminated by modifying the fingers of the gripper (see Fig. 26). Then the end-effector is positioned over the diaphragm tray (see Fig. 27) and, cap and body presentation points to eliminate interference. The resulting end-effector is then positioned at the nest of the ultrasonic weld station to insure that the end-effector will clear the weld head while placing a part.

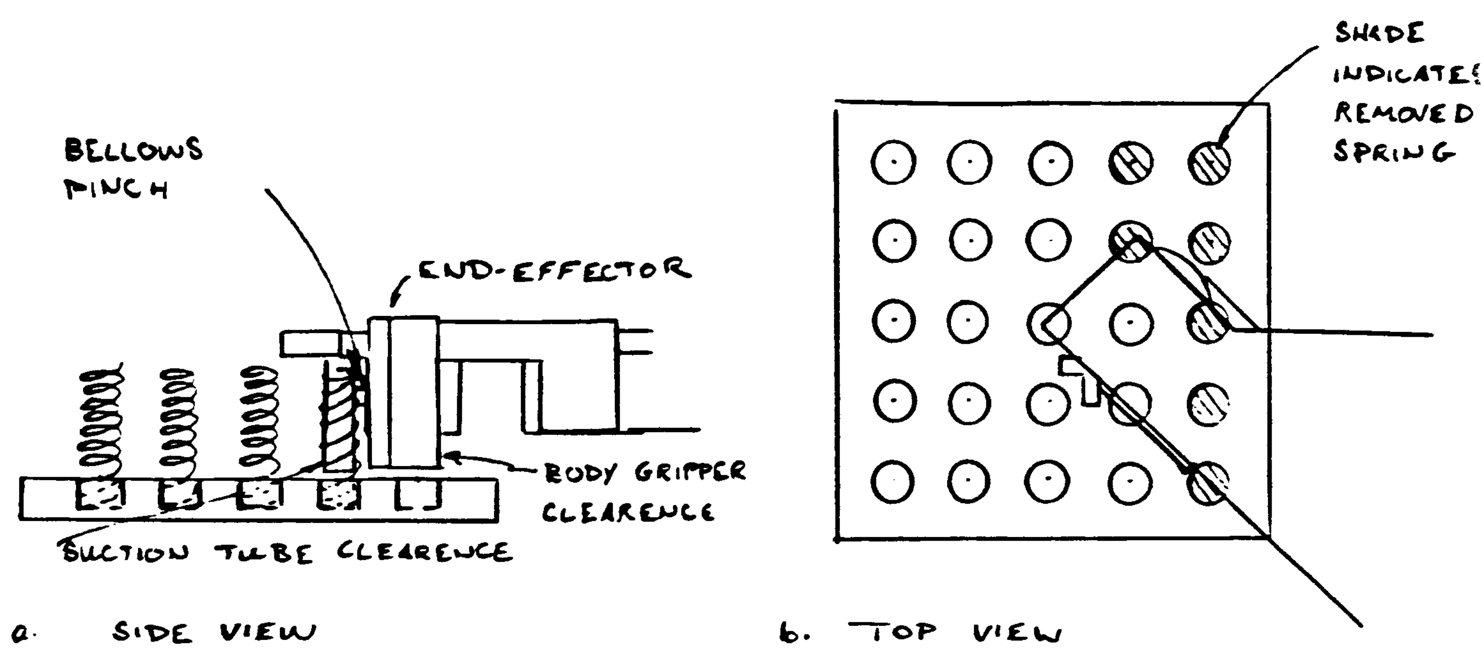
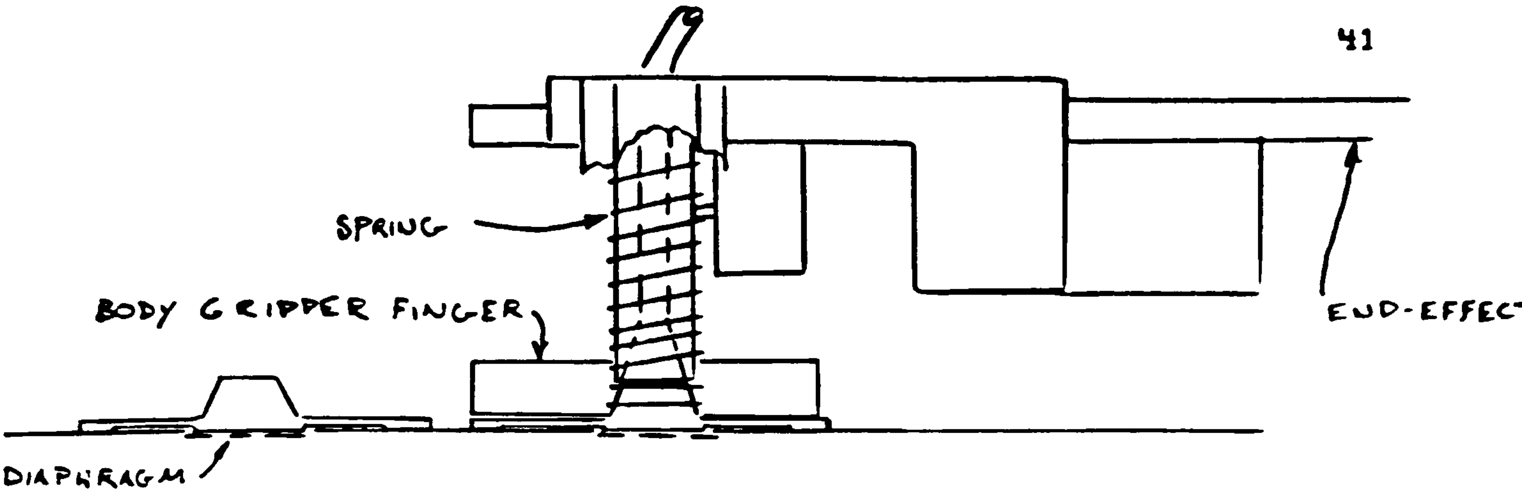
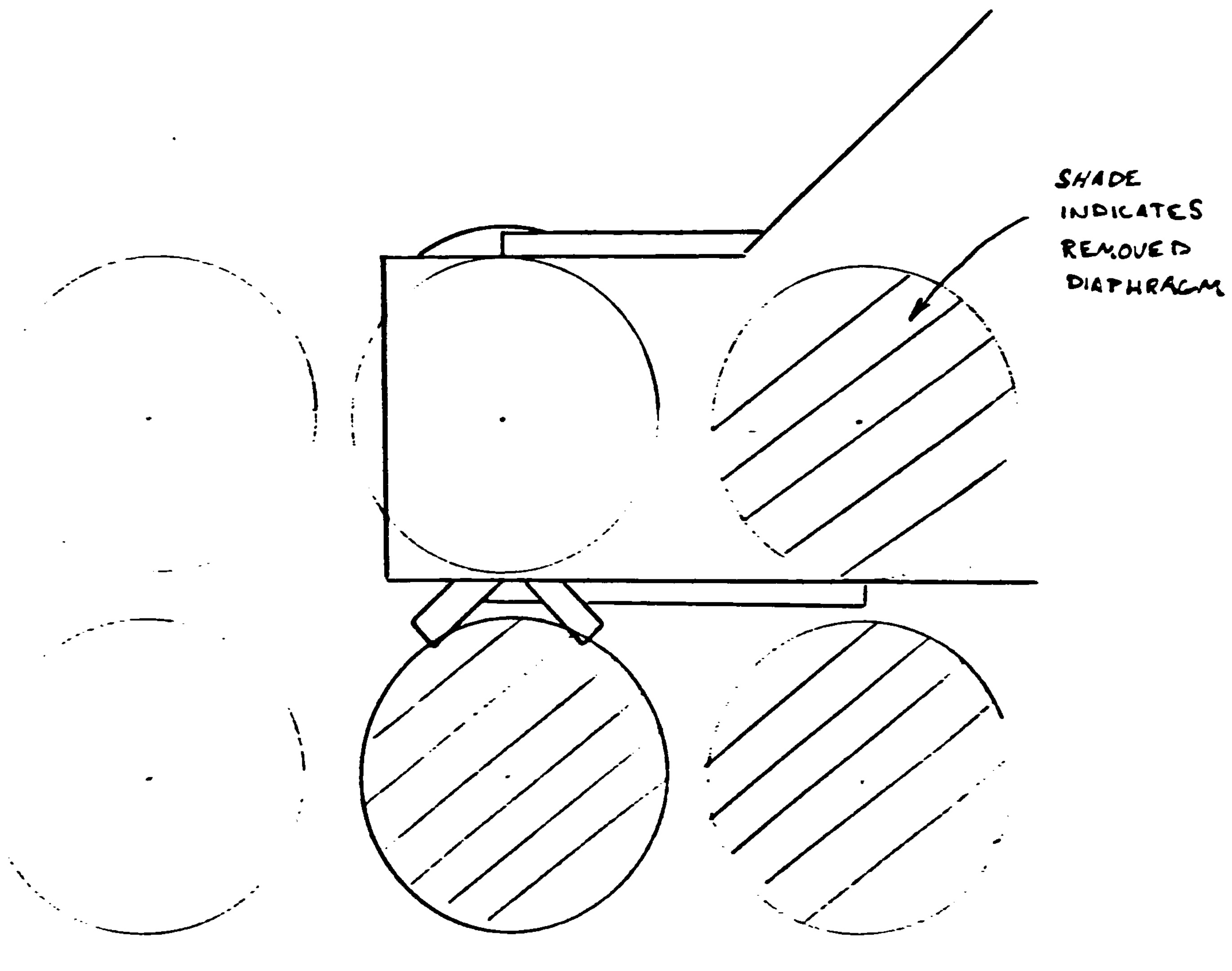


Figure 26. Spring Pick-up.



a. DIAPHRAGM PICK-UP SIDE VIEW



b DIAPHRAGM PICK-UP TOP VIEW

Figure 27. Diaphragm Pickup

Chapter VIII

Backup End-Effector.

There is a possibility that picking up the diaphragm by suction will work poorly compared to the other methods. To accommodate for this, a backup pickup method will be incorporated in the design of the end-effector. An extra finger to grasp the diaphragm will be incorporated into the cap pickup gripper (see Fig. 28). The diaphragm will have to be placed into the body before the cap and body are picked up. This will add four more steps in the process flow, but this concept will still have a faster cycle time than the conceptual process flow without modifications (see Fig. 29 for the process flow for the backup end-effector). See design drawings for actual dimensioning.

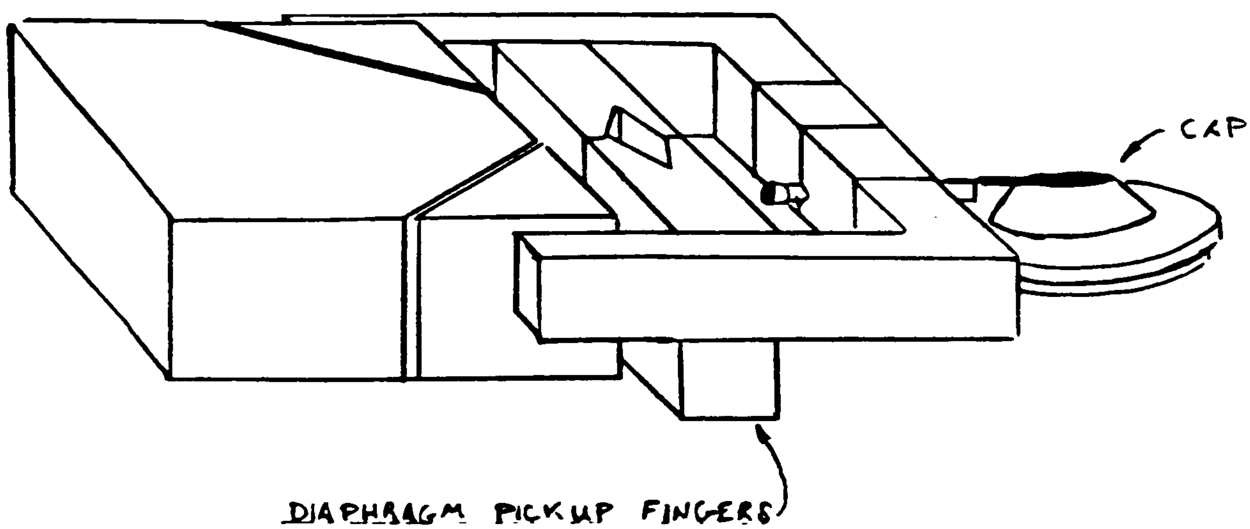


Figure 28. Extra Finger to Pick Up Diaphragm.

PICK UP SPRING
MOVE END-EFFECTOR TO CLEAR SPRING TRAY
MOVE TO DIAPHRAGM TRAY
LOWER END-EFFECTOR
PICK UP DIAPHRAGM
MOVE TO BODY FEEDER *
LOWER END-EFFECTOR *
DROP DIAPHRAGM INTO BODY *
RAISE END-EFFECTOR *
ROTATE END-EFFECTOR (TO POSITION OVER CAP AND BODY PRESENTATION POINTS)
LOWER END-EFFECTOR
CLOSE CAP AND BODY JAWS
MOVE TO CLEAR CAP AND BODY FEEDERS
MOVE TO WELD NEST
LOWER BODY INTO WELD NEST
OPEN BODY JAWS
MOVE TO CLEAR WELD NEST
ROTATE END-EFFECTOR
MOVE TO POSITION CAP
OPEN CAP JAWS
MOVE TO SPRING TRAY
LOWER END-EFFECTOR ON TO A SPRING

ESTIMATING EACH STEP TAKES .5 SECONDS

* INDICATED EXTRA STEPS

TOTAL ESTIMATED TIME FOR ONE CYCLE IS 11.0 SECONDS

Figure 29. Conceptual Process Flow for Backup End-Effector

CHAPTER IX.

Assembly Cell Simulation

The simulated assembly cell was designed to operate as if it were in an industrial environment (see Appendix D for pictures of all feeders and process flow). Rochester Products purchased an Adept-One robot for this project. The robot was installed in Room 1169 in the Engineering Building on the Rochester Institute of Technology Campus. Tables were placed around the robot and the simulated devices (parts feeders, matrix trays, and ultrasonic welder) were built and bolted to the tables. The actual end-effector was designed and installed. The end-effector controls were also designed and built. Finally, the assembly program (BAWPU) was written, debugged and tested.

A. End-Effector Controls.

The end-effector was pneumatically actuated by the robot controller. This is done by using electronically controlled valves and a power source. The valve actuators are connected to the output ports of the Adept One controller. The valves are actuated in the program by using the command "signal" (output device number). The assembly cell program and valving layout are in Appendix A.

B. Simulated Trays and Feeding Devices.

The spring and diaphragm trays were manufactured from aluminum plate. Holes were made for 25 parts on each tray in the same pattern, as if the trays were to be used in industry (see Appendix B for tray design). The cap and body feeder devices were simulated by using two parts nests bolted to the table in the assembly cell (see Fig. 30).

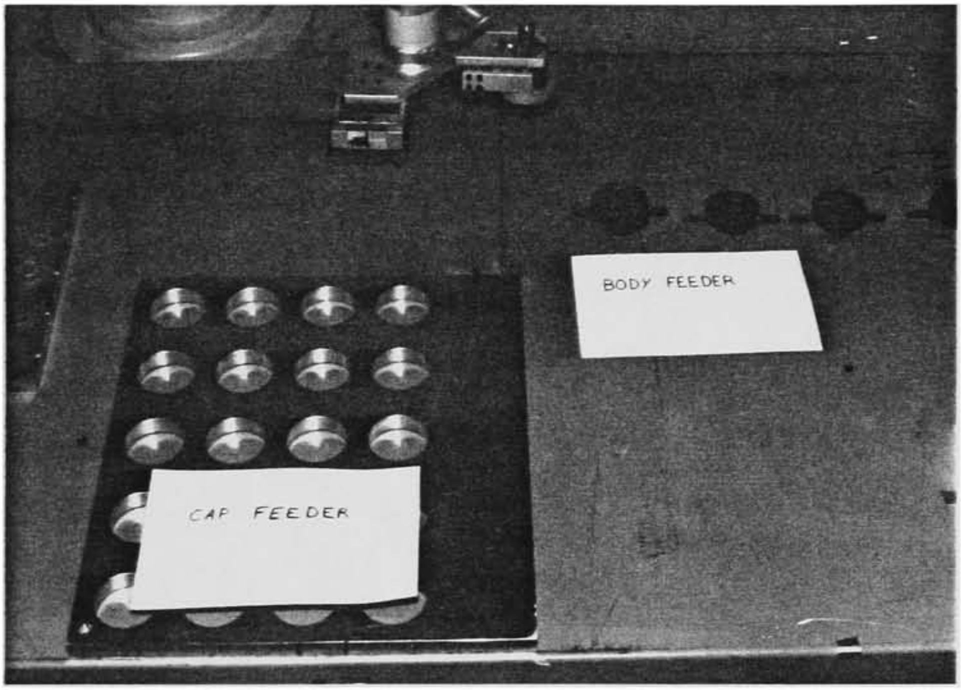


Figure 30. Simulated Feeders.

C. Simulated Weld Station.

The simulated weld station was made with a particle board base and 2 x 4 sections of wood (see Fig. 31). A nest was used for the body similar to the nest used to represent the body feeder. The information was obtained from Sonics and Materials, a company that supplies ultrasonic welders to Rochester Products Division.

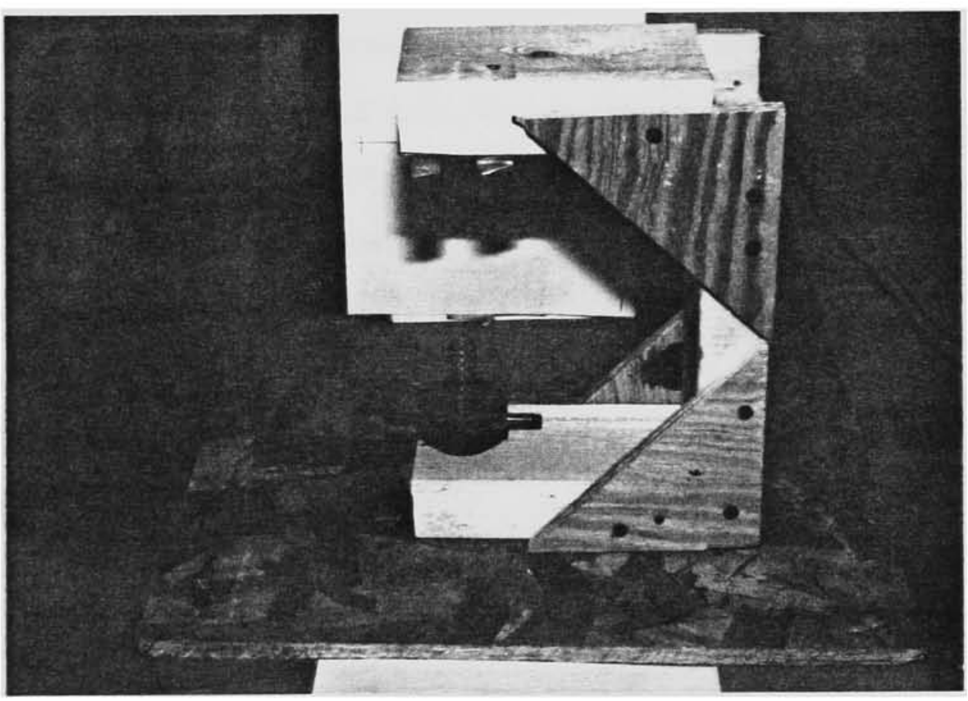


Figure 31. Simulated Ultrasonic Welder.

CHAPTER X.

SIMULATED ASSEMBLY CELL TESTING

A. Objective:

The objective of the testing is to find the flaws in the design of the assembly cell and the end-effector. The flaws can be found by running the assembly cell for an extended period of time. If there are design flaws, they will be evident by the percent of parts not being assembled. The percent of parts not being assembled will then be classified into groups. Each group represents a process that prevents the parts from being assembled. The errors in the design are then analyzed and recommendations in the design will be made to reduce the errors. The test will be performed on the assembly cell with the original end-effector and the backup end-effector.

B. Procedure:

One thousand cycles will be performed by running the assembly cell 40 times. Each run will assemble 25 parts. The parts will then be disassembled and placed back into the feeding devices for the next run. The frequency of assembly failures and the reasons for them will be recorded. The procedure used is as follows:

1) Start Adept One Robot.

2) Load assembly cell program into the controller.

3) Teach points to the robot (see Fig. 32).

a) Three points on each tray.

b) Point to drop off the diaphragm into the body.

c) Point to pick up cap and body.

d) Point to drop off body.

e) Point to drop off cap.

4) Place 25 springs in the spring tray and 25 diaphragms in the diaphragm tray.

5) Put a cap and body in their feed positions.

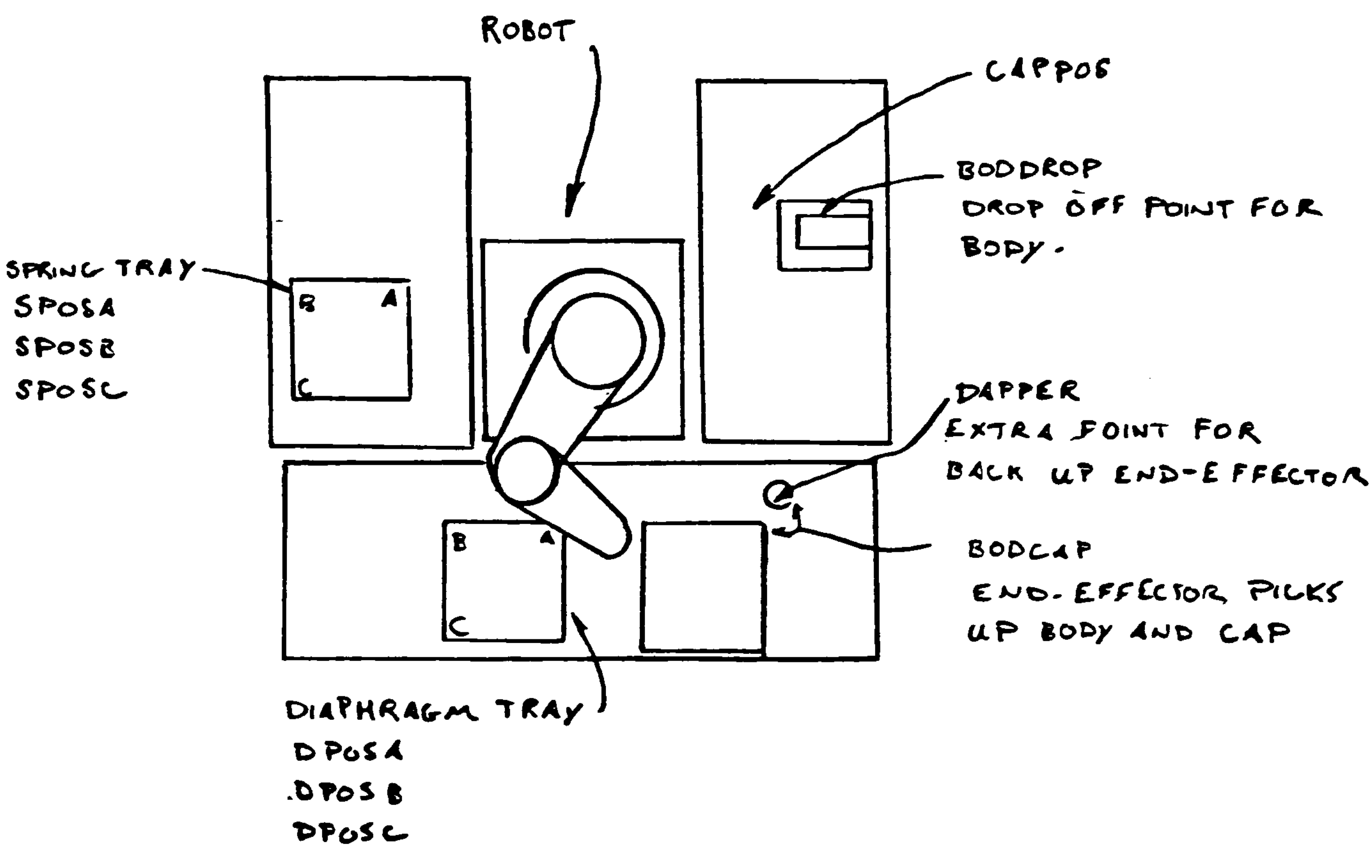


Figure 32. Points for Assembly Cell Program.

6) Execute BAWPU program.

   a) While robot is running, remove cap and body from simulated ultrasonic weld nest and place them back into the feed positions. Discharge spring and diaphragm into a box.

   b) If a part is incorrectly assembled, record the reason for incorrect assembly.

7) Repeat steps 4 through 6 a total of 39 times for the end-effector and back-up end-effector.

C. TEST RESULTS.

For the original end-effector only, four runs were made. This is because the end-effector successfully picked up the diaphragm 48% of the time (see Appendix C for raw data and reduced data for the original end-effector). The same assembly cell with the backup end-effector successfully assembled 97% of the 1,000 canister control valves having a 12.1 second cycle time (see Appendix C for raw data and reduced data for the backup end-effector).

D. CONCLUSION AND RECOMMENDATIONS FOR THE ORIGINAL END-EFFECTOR.

The original end-effector design only completed 48% of the parts. The reason for such poor results is that the suction pick up for the diaphragms was unable to form a vacuum on the diaphragms.

To improve the suction pick up two things can be done.

The first is to build the suction tube out of a stiff rubber material (see Fig. 33). The hard rubber will enable a vacuum to be formed between the diaphragm and the suction tube. The next step is to increase the horse power on the vacuum pump. This will increase the suction out of the tube.

E. CONCLUSIONS AND RECOMMENDATIONS FOR THE BACK UP END-EFFECTOR.

This section discusses the possible solutions to the problems that caused the parts not to be assembled 3 % of the time. Some errors were a result of other errors. For example, the spring falling over the nest is caused by poorly placing the body into the nest or diaphragm inaccurately placed in the body. Some design improvements involving the air lines and other components of the end-effector are included.

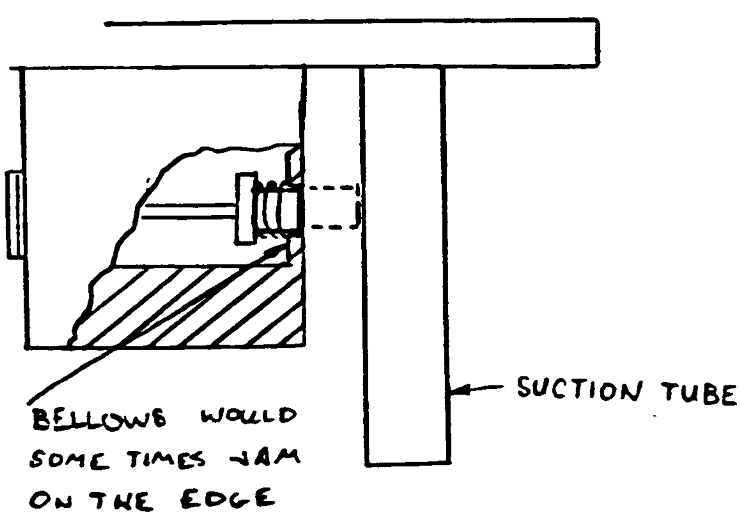


Figure 33. Bellows Jam

1) **Problem**:

Springs were not picked up from the spring tray. Springs were not picked up because the bellows did not expand out of the block (see Fig. 33).

Solution:

Lubricate the contact surfaces and polish the block. This will prevent the bellows from getting caught in the block when pressurized.

2) **Problem**:

Diaphragm not picked up from the tray. This was caused by the gripper fingers not getting a good hold of the part.

Solution:

Increase the coefficient of friction between the gripper fingers and part. This can be done by gluing or fastening a different material with a higher coefficient of friction on the face of the gripper finger.

3) **Problem**:

Body not picked up from the feeder. This was caused by incorrectly placing the body in the feed position, a human error.

Solution:

Place the body in the simulated feeder correctly.

4) Problem:

Cap not picked up from the feeder. This was caused by incorrectly placing the cap in the feed position, a human error.

Solution:

Place the cap into the simulated feeder correctly.

5) Problem:

Spring fell over the weld nest. This was caused by the position of the body in the nest or the position of the diaphragm in the body (see Fig. 34).

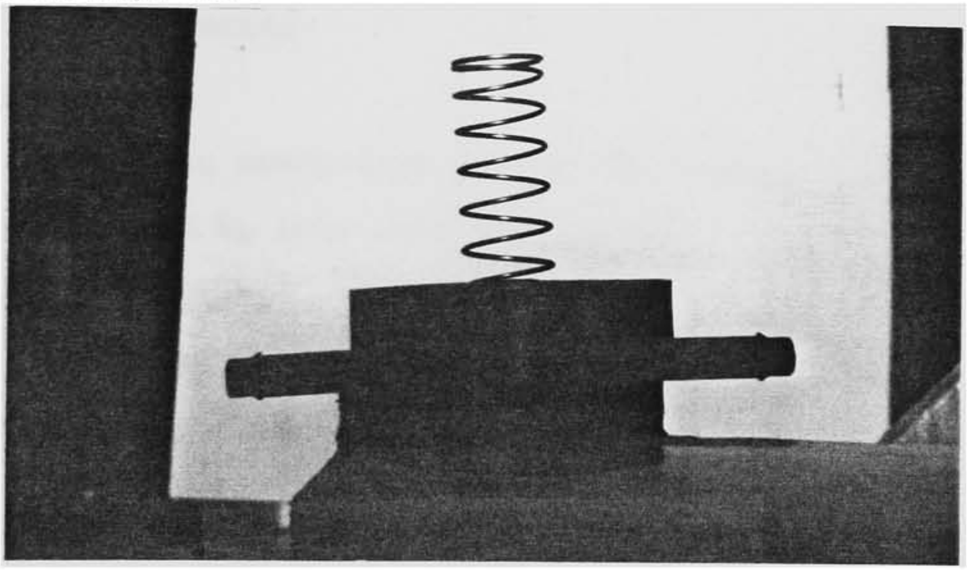


Figure 34. Poor Positioning of the Bodies.

Solution:

Improve the weld nest and feed point for the body pick up. The simulated body feed point and weld nest were simple designs. This was done to minimize the cost of the simulated assembly cell. This caused the poor positioning of the bodies.

6) Problem:

Diaphragm poorly placed in the body. This was caused by placing the body incorrectly into the feed nest, a human error.

Solution:

Place the body into the simulated feeder correctly.

7) Problem:

Body incorrectly positioned in the weld nest. This was caused by poor weld nest design.

Solution:

Design a weld nest which supports the body more effectively.

F. GENERAL END-EFFECTOR DESIGN IMPROVEMENTS.

The design for gripper fingers for the diaphragm pick-up should be redesigned with a rubber surface to contact the diaphragm. A thin rubber material should be glued to the diaphragm gripper fingers.

The pneumatic air lines should also be relocated. This can be done by using 90 degree elbows on the air cylinders for the cap and body grippers. The elbows will prevent the air lines from hanging down and possibly hitting something in the assembly cell. A hole should be incorporated in the design of the gripper plate for the air lines. Placing them through the hole will also help in preventing the air lines from hanging loosely.

CHAPTER XI

Summary

The manually operated cell at Rochester Products Division presently has an average cycle time of 10.0 seconds. The total average completed parts per eight hour shift is 2,343 parts.[1] The average reject rate is 1.0% of the total parts.[1] The manual cell requires the attention of an operator to load the parts bins and an operator to assemble the canister control valves. The approximate cost break down for a manual assembly cell is shown in Table 7.

Table 7. Cost Break Down of the Manual Canister Control Valve Assembly Cell Having 10.0 Second Cycle Time.

BODY BIN	$ 100
CAP BIN	100
SPRING TRAY BIN	100
DIAPHRAGM BIN	100
ULTRASONIC WELDER	15,000
YEARLY SALARY/BENEFITS OPERATOR (8 HR. SHIFT)	40,000
ENGINEERING DESIGN	1,000
TOTAL FOR ONE 8 HR. SHIFT	$ 56,400
TOTAL FOR TWO 8 HR. SHIFTS	$ 96,400
TOTAL FOR THREE 8 HR. SHIFTS	$136,400

Note: a) Totals above are for one year of use.
b) For each additional shift after a year add yearly salary and benefits of an operator.
c) Cost of set-up person is not included.

The robotic assembly cell designed and analyzed in this report proved to be capable of replacing the present manually operated cell at Rochester Products Division. The robotic assembly cell was found to have a 97.0% successful completed parts rate at a cycle time of 12.1 seconds. This amounts to 297 completed parts per hour and 2380 completed parts per eight hour shift.

This 3.0% reject rate can be reduced by modifying the existing end-effective design according to the general end-effective design improvement in chapter X. Also, the existing end-effector should be redesigned according to the same section to reduce the problems of loose-hanging air lines.

The robotic assembly cell does require the attention of a set-up person which starts the assembly cell and loads the parts into the feeding devices. The amount of time allowed between filling the feeding devices will depend on the capacity of the parts feeders.

The approximate cost break down for a canister control valve assembly cell is shown in Table 8.

Table 8. Cost break down of the canister control valve assembly cell having 12.1 second cycle time.

BODY BOWL FEEDER	$ 10,000
CAP BOWL FEEDER	10,000
SPRING TRAY HANDLING SYSTEM	20,000
DIAPHRAGM TRAY HANDLING SYSTEM	20,000
ULTRASONIC WELDER	15,000
END-EFFECTOR	3,000
AIR VALUING AND CONTROLS FOR END-EFFECTOR	2,000
ADEPT ONE CONTROL ROBOT AND VISION SYSTEM	70,000
LABOR FOR INSTALLATION AND ASSEMBLY	20,000
TOTAL	$160,000

Note: a) Cost of spring and diaphragm trays are not included.
b) Cost of set up person is not included.

Normally, Rochester Products Division would rely on an outside vendor to carry out the responsibilities of engineering and design of an assembly cell. By using the design concepts included in this report and building the assembly cell in-house, Rochester Products Division will save money. The savings is the cost of a vendor performing the engineering and design.

Both the manual and robotic assembly cell produce roughly the same amount of canister control valves per eight hour shift. The cost of a set-up person was not included in the cost break down for the manual and robotic assembly cell since both cells require the same amount of time to reload parts bins.

After fourteen months of operation the cost of the manual assembly cell will equal the cost of the automated assembly cell.

In addition the robotic assembly cell only has an initial cost, unlike the manual assembly cell. After fourteen months the cost of the manual assembly cell will continue to increase since it requires an operator.

It is therefore recommended that the robotic cell be used if there is enough valves on order to keep the assembly cell in operation for fourteen months.

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APPENDIX A: VAL II PROGRAM,DESCRIPTION OF VAL II LANGUAGE AND ASSEMBLY CELL VALVING

Val II is a simple language which is used to program the Adept One robot. The Val II language is similar to PASCAL. To perform a continuous sequence of operations, a FOR loop would be used similar to the FOR loop used in PASCAL. The beginning of a program is identified by PROGRAM followed by the name of the program. The end of a program is identified by the END statement. See Table A-1 for Val II commands.

Table A-1. Val II commands.

Note: The left column represents a Val II command with an example below it and the right column is a description of the command.

APPROACH POINT NAME, DISTANCE APPROACH BODCAP, 80	Moves end-effector directly above or below a desired point. (Distance in cm.)
MOVE POINT NAME MOVE BODCAP	Move end-effector to a point.
DELAY TIME DELAY .03	Keeps end-effector at a point for a for a period of time. (Time is in seconds.)
SIGNAL OUTPUT PORT NUMBER SIGNAL 33	Sends an electrical impulse from an output port of the controller to open or close an electrical switch. The electrical switch is used to control air valves.
NAME = 33 BODPIC = 33	A name can be substituted for the output port number.

CALL PROGRAM NAME CALL SNG.PICK.UP()	Activates a program within another program.

To run a program, the user must locate the coordinates of the points used in the program. This is done in the system mode. The end-effector is first positioned at the point of interest, and then the command HERE point name (i.e., HERE BODCAP) is used. After that, the program is ready to be executed.

TPCV's.

Mark Richmond, Feb 1986

```
DECOMPOSE sng11[] = sposa  , ;sng11 = sng trav row1 column1, etc.
DECOMPOSE sng51[] = sposb   ;sposa = sng position a, etc..
DECOMPOSE sng55[] = sposc   ;
DECOMPOSE dia11[] = dposa   ;  -----------------
DECOMPOSE dia51[] = dposb   ;  I a             I
DECOMPOSE dia55[] = dposc   ;  I               I
                            ;  I               I
                            ;  I               I
                            ;  I b           c I
                            ;  -----------------



bod.pck = 33    ; Assign variable names to solenoid output lines
bod.rls = -33
cap.pck = 34
cap.rls = -34
sng.pik = 35
sng.rls = -35
vac.on = 37
vac.off = -37
blow.on = 38
blow.off = -38


sngx = sng11[]   ; Initialize the x,y,z, and  roll coords for
sngy = sng11[1] ; the springs and diaphrams
sngz = sng11[2]
sngr = sng11[5]
diax = dia11[]
diay = dia11[1]
diaz = dia11[2]
diar = dia11[5]




sngxsteps = ABS(sng51[]-sng55[])/4   ; Determine incremental
sngysteps = ABS(sng51[1]-sng11[1])/4 ; distances in the x and y
diaxsteps = ABS(dia51[]-dia55[])/4    ; directions for the
diaysteps = ABS(dia51[1]-dia11[1])/4 ; sng and dia trays
FOR row = 1 TO 5
     TIMER 1 = 0
     FOR column = 1 TO 5
          CALL sng.pick.up()
          CALL dia.pick.up()
          CALL bodcap.pick.up()
          CALL drop.bod.assy()
          CALL capdrop()
          diay = diay-diaysteps ; Increment to next position
          sngy = sngy-sngysteps
     END
     TYPE "Elapsed time for 5 valves assembled is", TIMER(1), " seconds."
     TYPE
     TYPE
     vps = TIMER(1)/5
     TYPE "Or in other words a ", vps, " second cycle time."
     TYPE
     TYPE
```

```
            sngy = sng[i,1]
            diax = diax+diaxsteps
            sngx = sngx+sngxsteps
        END
END
PROGRAM bodcap()
END
PROGRAM bodcap.pick.up()
        APPRO capper, 80
        MOVE capper
        DELAY 0.3
        SIGNAL -34
        APPRO bodcap, 80
        SIGNAL bod.rls, cap.rls
        SPEED 50
        MOVE bodcap
        DELAY 0.3
        SIGNAL bod.pck, cap.pck
        DEPART 50
        SPEED 100
END
PROGRAM cappos()
END
PROGRAM capdrop()
        MOVE precap
        APPRO cappos, 60
        MOVE cappos
        DELAY 0.2
        SIGNAL cap.rls
        MOVE clsfree
END
PROGRAM dia.pick.up()
        APPRO TRANS(diax, diay, diaz, 0, 180, diar), 60
        SIGNAL blow.off, vac.on
        SIGNAL -33
        SPEED 50
        SIGNAL -34
        MOVE TRANS(diax, diay, diaz, 0, 180, diar)
        DELAY 1
        SIGNAL 34
        DEPART 60
        SPEED 100
END
PROGRAM drop.bod.assy()
        MOVE prelimdrop
        DISABLE CP
        APPROS boddrop, 30
        SPEED 50
        MOVE boddrop
        DELAY 0.3
        SIGNAL bod.rls
        DELAY 0.2
        DEPART 2
        SIGNAL vac.off, blow.(
        DELAY 0.2
        SIGNAL blow.off
        SIGNAL sng.rls
        DELAY 0.3
        DEPART 60
        ENABLE CP
        SPEED 100
        MOVE prelimdrop
END
PROGRAM sng.pick.up()
        SIGNAL bod.pck
```

```
SIGNAL sng.rls
      SPEED 50
      MOVE TRANS(sngx, sngy, sngz, 0, 180, sngr)
      DELAY 0.3
      SIGNAL sng.pck
      DEPART 50
      SPEED 100

LOCATIONS
podcap          0.79757565 0.60321897 0 0.60321897 -0.79757565 0
0 0 -1 611.02693 328.82522 703.05114
poddrop         0.80152291 0.59796416 0 0.59796416 -0.80152291 0
0 0 -1 -253.16547 642.86022 716.02563
cappos          -0.55731499 0.83030116 0 0.83030116 0.55731499 0
0 0 -1 -295.17373 530.72674 695.24591
capper          0.7809757 0.62456142 0 0.62456142 -0.7809757 0
0 0 -1 515.77117 461.06407 707.81359
aposa           0.78607607 0.61812985 0 0.61812985 -0.78607607 0
0 0 -1 519.71594 -61.983184 696.91607
aposb           0.78605926 0.61815118 0 0.61815118 -0.78605926 0
0 0 -1 519.73022 -263.7861 698.21252
aposc           0.78616867 0.61801177 0 0.61801177 -0.78616867 0
0 0 -1 724.24066 -263.79687 697.13769
precapplace     -0.63014674 0.77647614 0 0.77647614 0.63014674 0
0 0 -1 -301.45019 631.10595 790.08251
precap          0.81800067 0.5752173 0 0.5752173 -0.81800067 0
0 0 -1 -233.76054 550.50799 801.18835
prelimdrop      0.7622801 0.64724731 0 0.64724731 -0.7622801 0
0 0 -1 -247.56964 567.79547 734.31414
rlsfree         -0.67792934 0.73512715 0 0.73512715 0.67792934 0
0 0 -1 -293.46777 580.19134 864.78759
sposa           -0.1416164 -0.98992163 0 -0.98992163 0.1416164 0
0 0 -1 -123.42398 -537.55914 701.60913
sposb           -0.14173819 -0.98990422 0 -0.98990422 0.14173819 0
0 0 -1 -120.3894 -690.52978 700.00177
sposc           -0.14161664 -0.98992163 0 -0.98992163 0.14161664 0
0 0 -1 31.968536 -688.73095 702.62451
END
REALS
blow.off        -38
blow.on         38
pod.pck         33
pod.rls         -33
cap.pck         34
cap.rls         -34
column          6
dia11[0]        519.71594
dia11[1]        -61.983184
dia11[2]        696.91607
dia11[3]        0
dia11[4]        180
dia11[5]        141.82031
dia51[0]        519.73022
dia51[1]        -263.7861
dia51[2]        698.21252
dia51[3]        0
dia51[4]        180
dia51[5]        141.81875
dia55[0]        724.24066
dia55[1]        -263.79687
dia55[2]        697.13769
dia55[3]        0
dia55[4]        180
dia55[5]        141.82891
diar            141.82031
```

```
diaxsteps       51.127609
diay            -314.23684
diaysteps       50.450729
diaz            696.91607
row             1
sng.pck         -35
sng.rls         35
sng11[0]        -123.42398
sng11[1]        -537.55914
sng11[2]        701.60913
sng11[3]        0
sng11[4]        180
sng11[5]        -81.858619
sng51[0]        -120.3894
sng51[1]        -690.52978
sng51[2]        700.00177
sng51[3]        0
sng51[4]        180
sng51[5]        -81.85157
sng55[0]        31.968536
sng55[1]        -686.73095
sng55[2]        702.62451
sng55[3]        0
sng55[4]        180
sng55[5]        -81.858604
sngr            -81.858619
sngx            -123.42398
sngxsteps       38.089485
sngy            -728.77252
sngysteps       38.24266
sngz            701.60913
vac.off         -37
vac.on          37
vps             11.612799
END
STRINGS
END
```

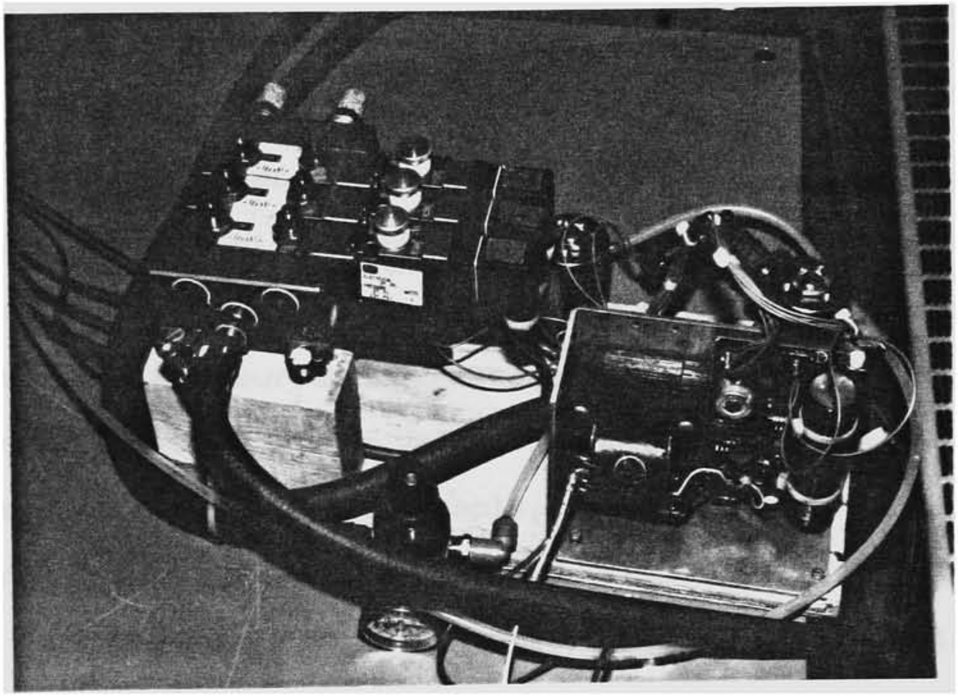


Figure A-1. Valves

VALVE LAYOUT

Figure A-2 is the equipment layout to control the end-effector. The valves are connected to a compressed air supply and the end-effector by air lines (see Fig. A-2). Each valve is connected to an output port of the Adept One controller and a power supply. Ports in the valves are opened or closed by an electrical impulse which is sent from the controller. This impulse activates a switch which then uses the power, supplied to the valve, to perform the opening or closing motion of a port. When a port is opened, air under pressure is allowed to pass through the valve. The pressurized air causes a component on the end-effector to move. Each valve controls a grasping motion on the end-effector. For example, valve 33 is connected to a pneumatic air cylinder on the end-effector. The valve can open and close the jaws connected to the air cylinder. This is done by typing in the command SIGNAL 33 into a CRT connected to the robot controller. The command activates an electrical impulse which passes through output port 33 of the robot controller. The electrical impulse will travel to valve 33. When valve 33 receives the impulse port one will open and port two will close. Air will pass through port one and the air supply will be shut off through port two. This will open the jaws of the pneumatic gripper on the end-effector. To activated the valves while running a program the command SIGNAL output port number is used within the program.

Figure A-3 shows the valves used to control the end-effector. Each valve is connected to an output port of the Adept controller. Valve 34 is connected to output port 34 and controls a pneumatic gripper. Valve 35 is connected to output post 35 and controls the bellows. Valve 37 and 38 are connected to output ports 37 and 38 respectively. Valves 37 and 38 control the suction on the suction tube (see Fig. 33 on page 50).

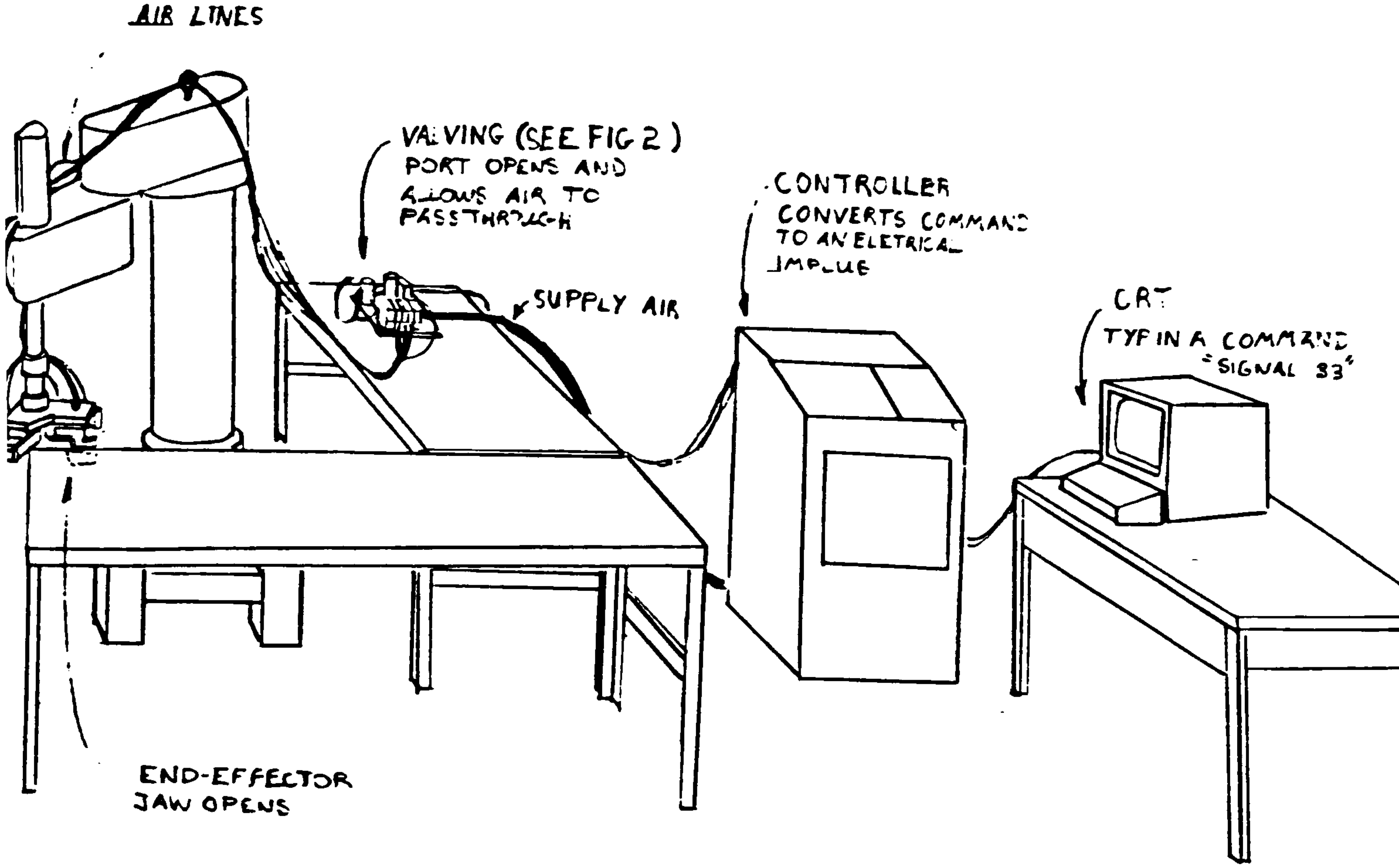


Figure A-2. Equipment Layout.

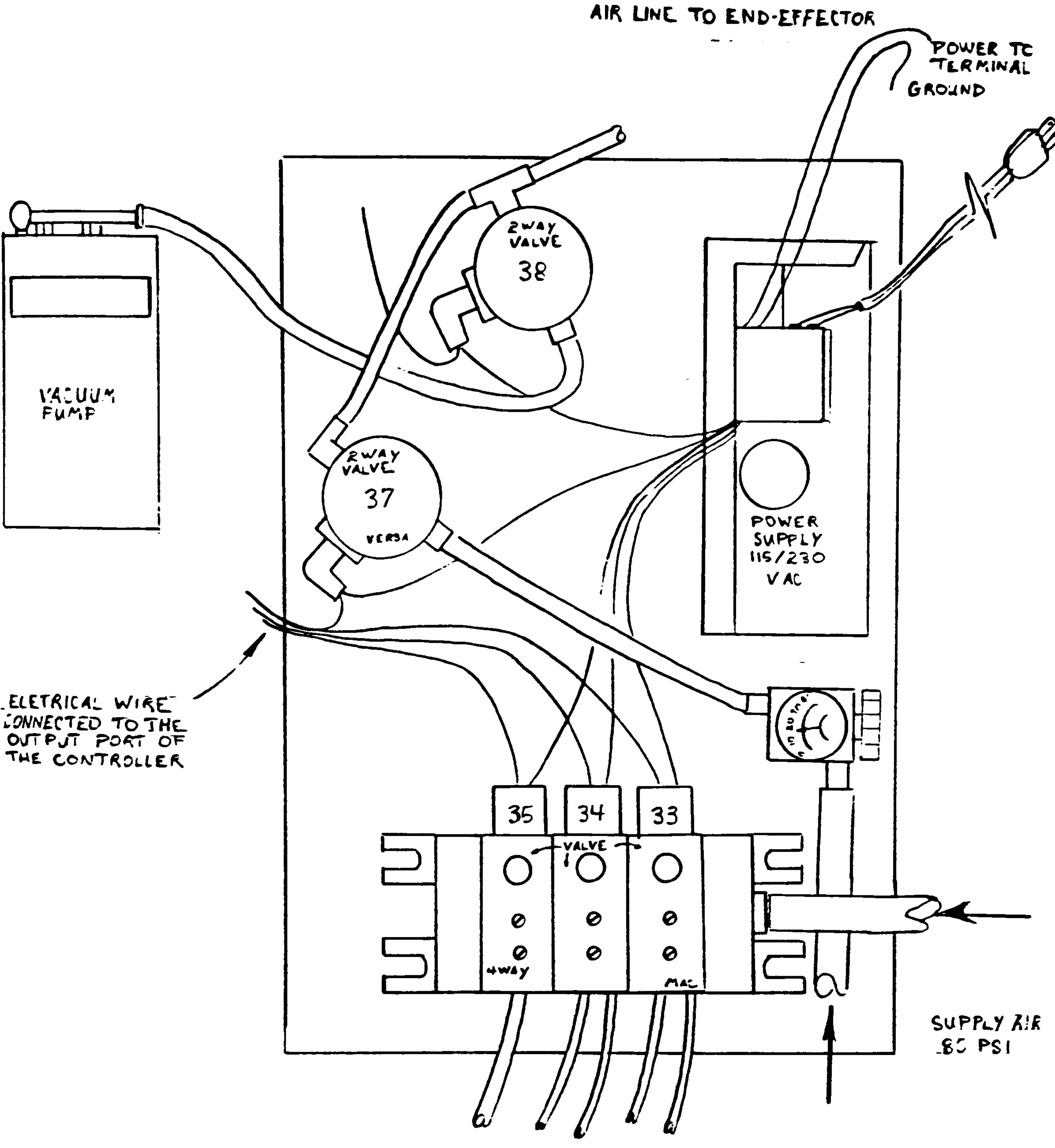
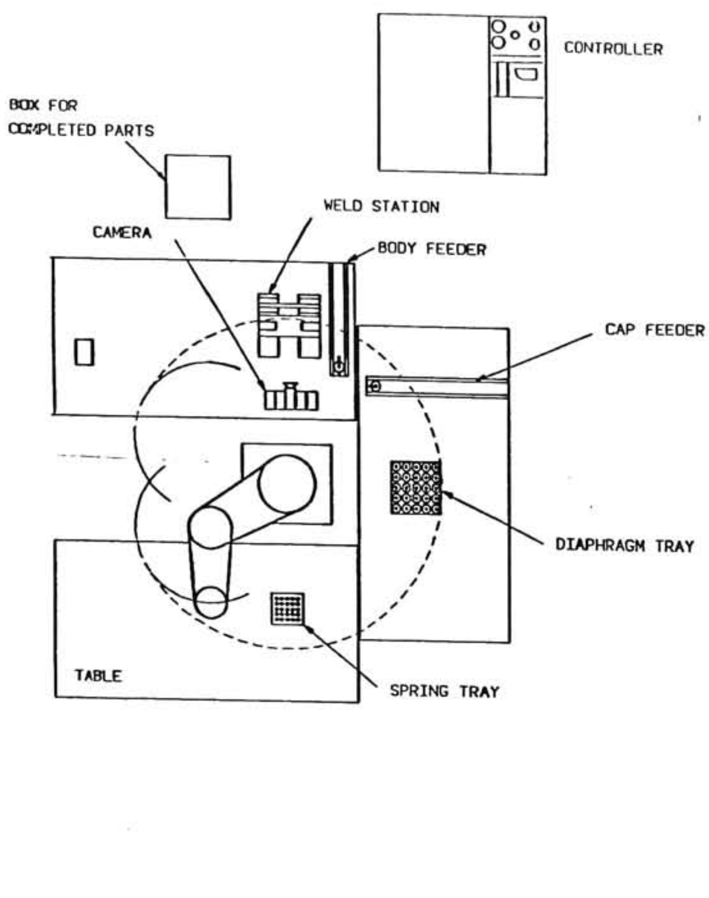
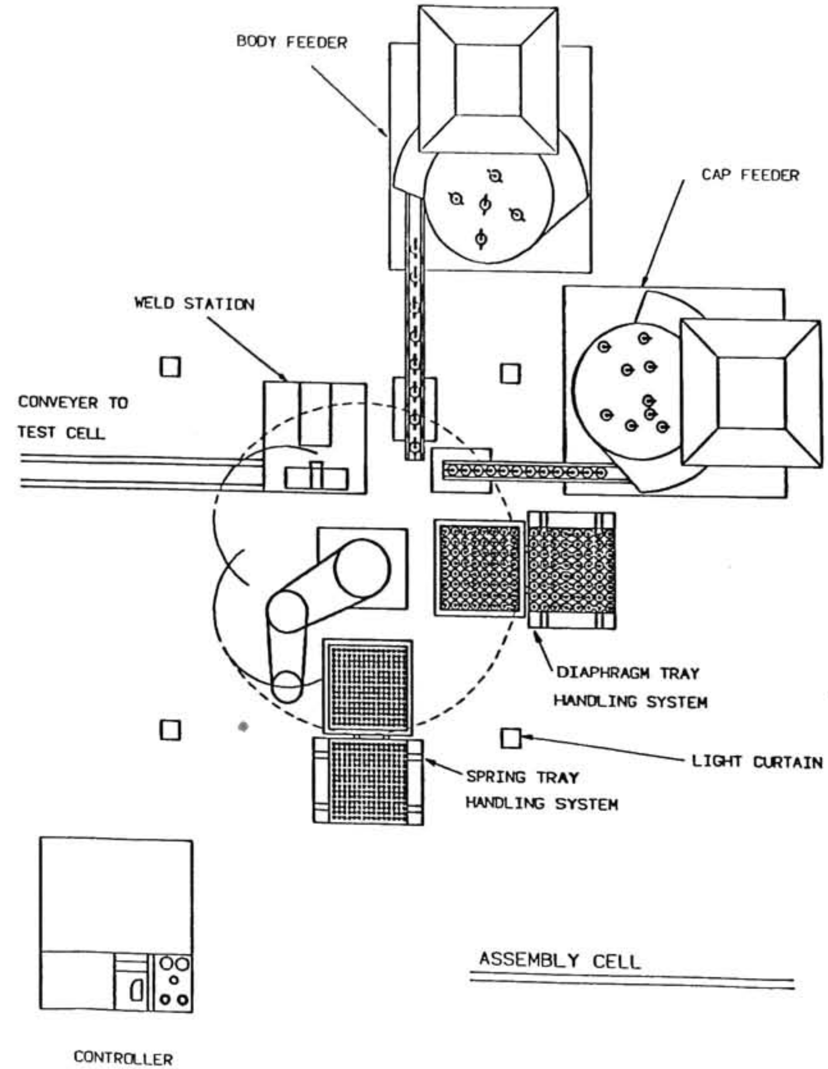


Figure A-3. Valve layout.

APPENDIX B: DESIGN DRAWINGS

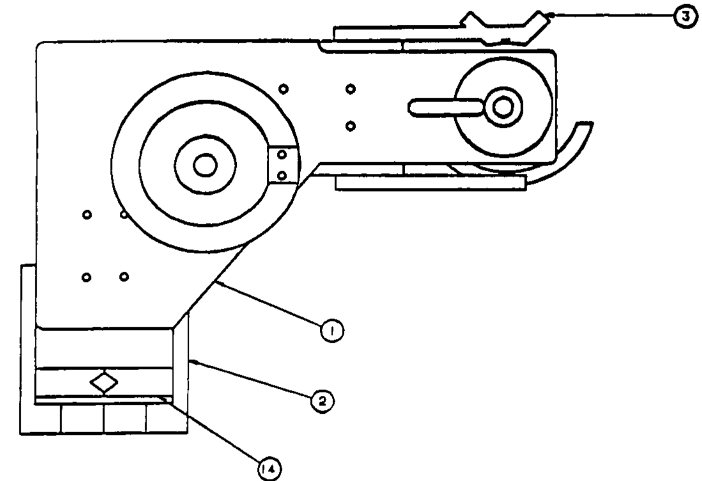


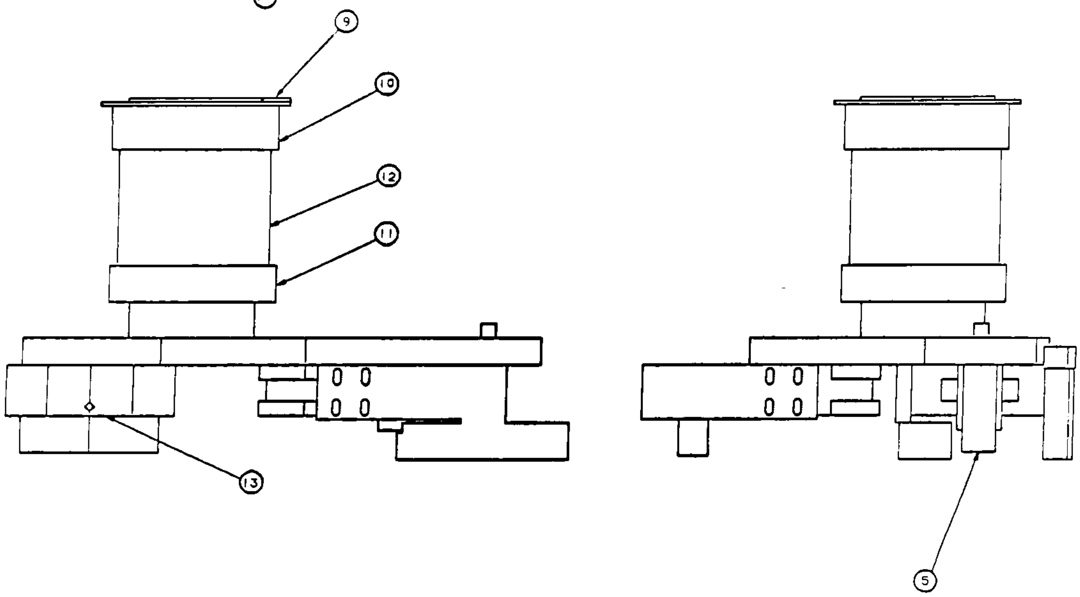
SIMULATED ASSEMBLY CELL

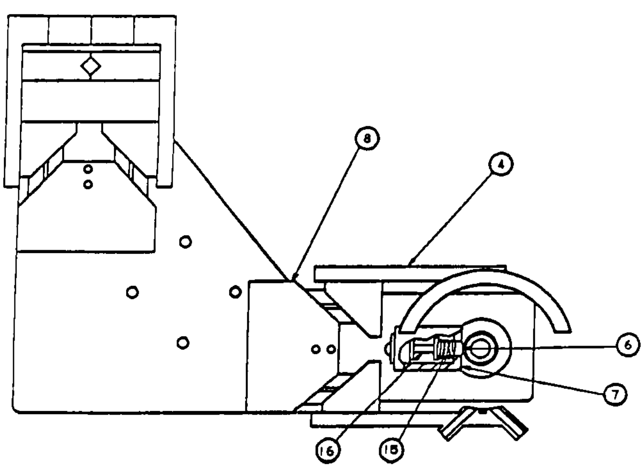


ASSEMBLY CELL

NO.	PART NAME	REQ	MAT'L
1	GRIPPER PLATE	1	ALU
2	CAP AND DIAPHRAGM ARMS	2	ALU
3	BODY HOLDER LEFT	1	ALU
4	BODY HOLDER RIGHT	1	ALU
5	SUCTION PICK UP	1	ALU
6	BELLOWS	1	VINYL
7	BLOCK	1	ALU
8	PHD MINATURE GRIPPER	2	STOCK
9	KEY	1	ALU
10	COMPLIANCE TOP	1	ALU
11	COMPLIANCE BOTTOM	1	ALU
12	COMPLIANCE MID	1	VINYL
13	CAP FINGERS	2	ALU
14	DIAPHRAGM FINGERS	2	ALU
16	SPRING	1	STOCK
16	NAIL	1	STOCK







SCALE .25

AL GATES EX 5206

END-EFFECTOR ASSEMBLY

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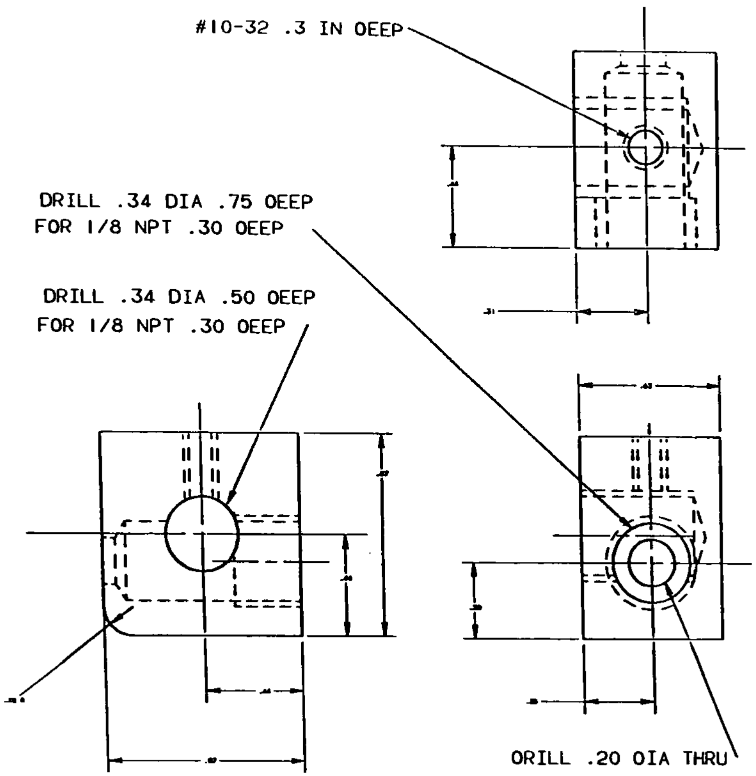
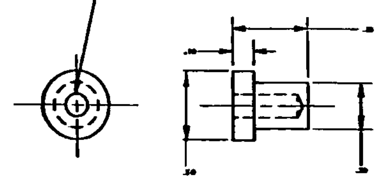


⑦ BLOCK

MAT'L ALU



⑥ BELLOWS

SPRING PICK UP

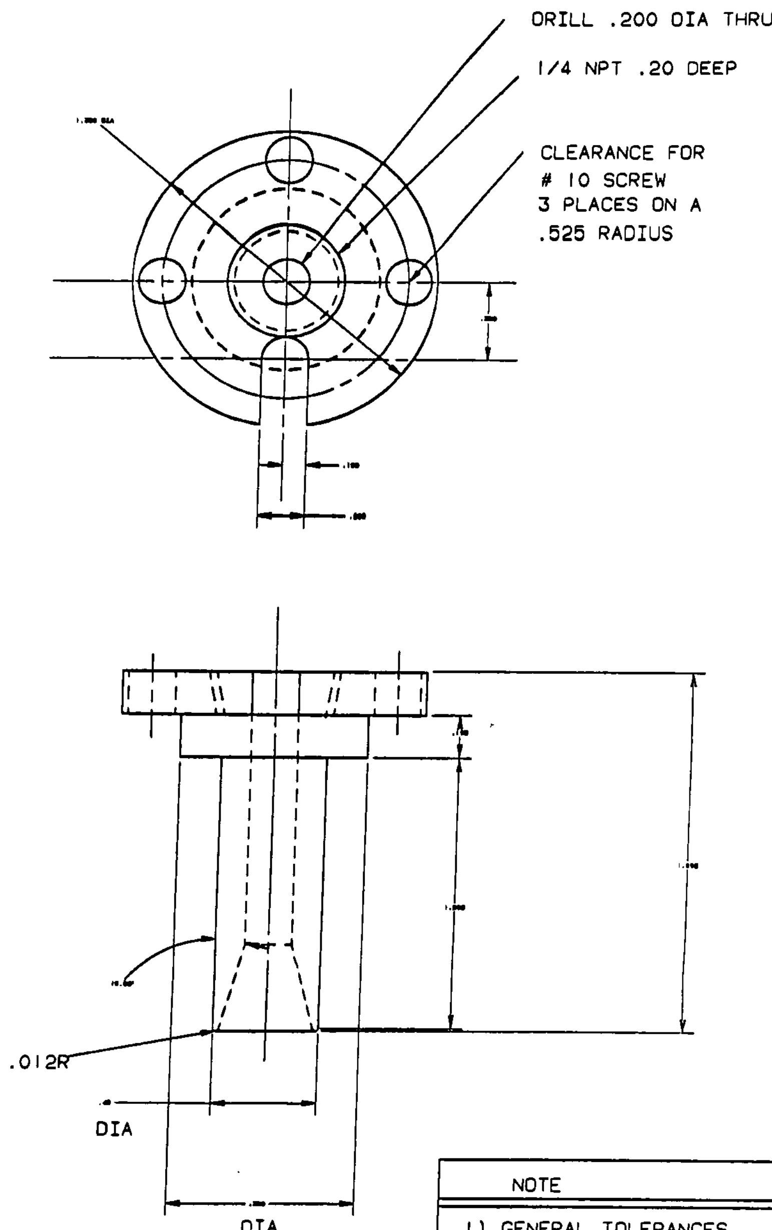
SCALE 3.0

AL GATES EX 5206

PAGE 2/6

NOTE

1) GENERAL TOLERANCES
.00 + OR - .01
.000 + OR - .001
UNLESS OTHER WISE SPECIFIED
2) PART IS TO BE ALUMINUM
3) OIMENSIONS ARE IN INCHES
4) MATERIAL IS TO BE ALUMINUM
UNLESS OTHER WISE SPECIFIED



⑤ SUCTION PICK UP

MAT'L ALU

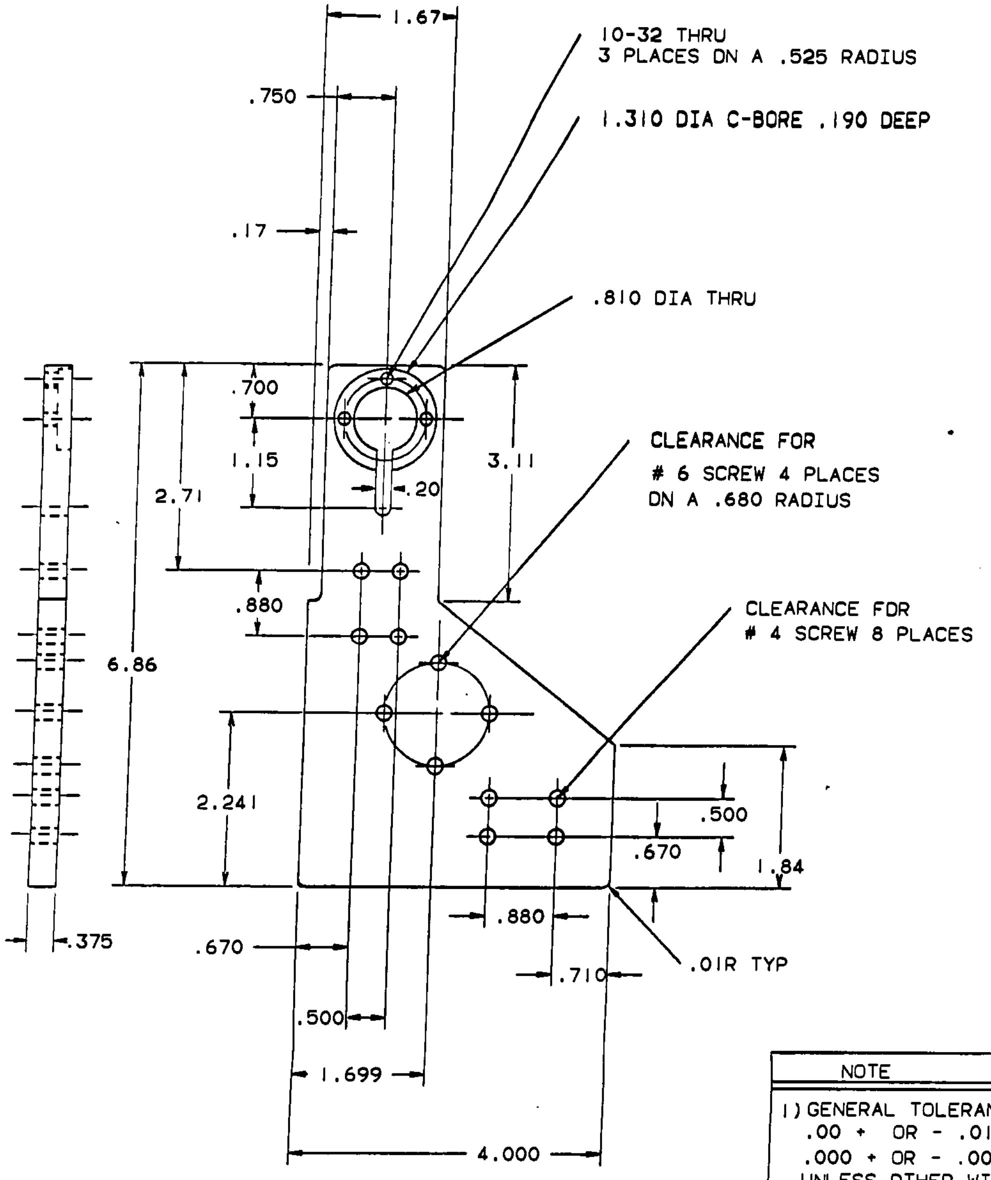
NOTE

1) GENERAL TOLERANCES
.00 + OR - .01
.000 + OR - .001
UNLESS OTHER WISE SPECIFIED
2) DIMENSIONS IN INCHES

SCALE 3.00

AL GATES EX 5206

PAGE 3/6



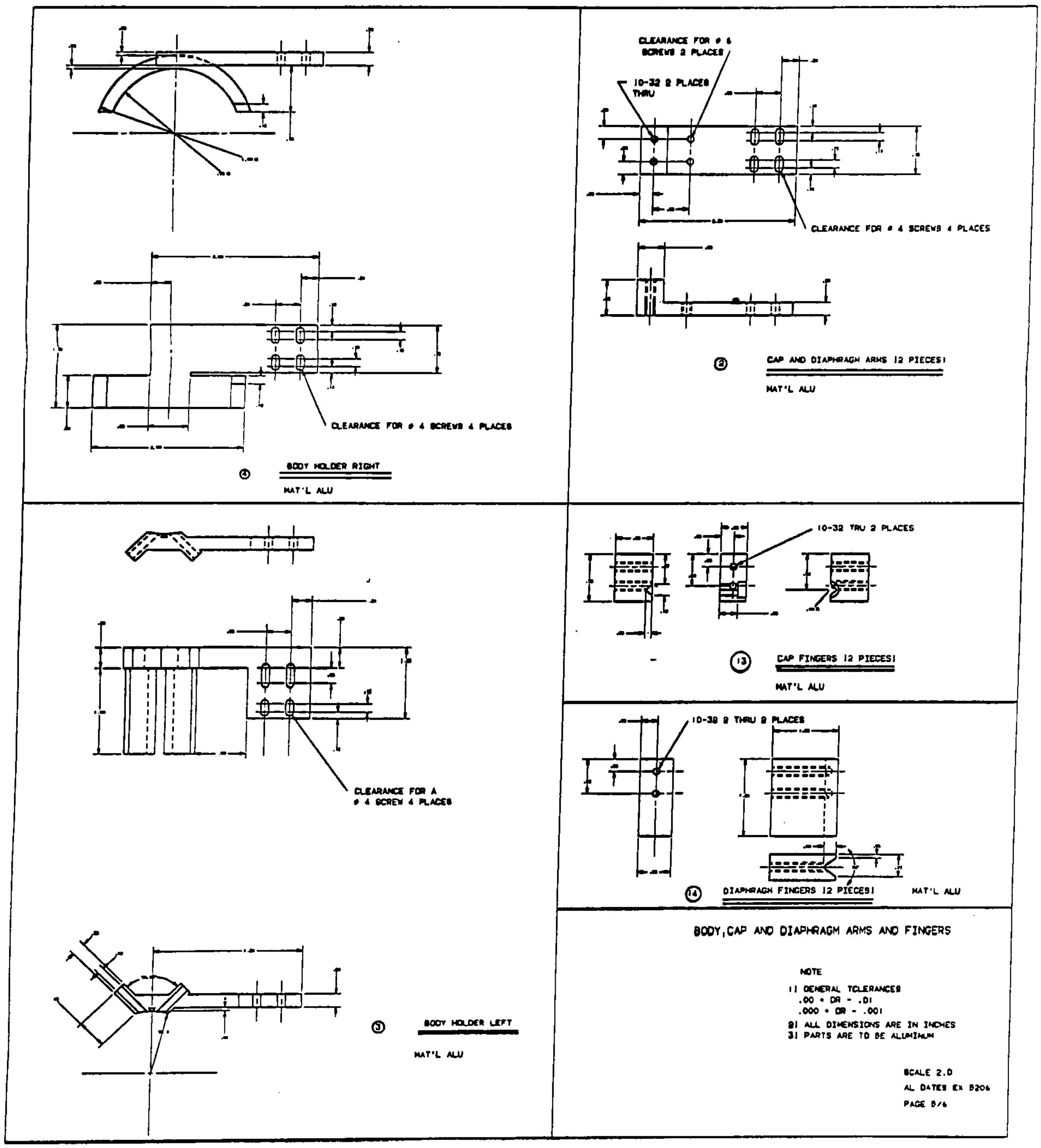
① GRIPPER PLATE

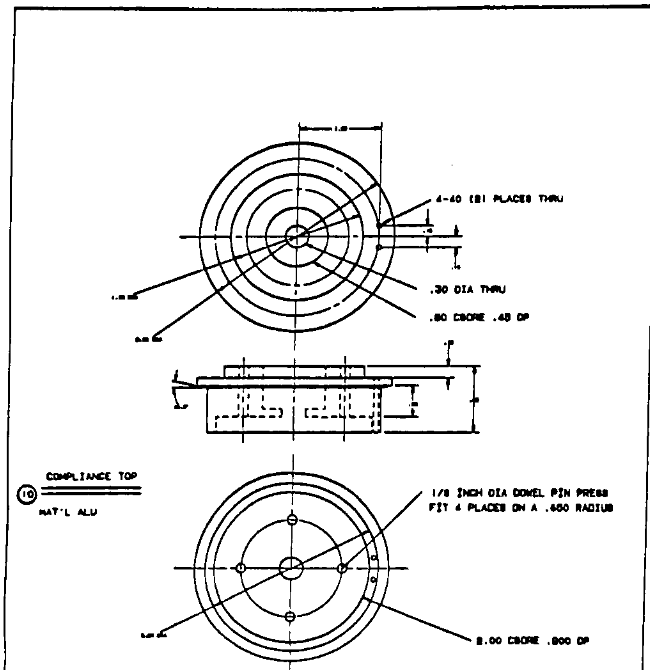
MAT'L ALU

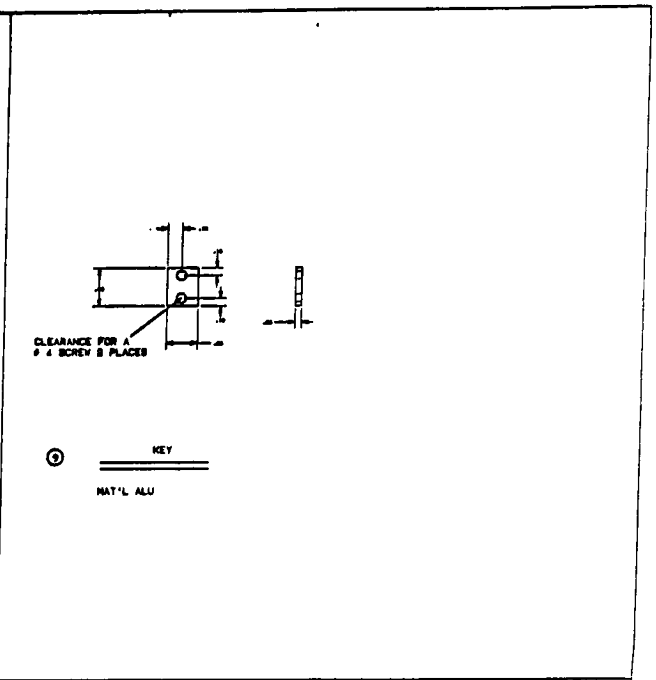
NOTE

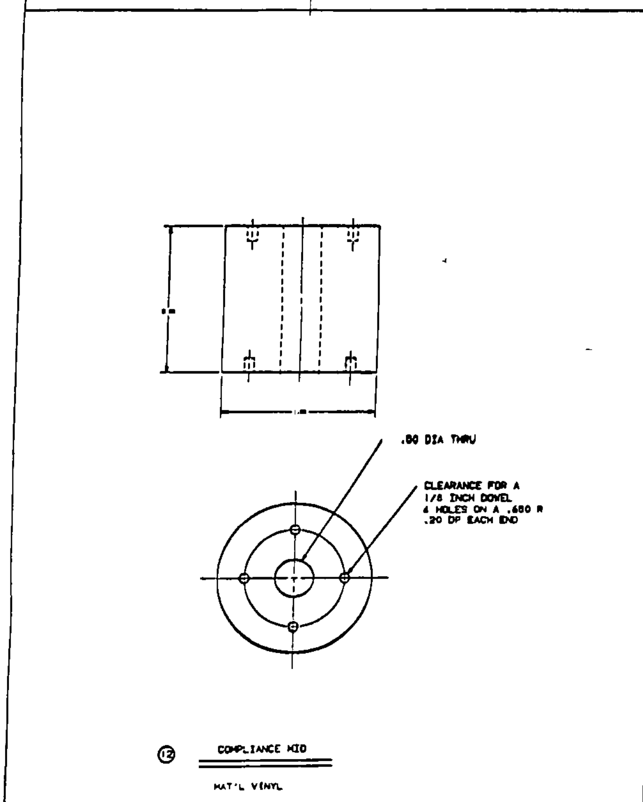
1) GENERAL TOLERANCES
   .00 + OR - .01
   .000 + OR - .001
   UNLESS OTHER WISE SPECIFIED
2) GRIPPER PLATE IS TO BE
   .375 IN THICK ALUMINUM PLATE
3) DIMENSIONS ARE IN INCHES

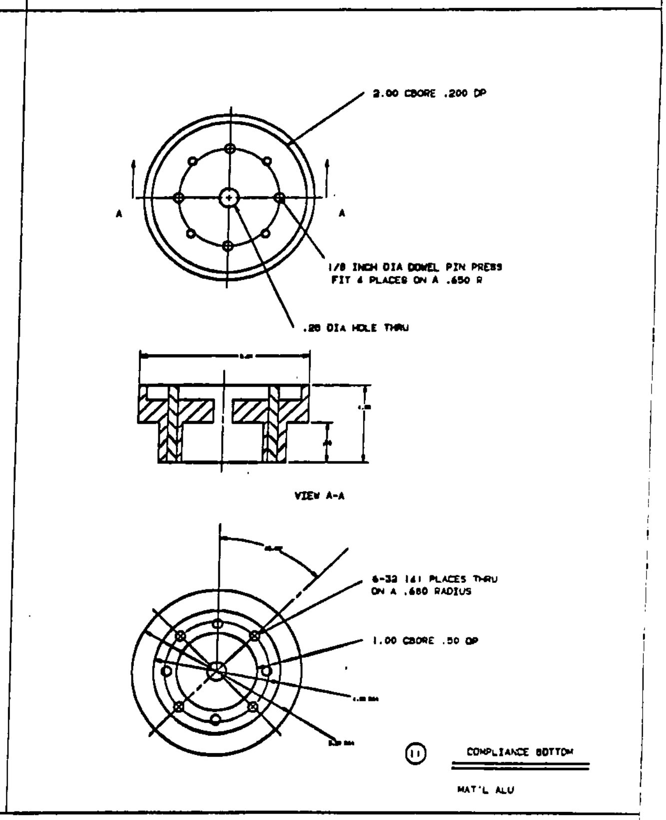
SCALE 1.0
AL GATES EX 5206
PAGE 4/6


CLEARANCE FOR # 6 SCREWS 2 PLACES
10-32 2 PLACES THRU
CLEARANCE FOR # 4 SCREWS 4 PLACES
② CAP AND DIAPHRAGH ARMS (2 PIECES)
MAT'L ALU
CLEARANCE FOR # 4 SCREWS 4 PLACES
④ BODY HOLDER RIGHT
MAT'L ALU
10-32 TRU 2 PLACES
⑬ CAP FINGERS (2 PIECES)
MAT'L ALU
10-32 2 THRU 2 PLACES
⑭ DIAPHRAGH FINGERS (2 PIECES)
MAT'L ALU
CLEARANCE FOR A # 4 SCREW 4 PLACES
③ BODY HOLDER LEFT
MAT'L ALU
BODY, CAP AND DIAPHRAGM ARMS AND FINGERS
NOTE
1) GENERAL TOLERANCES
.00 + OR - .01
.000 + OR - .001
2) ALL DIMENSIONS ARE IN INCHES
3) PARTS ARE TO BE ALUMINUM
SCALE 2.0
AL DATES EX 8206
PAGE 8/6









COMPLIANCE DEVICE

NOTE
1) GENERAL TOLERANCES
.00 + OR - .01
.650 + OR - .001
UNLESS OTHER WISE SPECIFIED
2) DIMENSIONS ARE IN INCHES
3) PARTS ARE TO BE ALUMINUM
UNLESS OTHER WISE SPECIFIED

SCALE 2.00
AL GATES EX 8206
PAGE 6/8

APPENDIX C: ASSEMBLY CELL DATA

RAW DATA FOR THE ORIGINAL END-EFFECTOR

RUN #	CYCLE TIME (sec)	# OF PARTS NOT ASSEMBLED	CAUSE
1	10.2	15	15 Diaphragms not picked up
2	"	13	13 "
3	"	10	10 "
4	"	14	14 "

TOTAL CYCLES 100
TOTAL RUNS 4
25 CYCLES PER RUN

REDUCED DATA

NUMBER OF COMPLETED PARTS		48
PERCENT OF COMPLETED PARTS		48%
PROBLEM	TIMES HAPPENED	% OF REJECTED PARTS
1) DIAPHRAGM NOT PICKED UP	52	100

RAW DATA FOR THE BACK UP END-EFFECTOR

RUN #	CYCLE TIME (sec)	# OF PARTS NOT ASSEMBLED	CAUSE
1	12.1	None	
2	"	1	Spring not picked up
3	"	1	Spring fell over in nest
4	"	2	Body not picked up Diaphragm not picked up
5	"	None	
6	"	None	
7	"	None	
8	"	None	
9	"	1	Spring not picked up
10	"	2	Diaphragm not picked up Body not positioned in weld nest
11	"	None	
12	"	None	
13	"	1	Spring not picked up
14	"	1	Spring not picked up
15	"	1	Diaphragm not picked up
16	"	None	
17	"	None	
18	"	None	
19	"	None	
20	"	1	Spring not picked up
21	"	None	
22	"	1	Cap not picked up
23	"	2	Diaphragm not picked up Body not positioned correctly in the weld nest
24	"	2	Body not positioned correctly in the weld nest Spring fell over in the nest
25	"	2	Diaphragm poorly placed in the body Spring fell over in the nest
26	"	1	Spring not picked up
27	"	1	Diaphragm not picked up
28	"	None	

29	"	3	Spring not picked up Diaphragm not picked up Spring fell over in nest
30	"	None	
31	"	None	
32	"	2	Diaphragm poorly placed into body Spring fell over in nest
33	"	1	Spring not picked up
34	"	2	Body not positioned correctly in weld nest Spring fell over in the nest
35	"	1	Spring fell over in the nest
36	"	1	Diaphragm not picked up
37	"	3	Body not positioned correctly in the weld nest Spring fell over in nest
38	"	1	Spring fell over in nest
39	"	None	
40	"	None	

Total Cycles 1000   Total Runs 40   25 Cycles per Run

REDUCED DATA

NUMBER OF COMPLETED PARTS 970

PERCENT OF COMPLETED PARTS 97.0%

PROBLEM	TIMES HAPPEN	% OF REJECTED PARTS
1) Spring not picked up	8	25
2) Diaphragm not picked up	6	21
3) Body not picked up	1	2
4) Cap not picked up	1	2
5) Spring fell over in nest	9	30
6) Diaphragm poorly placed in body	2	5
7) Body not incorrectly placed in weld nest	5	15

APPENDIX D: PICTURES OF THE FEEDERS, END-EFFECTOR AND PROCESS FLOW OF THE SIMULATED CELL

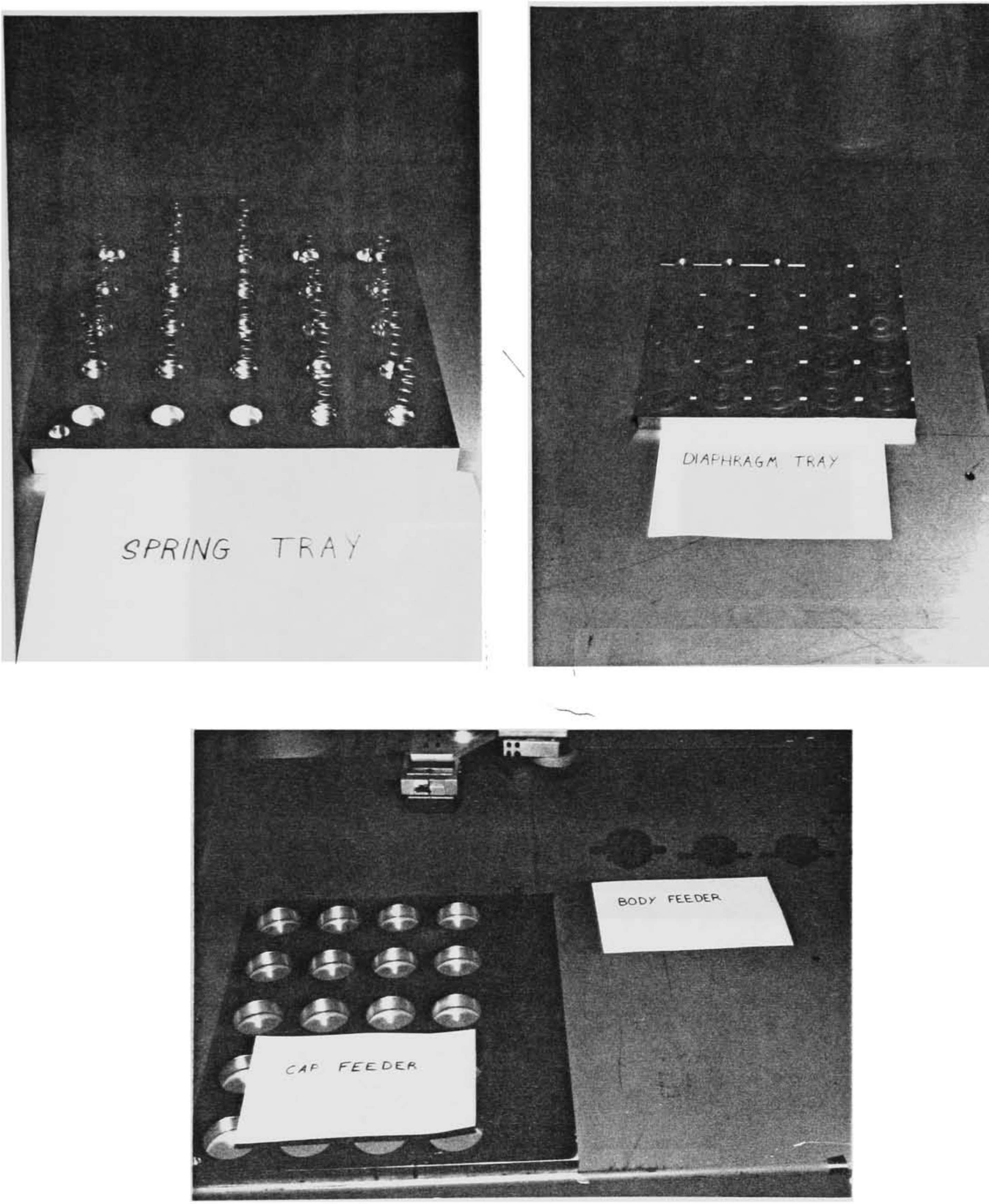


Figure D-1. Simulated Trays and Feeders

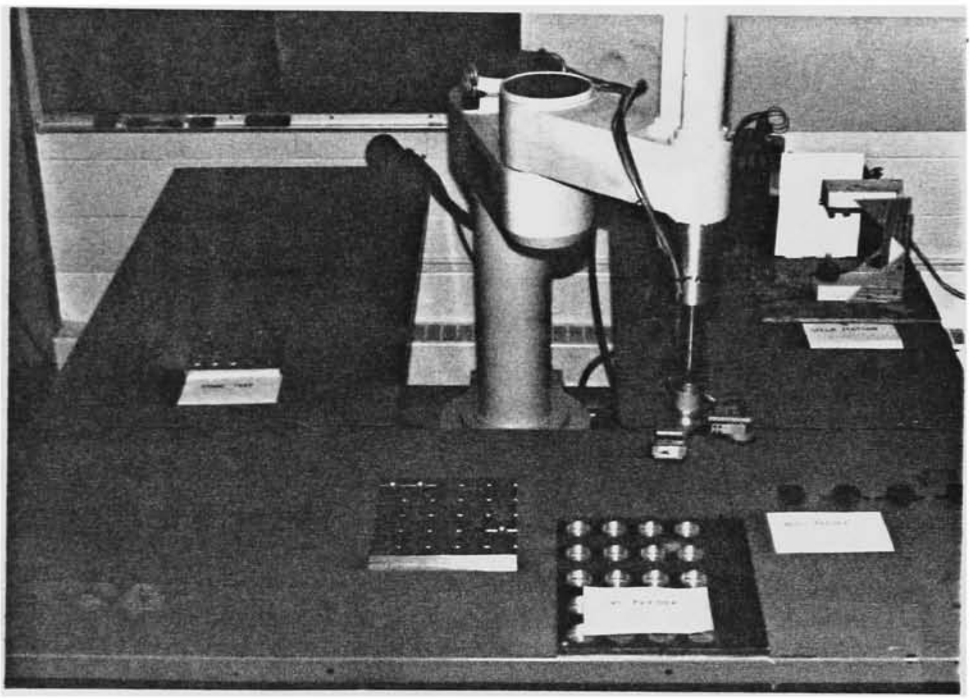


Figure D-2. Simulated Cell

Process Flow

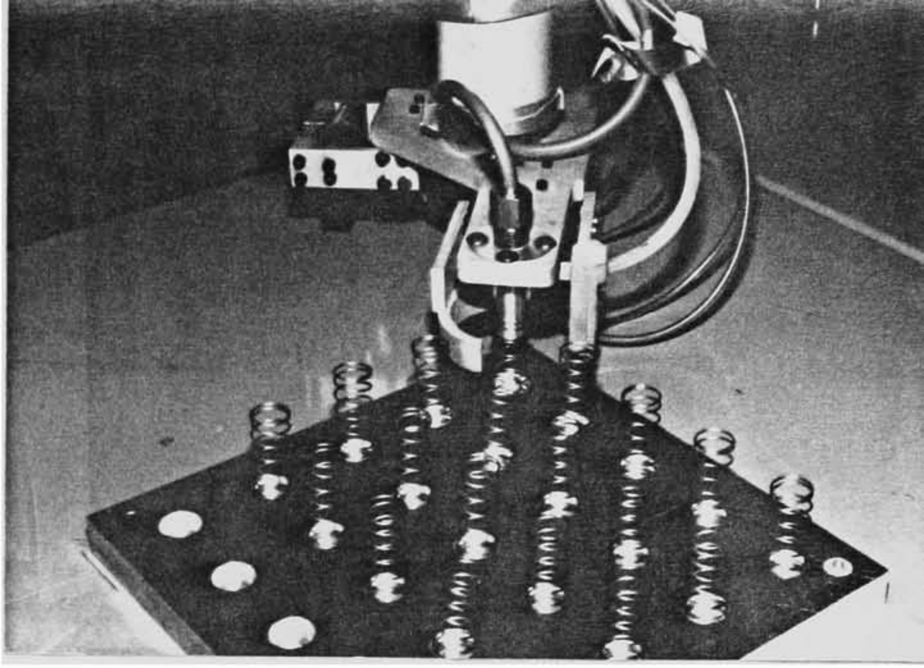


Figure D-3.
Spring Pick Up

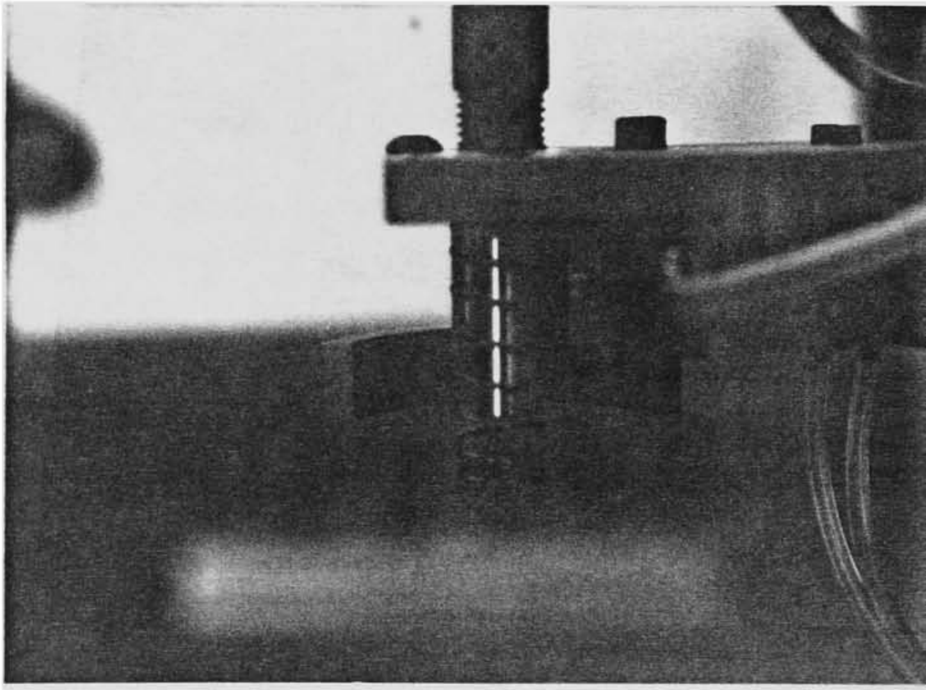


Figure D-4.
Spring Held By
a Bellows

Figure D-5.
Diaphragm Pick Up

Figure D-6.
Place Diaphragm
in Body

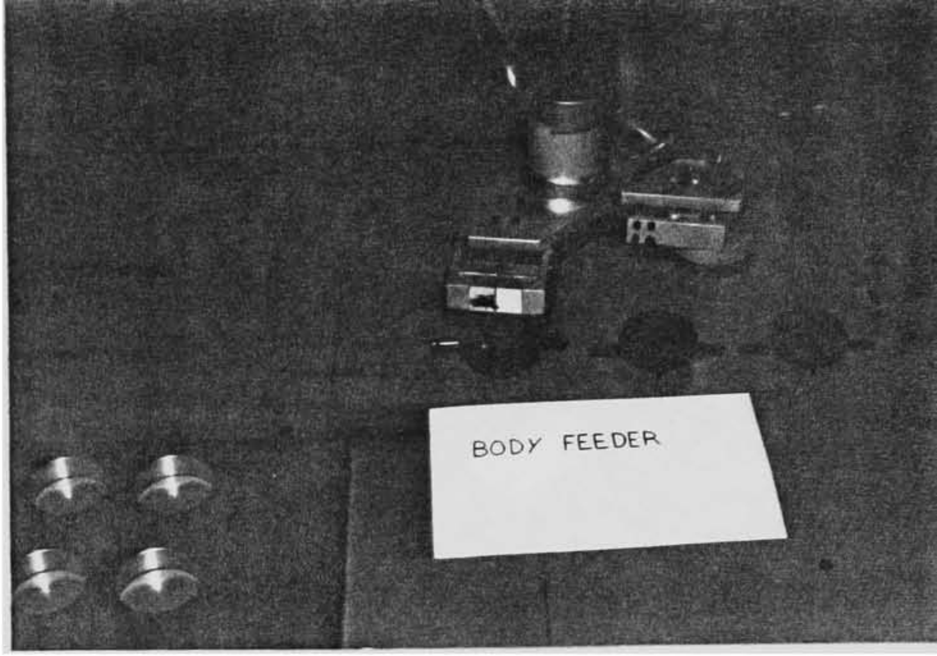


Figure D-7.
Pick Up Cap
and Body

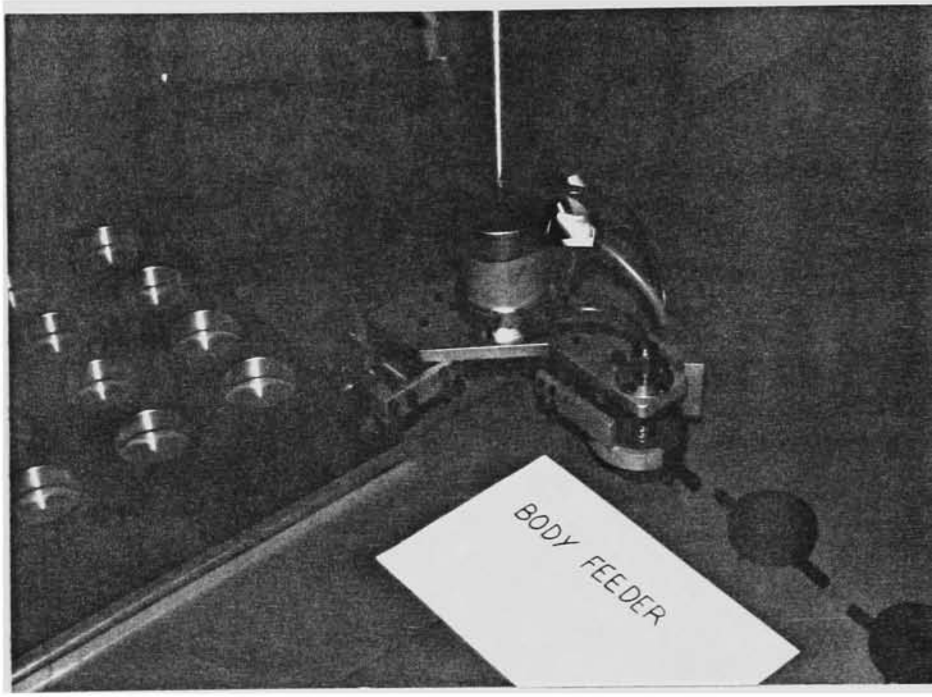
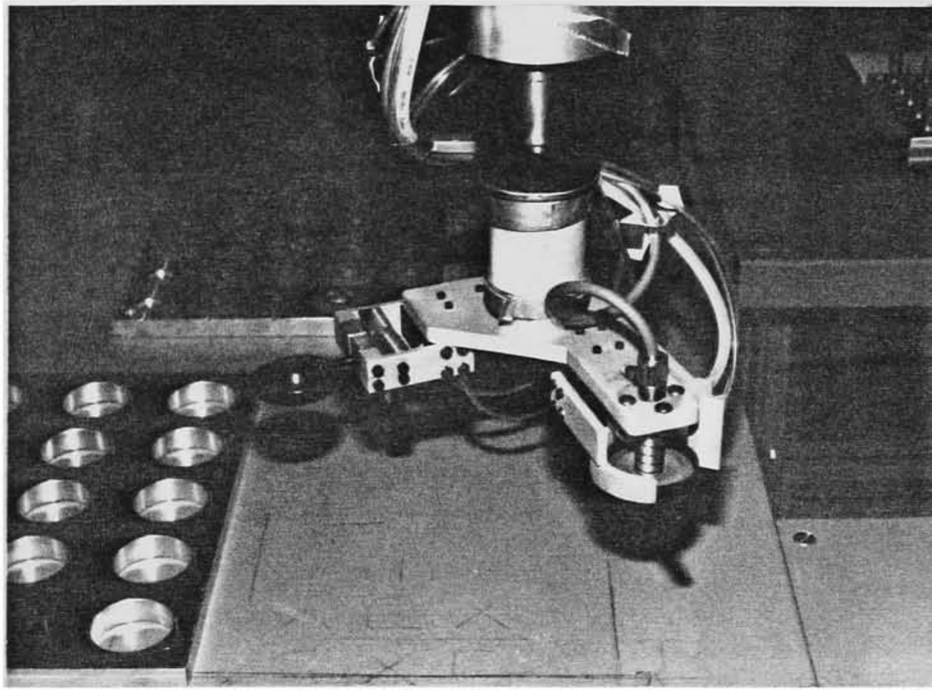


Figure D-8.
Move End-Effector



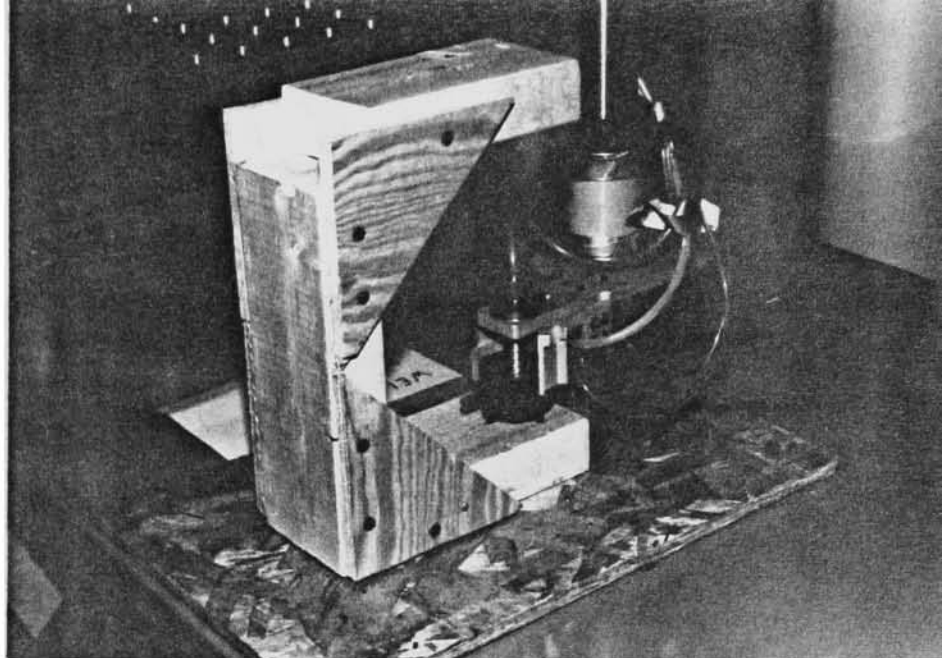


Figure D-9.
Drop off Body
Spring and
Diaphragm in
Simulated Weld
Nest

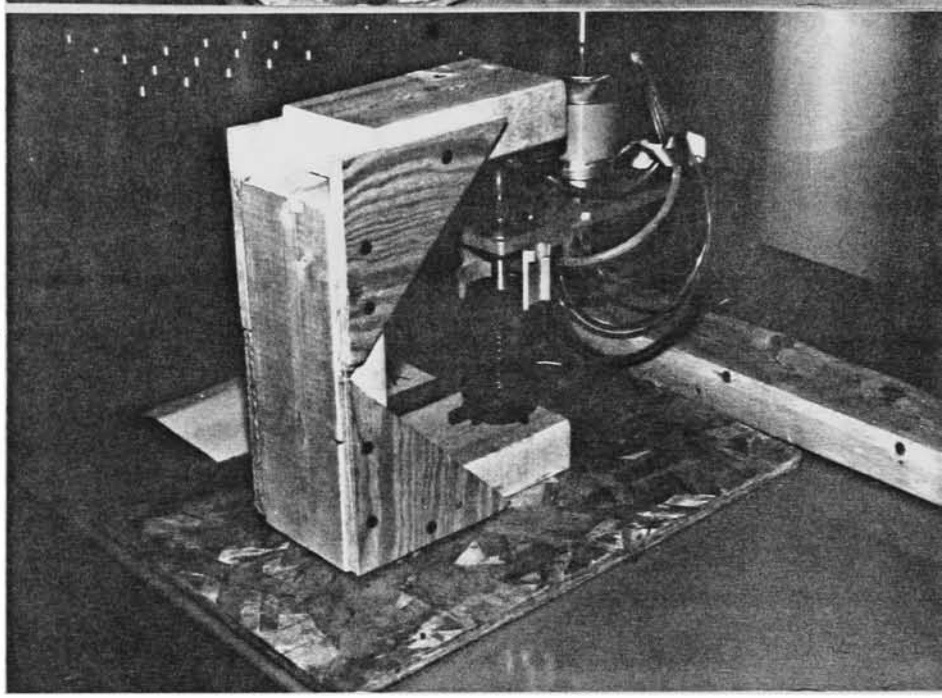


Figure D-10.
Move End-Effector

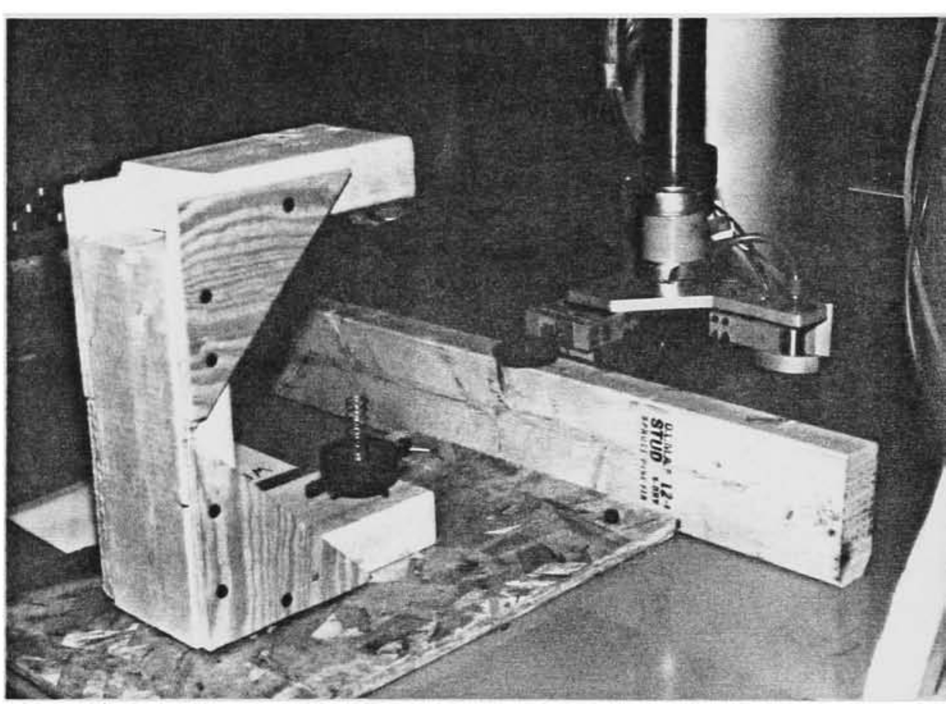


Figure D-11.
Drop off Cap

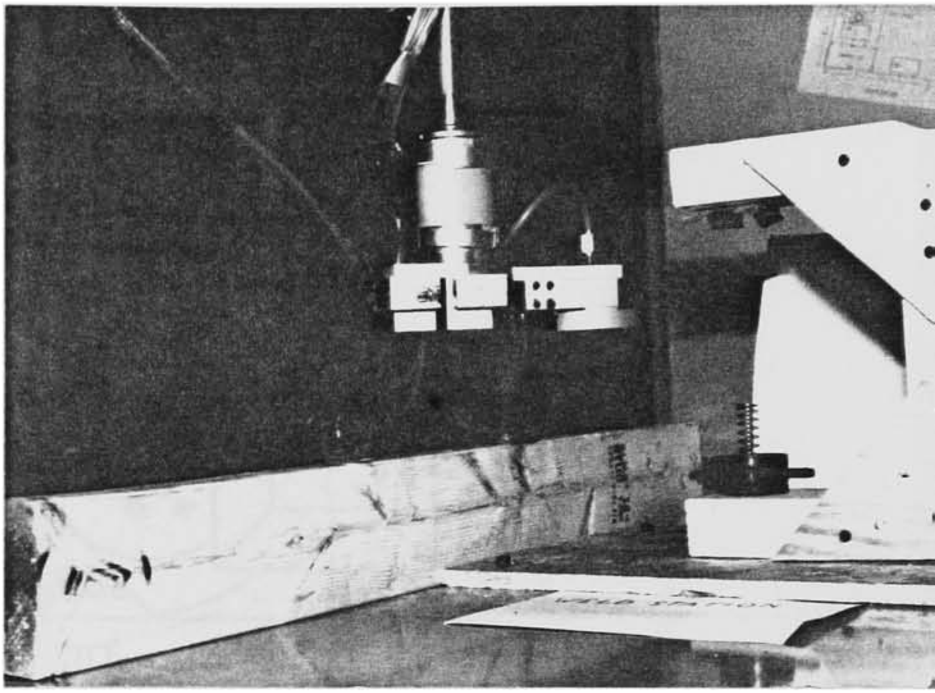
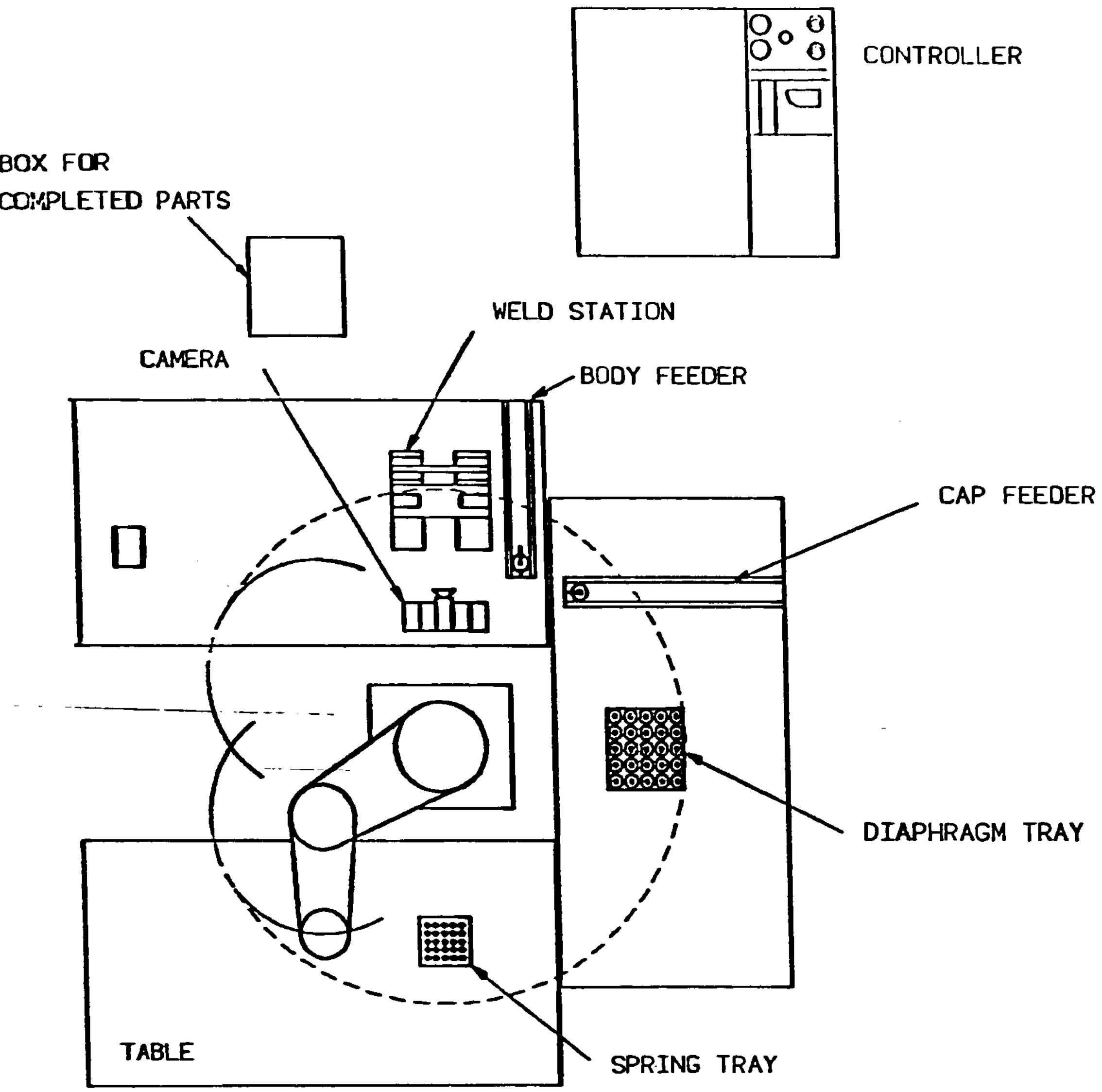
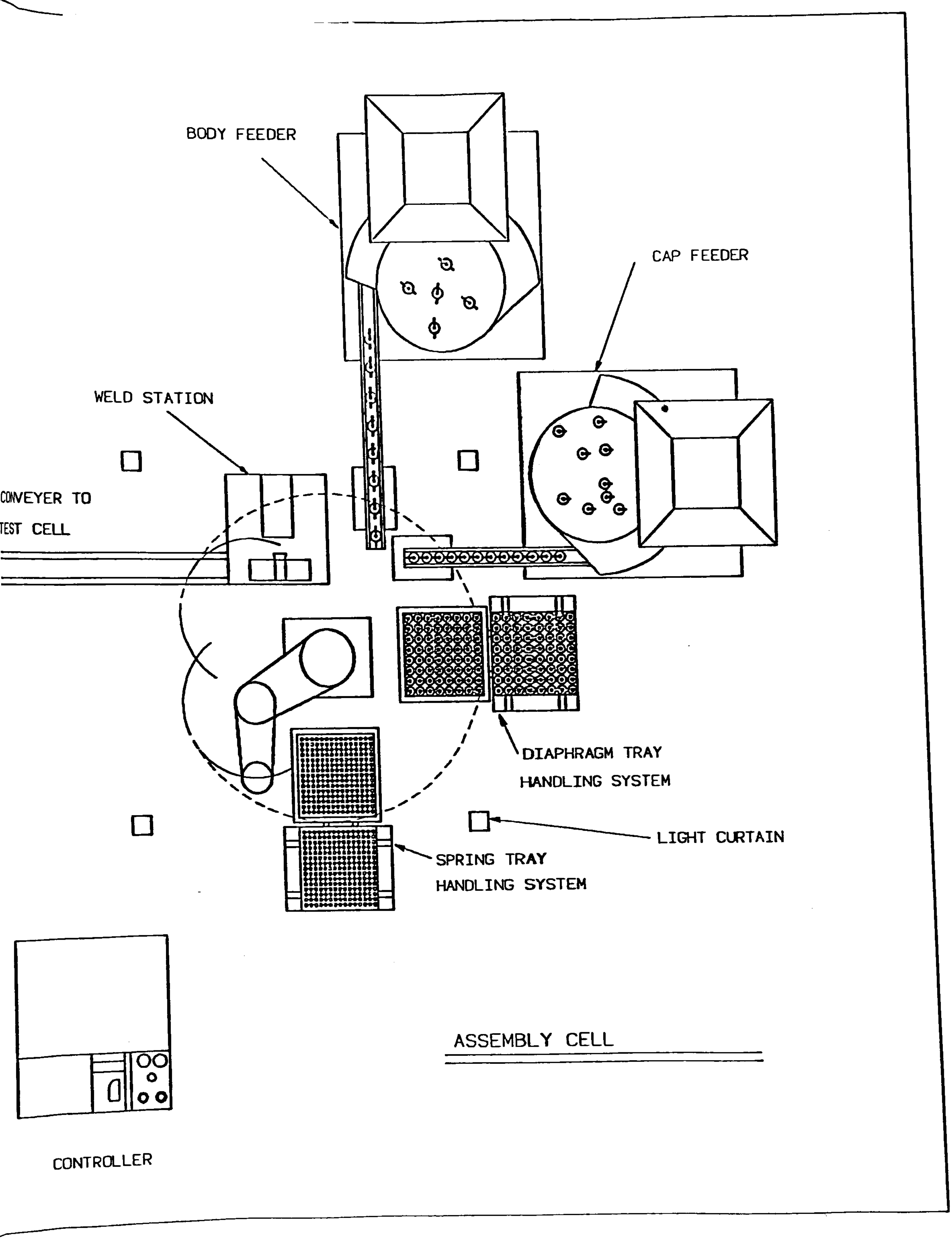


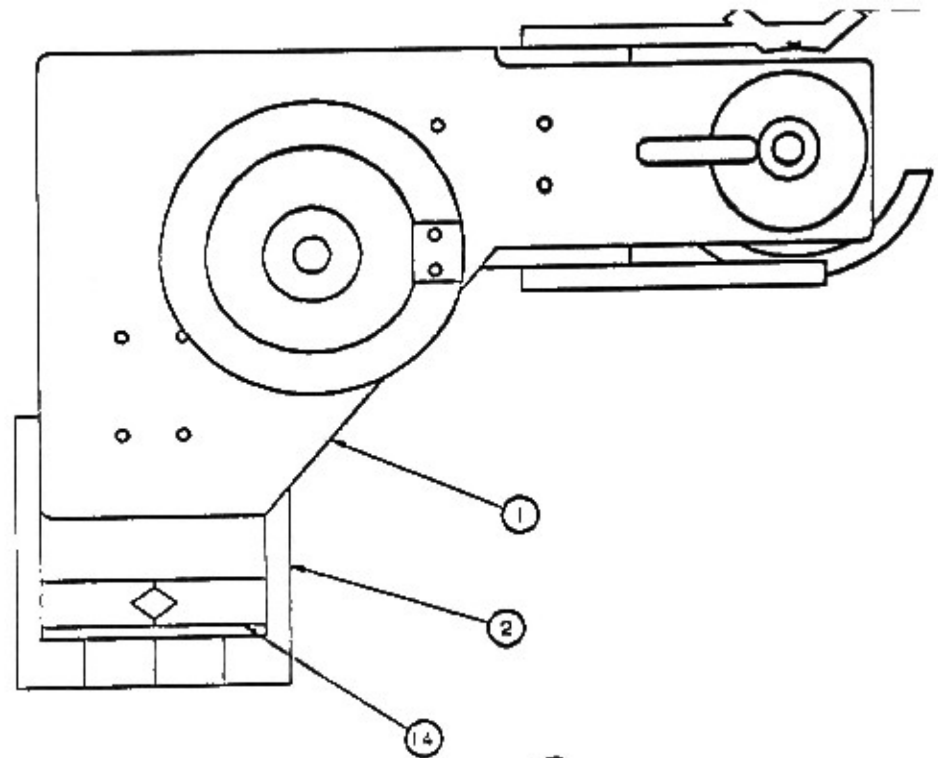
Figure D-12.
Move End-Effector
to Spring Tray

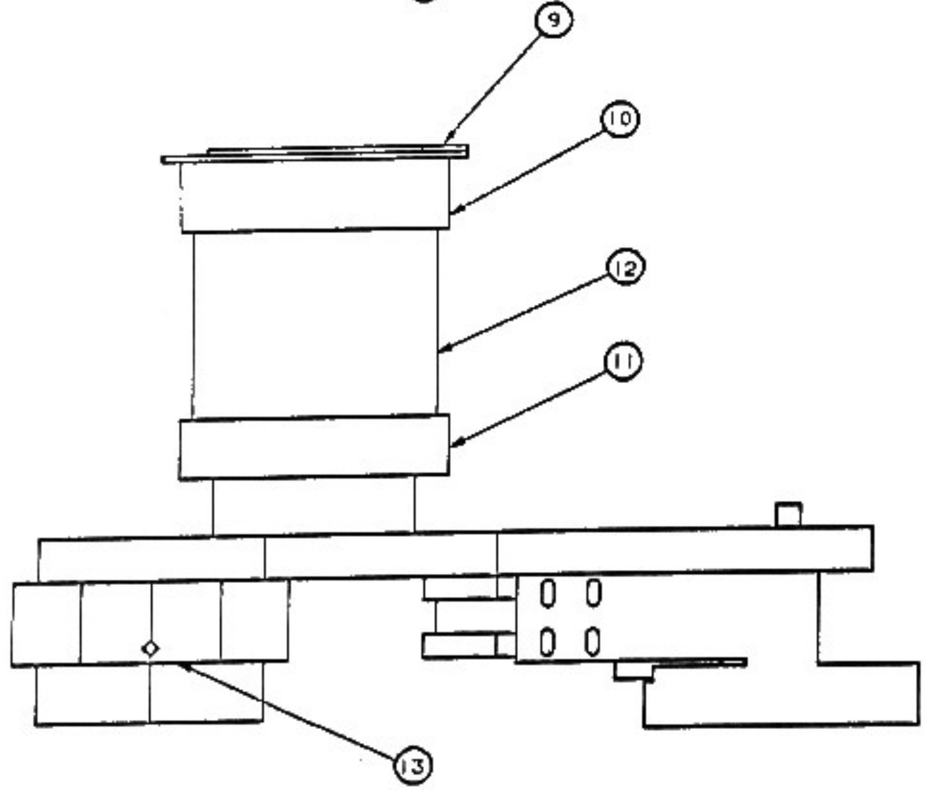


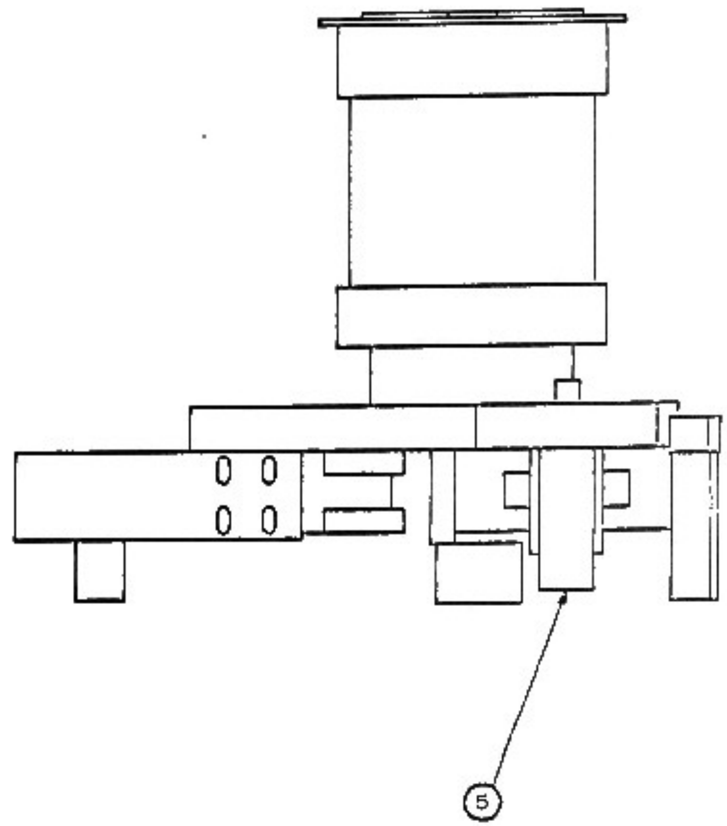
SIMULATED ASSEMBLY CELL

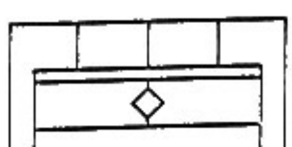

BODY FEEDER
CAP FEEDER
WELD STATION
CONVEYER TO
TEST CELL
DIAPHRAGM TRAY
HANDLING SYSTEM
LIGHT CURTAIN
SPRING TRAY
HANDLING SYSTEM
ASSEMBLY CELL
CONTROLLER

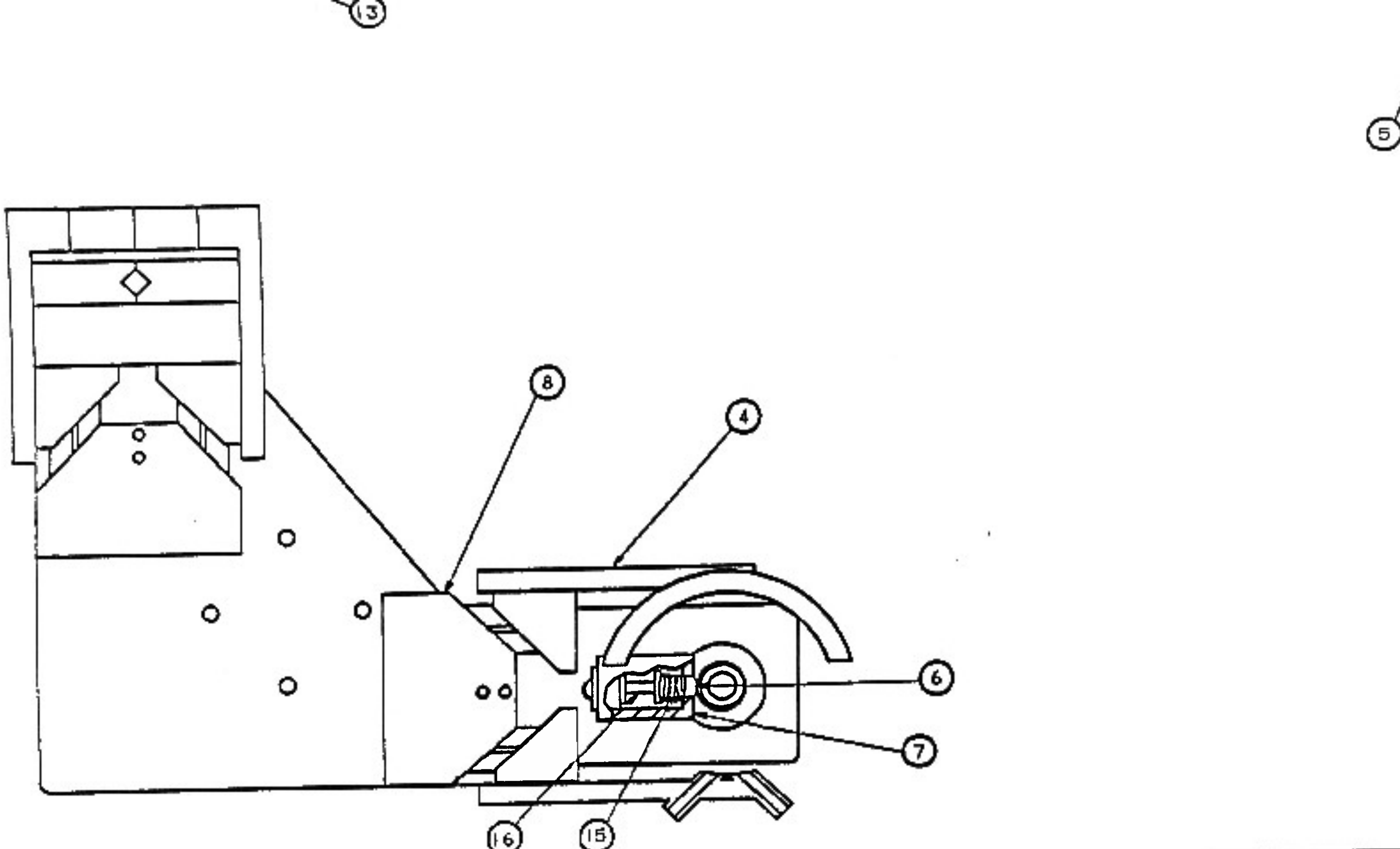
3	BODY HOLDER LEFT	[illegible]	[illegible]
4	BODY HOLDER RIGHT	1	AL
5	SUCTION PICK UP	1	A
6	BELLOWS	1	V
7	BLOCK	1	A
8	PHD MINATURE GRIPPER	2	S
9	KEY	1	A
10	COMPLIANCE TOP	1	A
11	COMPLIANCE BOTTOM	1	A
12	COMPLIANCE MID	1	V
13	CAP FINGERS	2	A
14	DIAPHRAGM FINGERS	2	A
15	SPRING	1	S
16	NAIL	1	S











SCALE .25

AL GATES EX 5206

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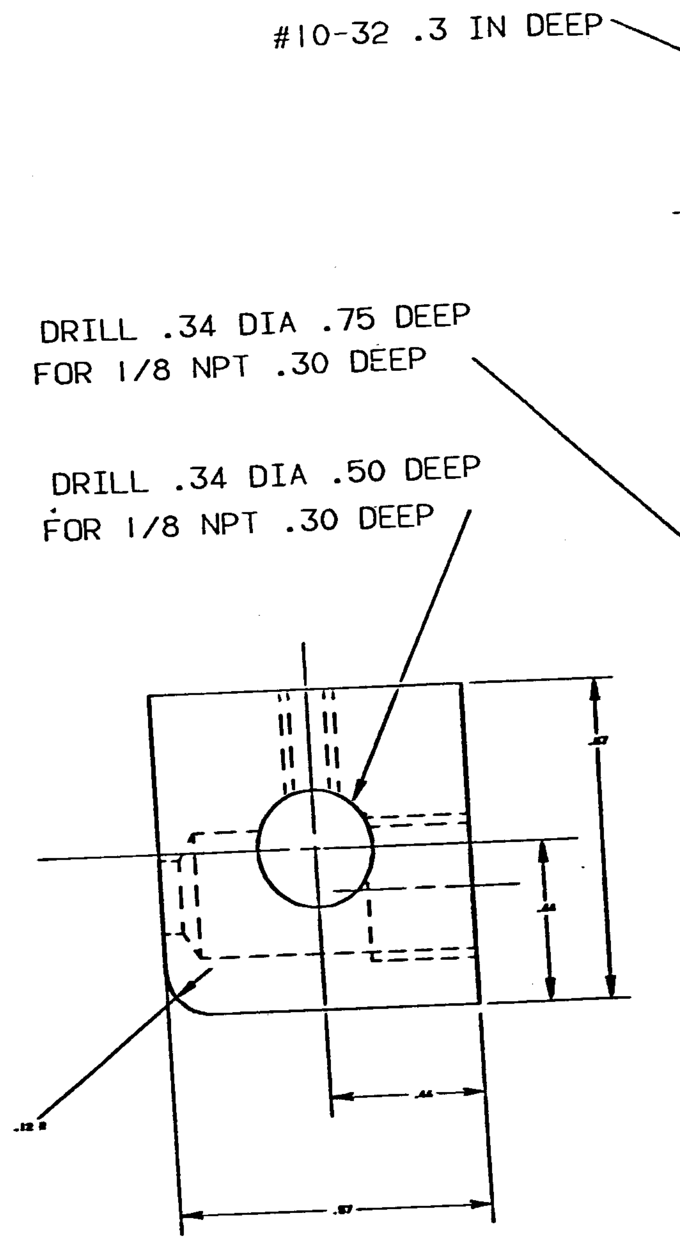
ENO-EFFECTOR ASSEMBLY

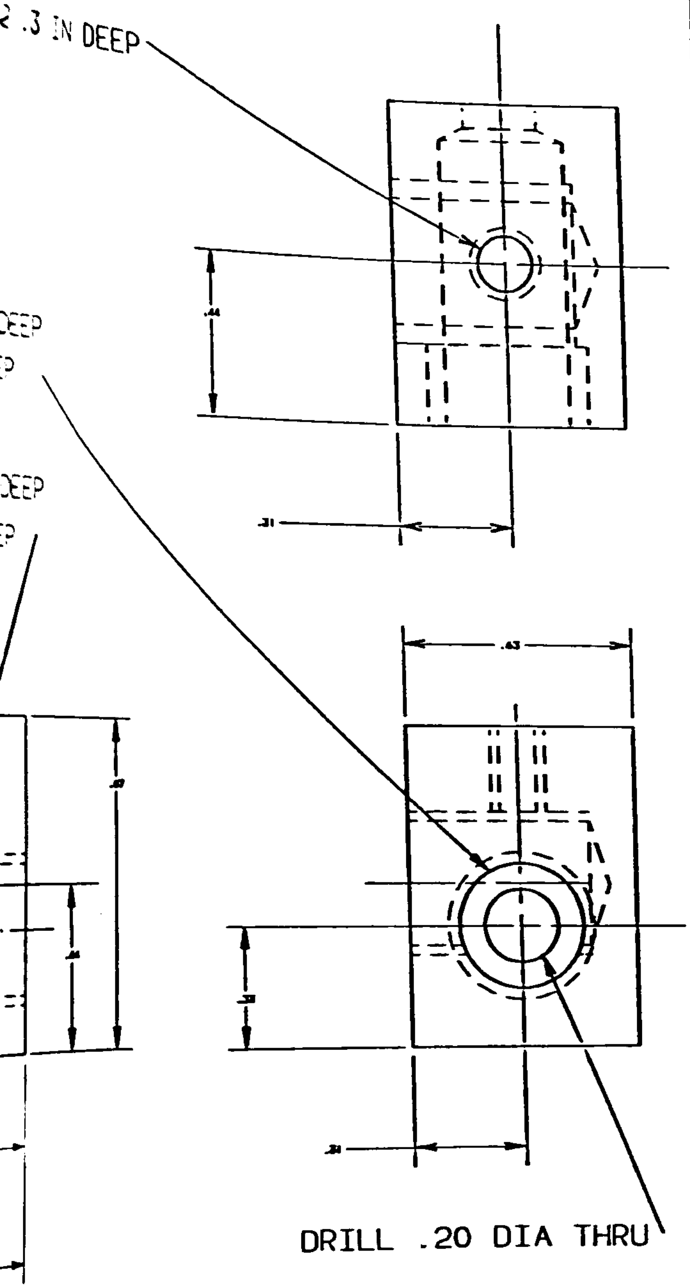


7

BLOC

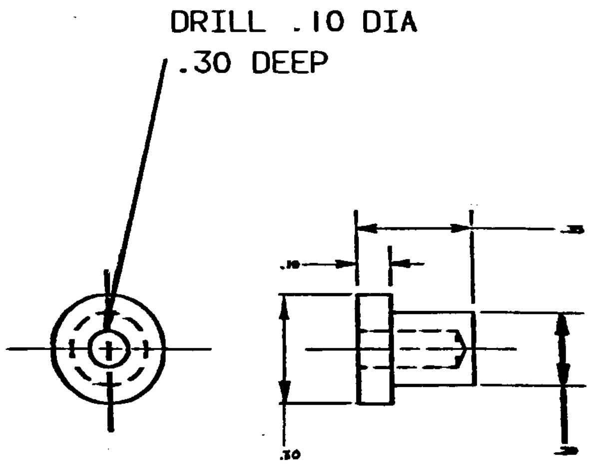
MAT'

SPRING PICK UP



BLOCK

MAT'L ALU



MAT'L VINYL

⑥ BELLDWS

CK UP

SCALE 3.0

AL GATES EX 5206

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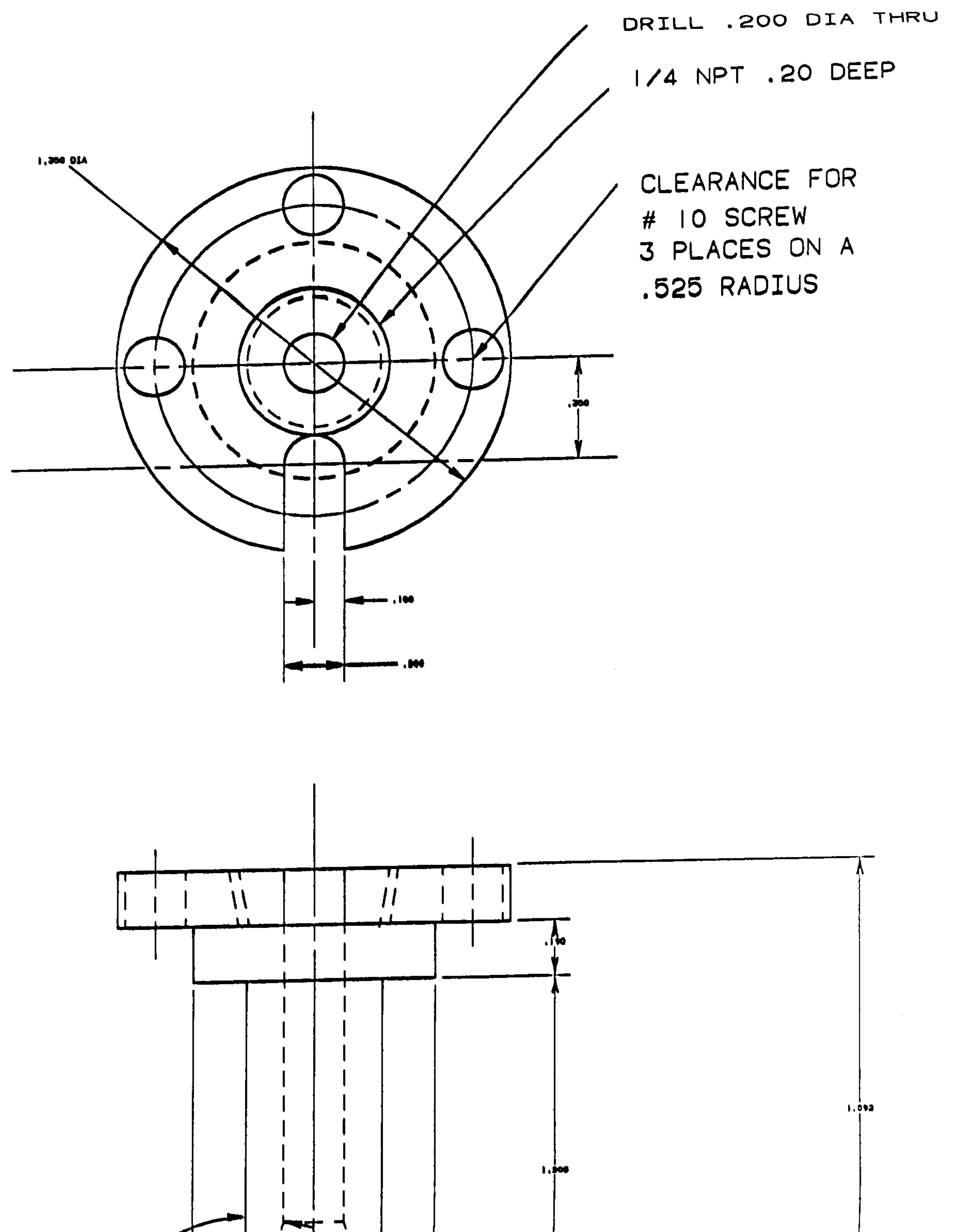
NOTE

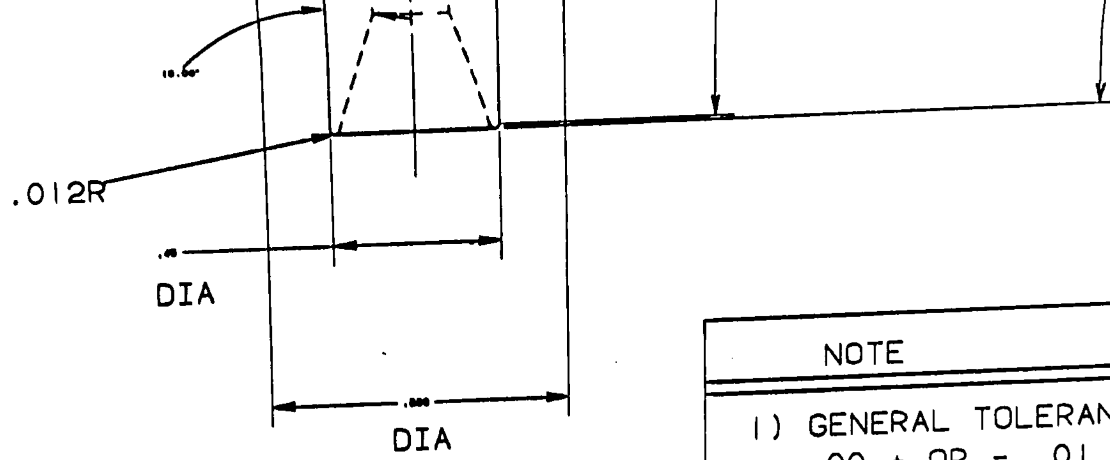
1) GENERAL TOLERANCES
.00 + OR - .01
.000 + OR - .001
UNLESS OTHER WISE SPECI

2) PART IS TO BE ALUMINU

3) DIMENSIONS ARE IN INC

4) MATERIAL IS TO BE ALU
UNLESS OTHER WISE SPECI


DRILL .200 DIA THRU
1/4 NPT .20 DEEP
CLEARANCE FOR
10 SCREW
3 PLACES ON A
.525 RADIUS



(5) SUCTION PICK UP

MAT'L ALU

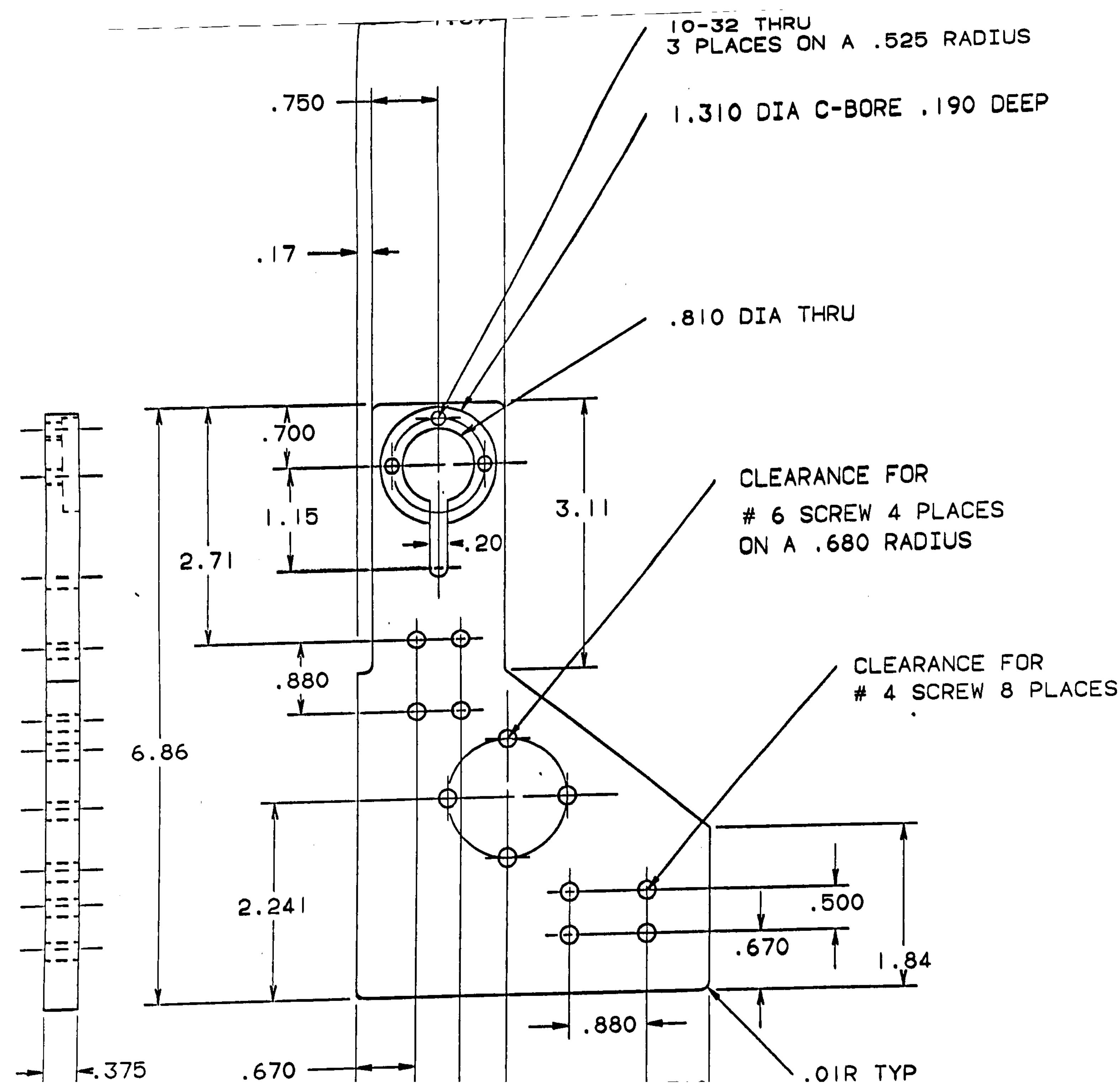
NOTE

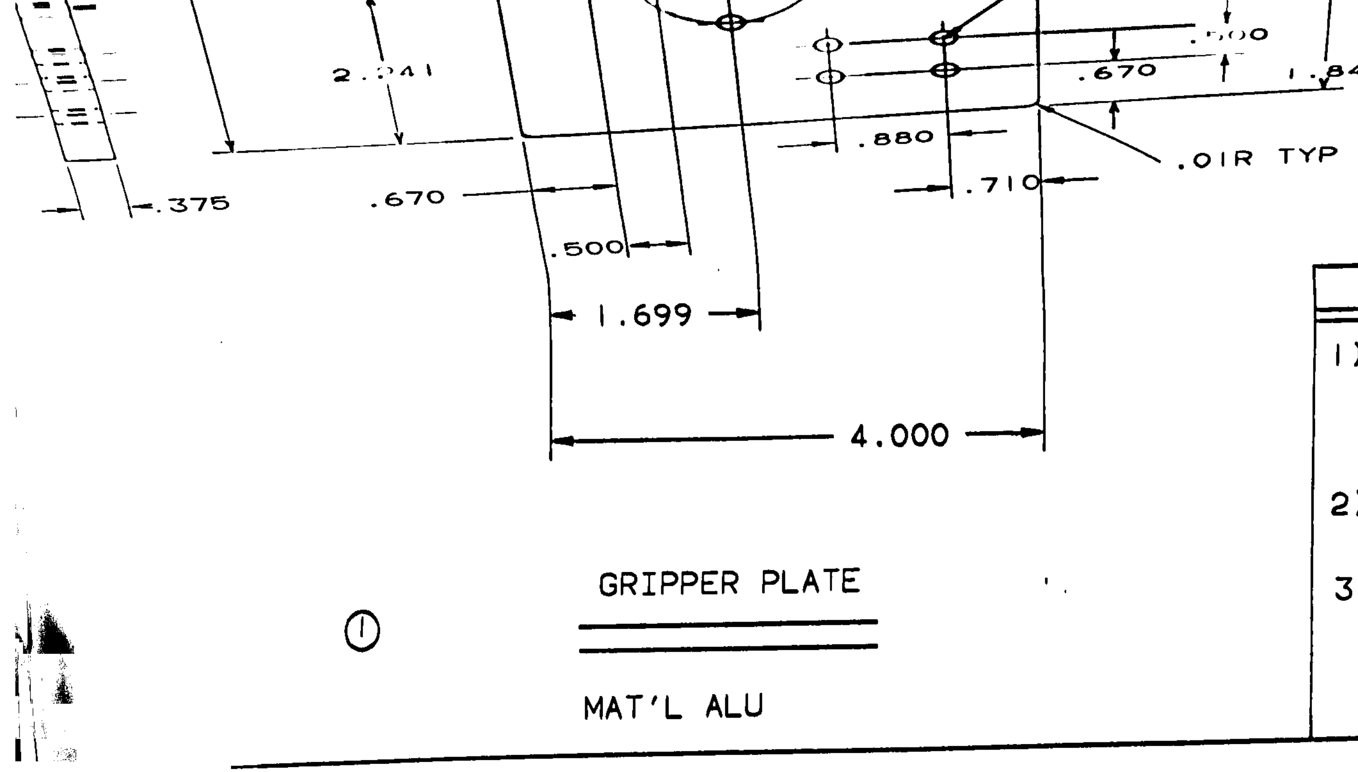
1) GENERAL TOLERANCES
.00 + OR - .01
.000 + OR - .001
UNLESS OTHER WISE SPECIFIED
2) DIMENSIONS IN INCHES

SCALE 3.00

AL GATES EX 5206

PAGE 3/6

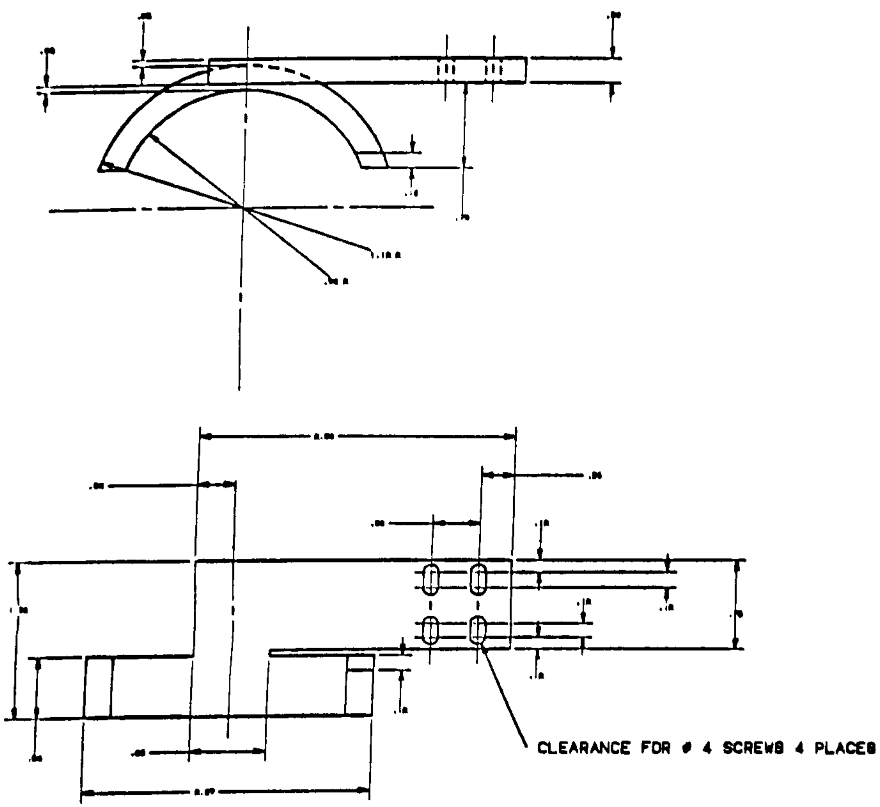

10-32 THRU
3 PLACES ON A .525 RADIUS
1.310 DIA C-BORE .190 DEEP
.810 DIA THRU
CLEARANCE FOR
6 SCREW 4 PLACES
ON A .680 RADIUS
CLEARANCE FOR
4 SCREW 8 PLACES
.750
.17
.700
1.15
.20
2.71
3.11
.880
6.86
2.241
.500
.670
1.84
.880
.375
.670
.01R TYP



NOTE

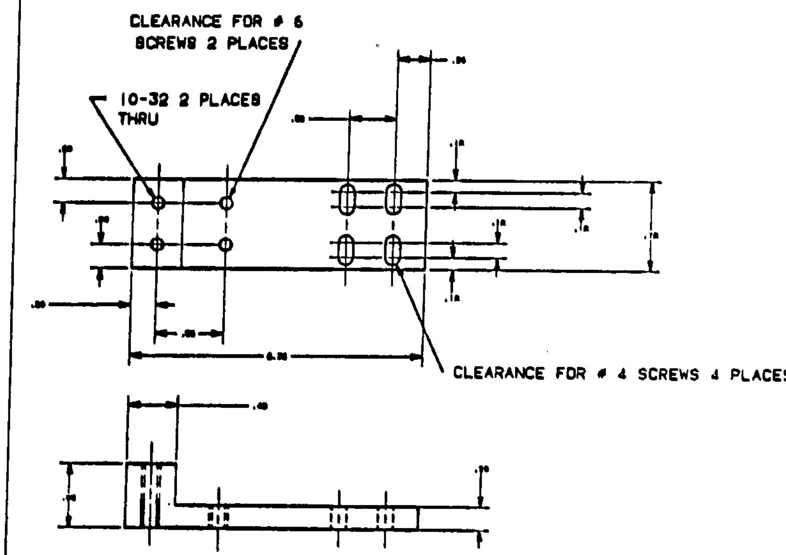
1) GENERAL TOLERANCES
.00 + OR - .01
.000 + OR - .001
UNLESS OTHER WISE SPECIFIED
2) GRIPPER PLATE IS TO BE
.375 IN THICK ALUMINUM PLATE
3) DIMENSIONS ARE IN INCHES

SCALE 1.0
AL GATES EX 5206
PAGE 4/6



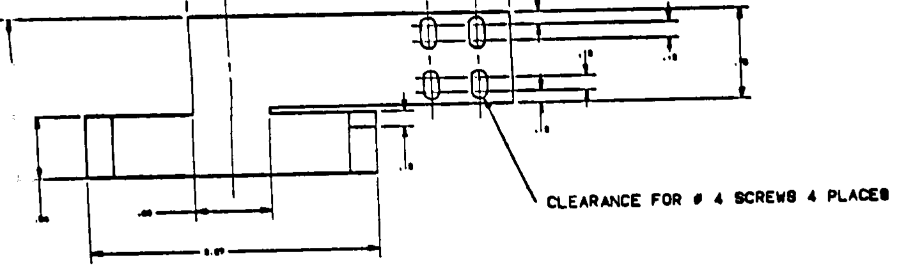
④ BODY HOLDER RIGHT

MAT'L ALU



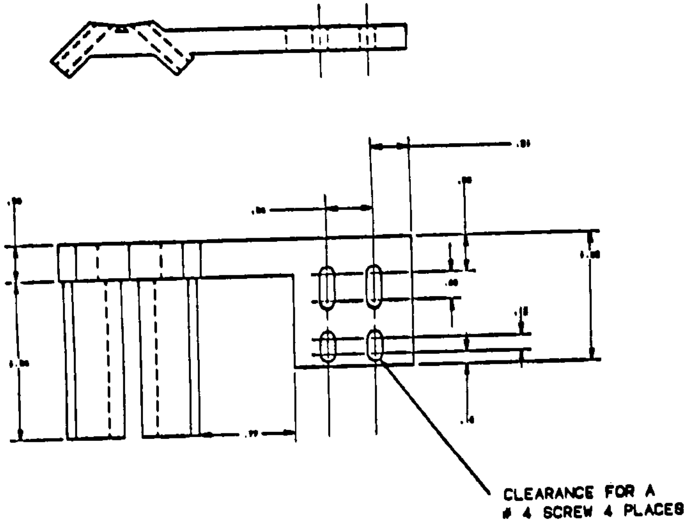
② CAP AND DIAPHRAGM ARMS (2 PIECES)

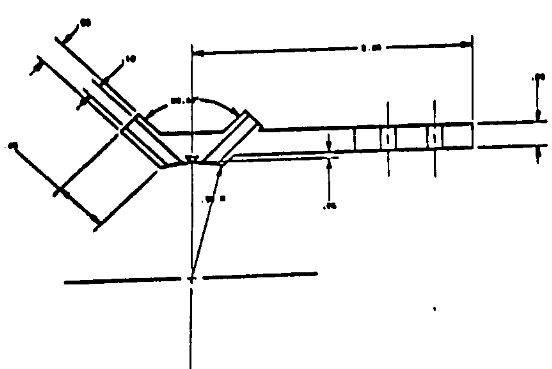
MAT'L ALU



④ BODY HOLDER RIGHT

MAT'L ALU



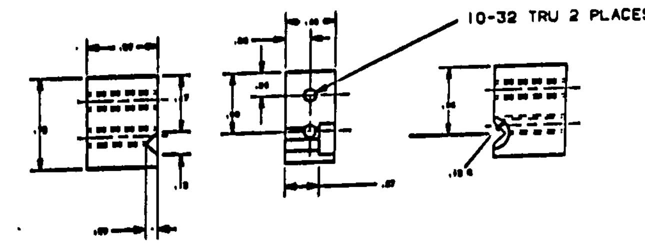


③ BODY HOLDER LEFT

MAT'L ALU

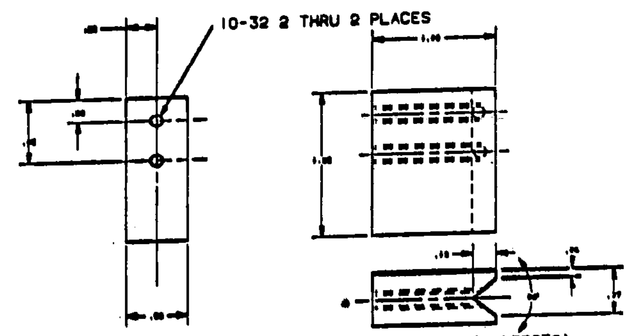
② CAP AND DIAPHRAGM ARMS (2 PIECES)

MAT'L ALU



⑬ CAP FINGERS (2 PIECES)

MAT'L ALU



⑭ DIAPHRAGM FINGERS (2 PIECES)

MAT'L ALU

BODY, CAP AND DIAPHRAGM ARMS AND FINGERS

NOTE

1) GENERAL TOLERANCES
.00 + OR - .01
.000 + OR - .001
2) ALL DIMENSIONS ARE IN INCHES
3) PARTS ARE TO BE ALUMINUM

SCALE 2.0

AL GATES EX 5206

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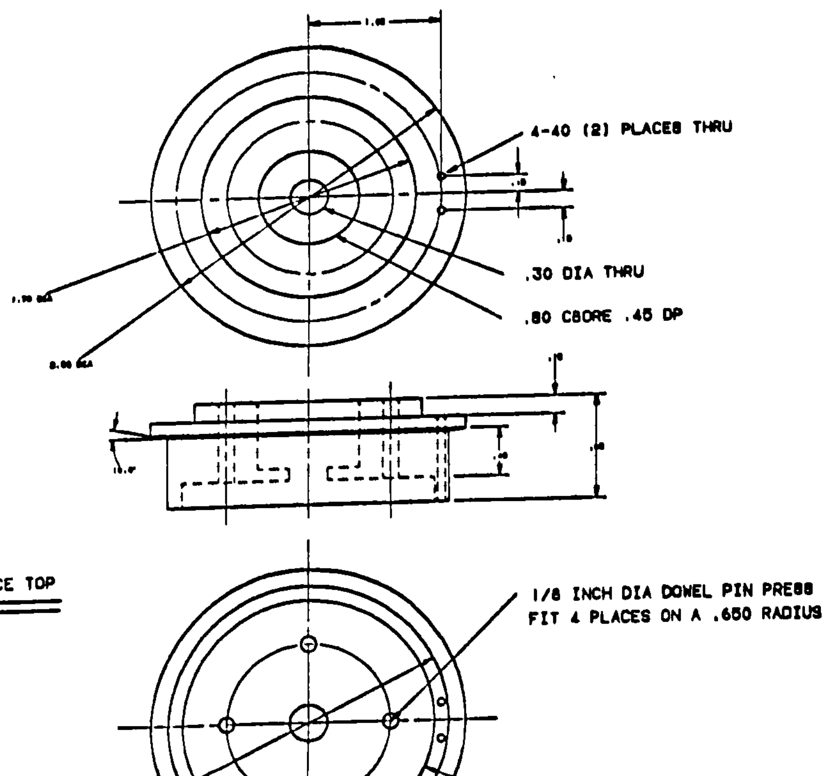
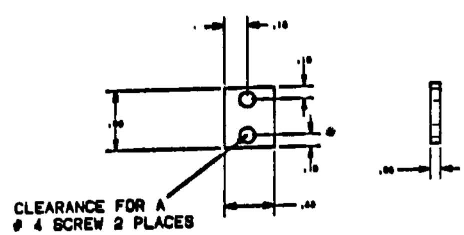


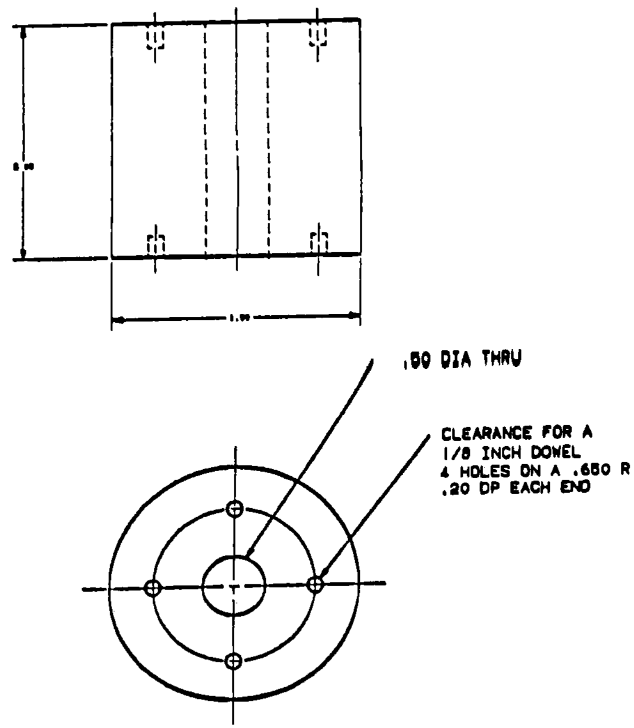
(10) COMPLIANCE TOP

MAT'L ALU



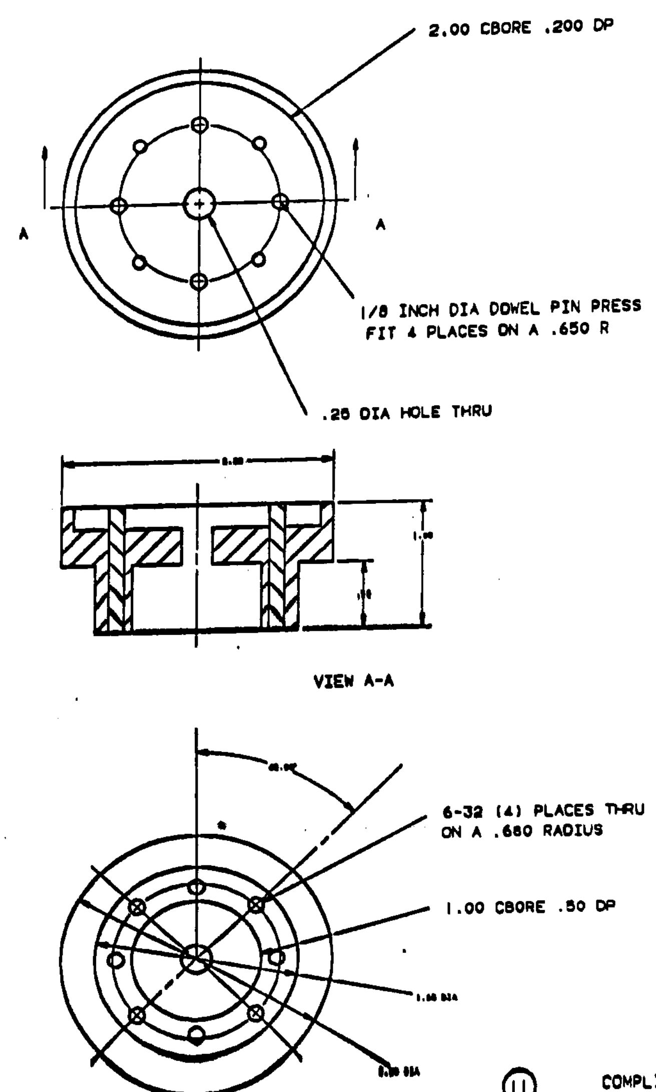
(9) KEY

MAT'L ALU



(12) COMPLIANCE MID

MAT'L VINYL



(11) COMPLIANCE BOTTOM

MAT'L ALU

COMPLIANCE DEVICE

NOTE
1) GENERAL TOLERANCES
.00 + OR - .01
.000 + OR - .001
UNLESS OTHER WISE SPECIFIED
2) DIMENSIONS ARE IN INCHES

SCALE 2.00
AL GATES EX 5206
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