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Robotic quick change end effector system

William Craig

ROBOTIC QUICK CHANGE END EFFECTOR SYSTEM

by

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Abstract

A quick change end effector (QCEE) system was developed and tested on a GMF model A-1 robot. The QCEE allows for the automatic interconnection of up to three independent pneumatic channels for gripper actuation. The QCEE was designed for a maximum payload of 15 lb. and weighs approximately 5.4 lbs. The system was tested using pneumatic grippers for pick and place operations, and functioned well in a simulated manufacturing environment.

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Acknowledgements

Many individuals at RPD and RIT were very helpful in assisting me in the development and construction of the QCEE system. I would especially like to thank Dr. Wayne Walter, my advisor on this project, for his valuable assistance and suggestions in the development of the QCEE system and the generation of this report. I am also very grateful to Kurt Hertzog at RPD for making available the resources of his department that made this project possible. In particular, I would like to thank Harry McCourt and Glen Snyder who each built a prototype of the QCEE system consisting of the components described in this section. Both Glen and Harry suggested some excellent design changes that improved the producibility of the AI and GI. I would also like to thank Leisha McKay and Joe Cocca who were very helpful in assisting me in the development of the QCEE system.

1.0 INTRODUCTION

The desire to produce consumer products that are inexpensive and of high quality has become exceedingly important to American manufacturers in recent years. Fierce competition at home and abroad has prompted the once conservative American industrial community to implement new approaches to mass production. Factory automation through robotics is just such an approach that is gaining wide acceptance in the American factory. The use of programmable equipment significantly shortens set up time when a new product line is established or an existing one changed. The flexibility of the factory is enhanced by this programmability. This paper deals with the development of a automatic gripper changing system that is designed to extend the flexibility of industrial robots.

1.1 Flexible Manufacturing. A flexible automated manufacturing environment is one which can be adapted to meet the changing requirements of the production facility. This is in contrast to the hard automation approach. Hard automation refers to the use of assembly equipment that is dedicated to perform a specific task. The movement patterns of dedicated equipment are determined by the mechanical configuration of the machine and cannot be altered without the redesign of key components. The flexible manufacturing environment is comprised primarily of computer controlled equipment such as robots that can be re-programmed as the need arises. Using programmable equipment minimizes the amount of new tooling that is required when the equipment is assigned to a new

manufacturing task. Minimizing set-up time means minimizing cost. The quick change end effector (QCEE) described in this paper allows the robot to change its end of arm tooling and thereby shorten set-up time when performing different tasks.

1.1.1 Use of Robots in the Factory. The most common applications of robotics in the factory have been welding, spray painting and pick and place operations. When the robot is set up for a welding or spray painting, the most common practice is to use an electrode or spray nozzle in place of the traditional gripper type end effector. The robot loses a degree of flexibility when such highly specialized end effector tooling is used. It is perhaps not practical to fit machines designated for these functions with a quick change end effector system such as the one described in this paper. Arc welding requires a great deal of electrical current to be delivered to the electrode. Designing a quick change system that meets this requirement would not be cost effective in most cases. Spray painting is done in an isolated environment. It is not likely that other assembly functions would occupy the same work cell with painting. Thus there is no need for a QCEE in this context. Pick and place operations include palletizing, machine loading and unloading, and so forth. This is the type of operation that would benefit from interchangeable tooling at the end of the robot arm. The interchangeable gripper system described in this report was developed for pick and place operations.

1.1.2 The Use of Robots for Component Assembly. For the most part, robots have not yet been successfully implemented to perform complex

assembly tasks. Robots often support such operations by loading and unloading dedicated machines that do the actual precision assembly. Robots are being held back in this area by the lack of suitable vision systems and tactile sensors for providing the proper feedback to the robot controller. Technology in this field is improving rapidly however, and it is only a matter of time until these obstacles are overcome.

1.1.3 Project Background. The development work on this project was undertaken in early October, 1983. The work was done with the support of the Rochester Products Division (RPD) of the General Motors Corporation. RPD had a need to automatically manipulate objects of varying size and shape in support of their manufacturing operations. The manipulations were defined to be pick and place operations. It was determined that robotics would be used to perform these pick and place operations.

The basic design elements of the QCEE system presented herein were first documented in mid November, 1983. The initial design was roughed out after the alternatives discussed in 2.2 were evaluated. More recent information has been added to section 2.2 to bring it up to date. Preliminary engineering drawings were generated on the RPD computerized drafting system in January and February of 1984. Following the generation of the engineering drawings, several RPD engineers reviewed the QCEE design. Some minor detail design changes were made following the review and the prints were revised accordingly. By about the middle of March, 1984, the QCEE prints were released to the model shop.

The RPD model shop started work on the prototype in early April and the prototype system was completed by the end of May. During the construction of the prototype, suggestions were made by the RPD tool builders to enhance the producibility of the QCEE. Some of these suggestions were incorporated. The final set of prints can be found in Figure 8 on page 18 through Figure 11 on page 21. During the summer of 1984 the prototype was evaluated using a mock up of an assembly cell and was found to function well.

2.0 QCEE SYSTEM SPECIFICATION

This chapter deals with the specific design criteria the QCEE interface system must satisfy. The rational for these requirements are also presented.

2.1 Problem Statement And Intent. The QCEE system was developed in conjunction with RPD manufacturing engineering. The potential need for such a system arose from a proposed automated throttle body testing cell. In the cell several test stands are to be loaded and unloaded automatically by a single robot. The machine is to handle several different types of throttle bodies of widely varying size and shape. For the sake of simplicity and reliability, different grippers have been designed to handle each type of throttle body. The problem with this approach is that the operator must intervene to change the end effector each time there is a change in the type of throttle body being tested. The QCEE interface system described herein is intended to eliminate operator intervention in pick and place operations such as this.

2.2 Alternative Solutions Considered. The obvious alternative solution to the problem is to design a multi-purpose gripper capable of picking up and orientating objects of varying size and shape. A gripper of this specification is not impossible to design and, in fact, many are currently under development at different institutions around the country. The most elaborate of these are the *anthropomorphic* grippers;

anthropomorphic meaning, of course, having human shape or characteristics.

2.2.1 Anthropomorphic End Effectors. Recently a great deal of effort has been directed to the development of multi-fingered robot hands with many degrees of freedom. These devices are designed to mimic the human hand as closely as possible. The most complex and impressive disclosure in the field is the Utah/MIT dextrous hand (ref. [1]). As can be seen in Figure 1 on page 7, each finger of this dextrous mechanical hand has four degrees of freedom and four such fingers are attached to the palm. The hand and wrist combination have a total of nineteen degrees of freedom. The joints of the fingers are actuated by polymer "tendons" that roll over small pulleys along the finger. The tendons are operated by a pneumatic system consisting of glass cylinders with graphite pistons. According to the authors, the pneumatic approach is advantageous in terms of speed of operation and light weight. Glass and graphite are used to minimize friction in the system.

Figure 1. Utah/MIT Dextrous Hand

Other anthropomorphic robot hands have been proposed by researchers at The University of Minnesota, (ref.[2]), and the Clarkson College of Technology (ref. [3]). The Clarkson dextrous hand is shown in Figure 2 on page 8 These designs have three and five fingers respectively. The three-fingered hand has nine degrees of freedom and the five-fingered hand has fifteen degrees of freedom. In both cases the fingers are actuated using sheathed cables and servomotors.

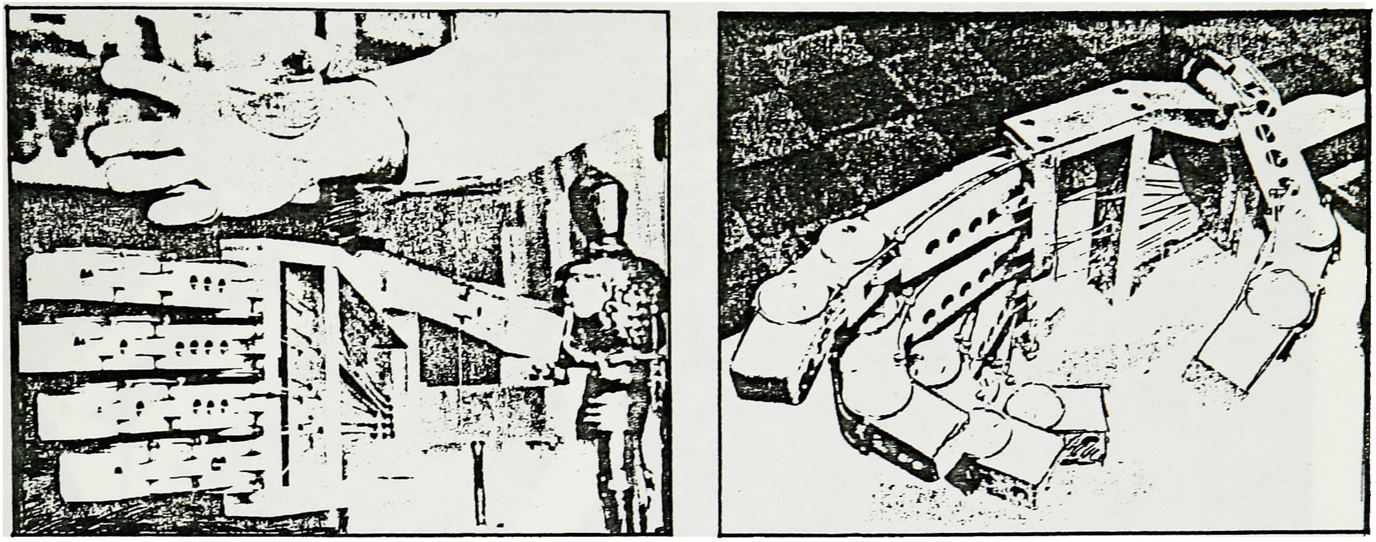

Figure 2. Clarkson Dextrous Hand

The Hatachi corporation (ref. [4]) uses an interesting approach to activate it's three-finger twelve joint hand shown in Figure 3 on page 9. Instead of using servomotors, the Hatachi hand uses shape memory alloy (SMA) actuators. These actuators are made from nickel and titanium wires that are stretched to a pre-determined length. When the SMA wires are heated, they tend to shrink back to their original length, providing linear motion for the actuation of the finger joints.

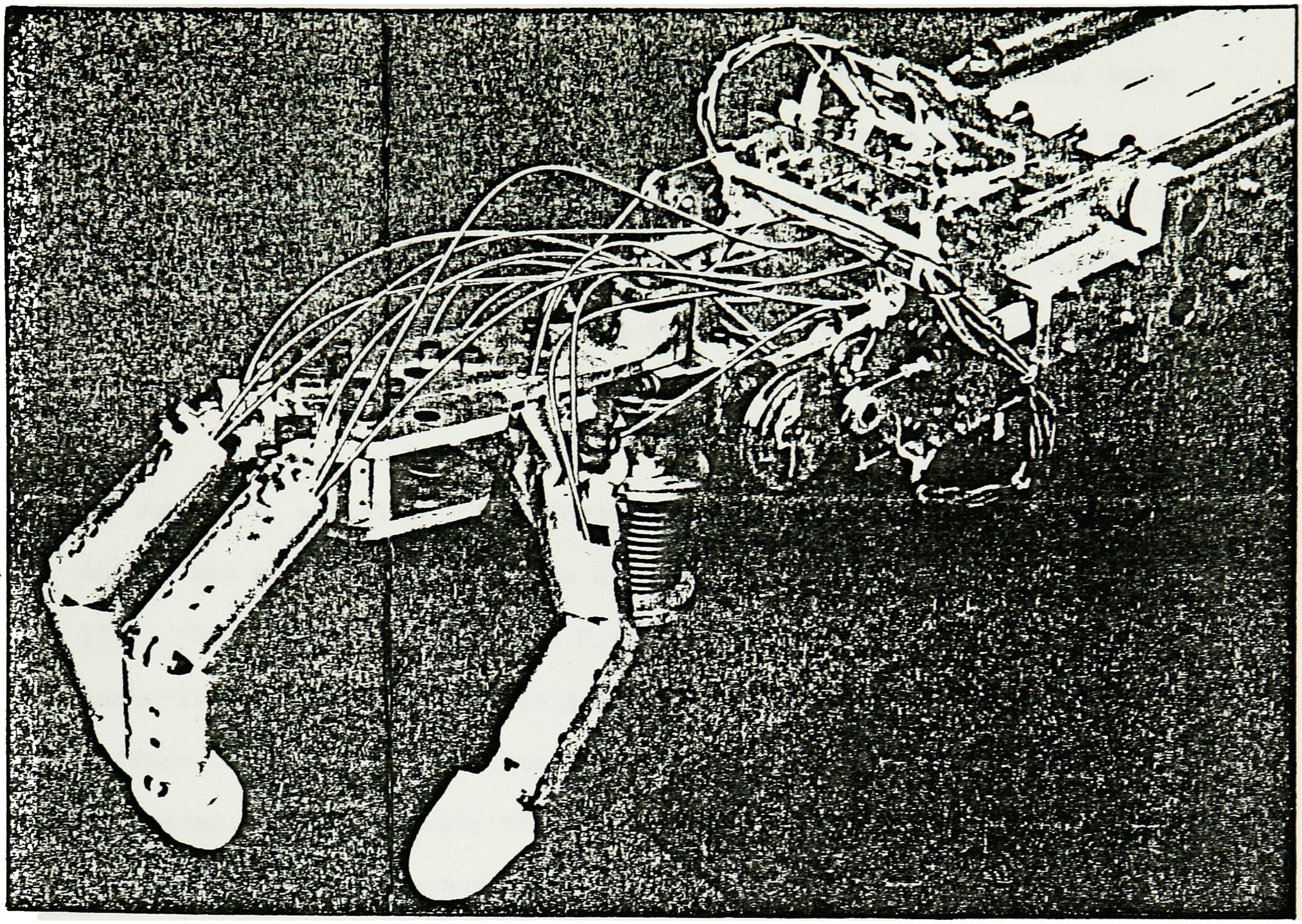

Figure 3. Hatachi Dextrous Hand

Although the anthropomorphic gripper shows great promise, researchers have found that the mechanical design problem is much easier to solve than the computer control problem. To control the hand a great deal of on line processing capability is required. The complexity of the control of the hand increases rapidly with the number of degrees of freedom. Researchers are currently developing algorithms that are efficient enough to allow on-line control of complex anthropomorphic grippers. Some anthropomorphic gripper control algorithms are described in references [5] and [6].

2.2.2 Other General Purpose End Effectors. Other researchers have taken a simpler but perhaps more practical approach to the design of a general purpose industrial gripper. One should note that not all anthropomorphic grippers are designed for the industrial environment. The Utah/MIT dextrous hand is being developed for biomedical applications.

In Japan, a so-called "Soft Gripper" was designed and developed to softly and gently conform to the shape (perimeter) of an object (ref. [7]). This gripper as shown in Figure 4 uses many joints and is almost snake-like in appearance. The gripper is cable activated and exerts a uniform force over the surface to which it grasps. Although innovative in design, it is unlikely that a gripper of this type could withstand the rigors of a manufacturing environment.

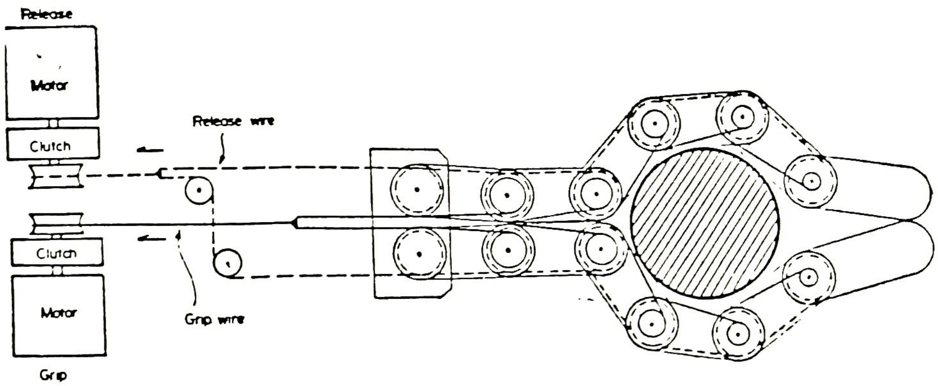

Figure 4. Soft Gripper

The general purpose end effectors developed by the Phillips corporation (ref. [8]) use vacuum cups either singly or in an array as can be seen in Figure 5 below. The vacuum cups adapt to the surface object being manipulated. This approach is simple and reasonably effective but the vacuum cups are prone to wear and need a smooth relatively flat surface to adhere to. The maximum payload of vacuum grippers is limited as well.

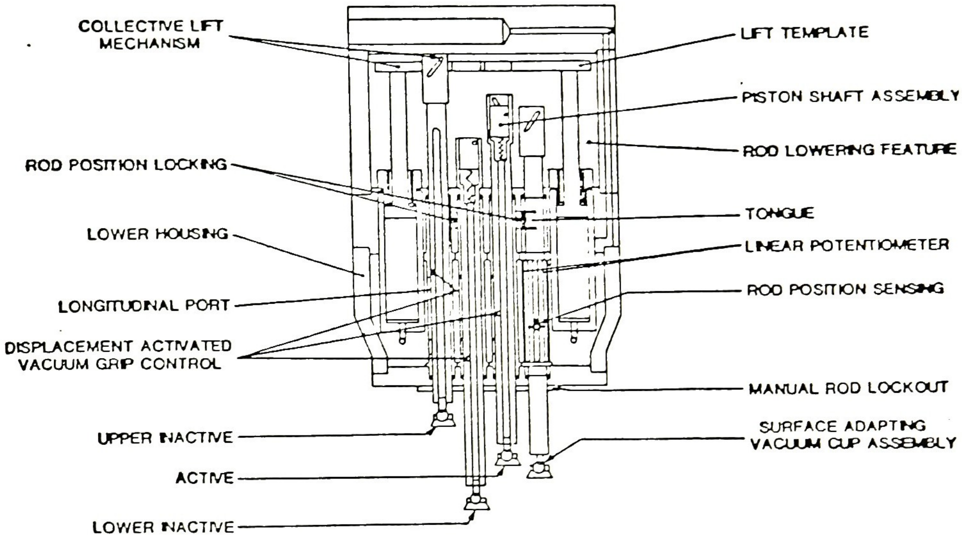

Figure 5. Phillips Vacuum Gripper

2.2.3 Summary of Alternatives. Many other complex if not human like designs have been proposed and in some cases developed. Most have the same problem with control of the many degrees of freedom such designs inherently have. For the proposed application, the additional complexity and development costs were not warranted. In the repetitive manufacturing environment, the simple design often enhances reliability and maintainability. Such virtues are highly prized for obvious reasons. Simplicity was thus an important design objective.

2.3 System Characteristics. During initial discussions with engineers at RPD certain desirable characteristics of the QCEE were identified. These characteristics were determined by evaluating the proposed applications of the QCEE equipped robot. As mentioned previously, the applications were determined to be various pick and place operations.

The QCEE characteristics are listed below in two categories, *general requirements* and *system constraints.* The general requirements are defined here to be desirable design objectives and are not specifically quantified. The system constraints on the other hand are quantified. The system constraints were determined to be critical to ensure that the QCEE system would perform the desired functions.

The general requirements are as follows, in descending order of estimated importance.

1. Positional Repeatability

2. Simplicity of Operation

3. Maintainability

4. Light Weight

5. Ease of Fabrication and Low Cost

The QCEE system constraints are as follows.

1. 15 lb. minimum load capacity

2. Provide at least 2 independent pneumatic channels for gripper actuation.

2.3.1 General Requirements. The following paragraphs describe each of the system requirements listed above.

2.3.1.1 Positional Repeatability. Any positional uncertainty of the gripper with respect to the end of the robot arm adds to the positional uncertainty of the machine itself. For this reason, the primary design consideration for the hand changer was repeatability.

2.3.1.2 Simplicity of Operation. The interface must be reliable in the production environment. Simple operation often results in superior reliability.

2.3.1.3 Maintainability. In the production environment, rapid fault isolation and correction are required to maximize the on-line availability of the system. For the same reason, routine preventative maintenance must be accomplished in a minimum of time.

2.3.1.4 Light Weight. The weight of the interface and gripper mechanism reduces the payload of the robot. Therefore, minimizing the weight of the QCEE interface system was an important objective.

2.3.1.5 Ease of Fabrication and Low Cost. Lastly, some consideration was given to the design in terms of how manufacturable and cost effective the product would be should the company decide to market it.

2.3.2 QCEE System Constraints. The following paragraphs describe each of the system constraints listed in paragraph 2.3 above. The QCEE must satisfy these constraints if it is to have the desired functional characteristics.

2.3.2.1 Pneumatic Channels. The air channels are to provide a means of actuation for the gripper mechanism or mechanisms attached to the interface.

2.3.2.2 Payload Capacity. The payload capacity was determined by the type of machine the gripper was to be used on and the range of part sizes to be manipulated by the robot.

3.0 QCEE SYSTEM DESIGN

The QCEE interface system was designed to meet the objectives outlined above. As shown in Figure 6 on page 16, the assembled mechanism consists of basically three components: the arm interface (AI), the gripper interface (GI), and the docking yoke (DY). An example configuration is presented in Figure 7 on page 17. The engineering drawings of all system components are presented in Figure 8 on page 18 through Figure 11 on page 21. The engineering drawings were generated for model shop use and are not as detailed as would be required for release into a manufacturing environment.

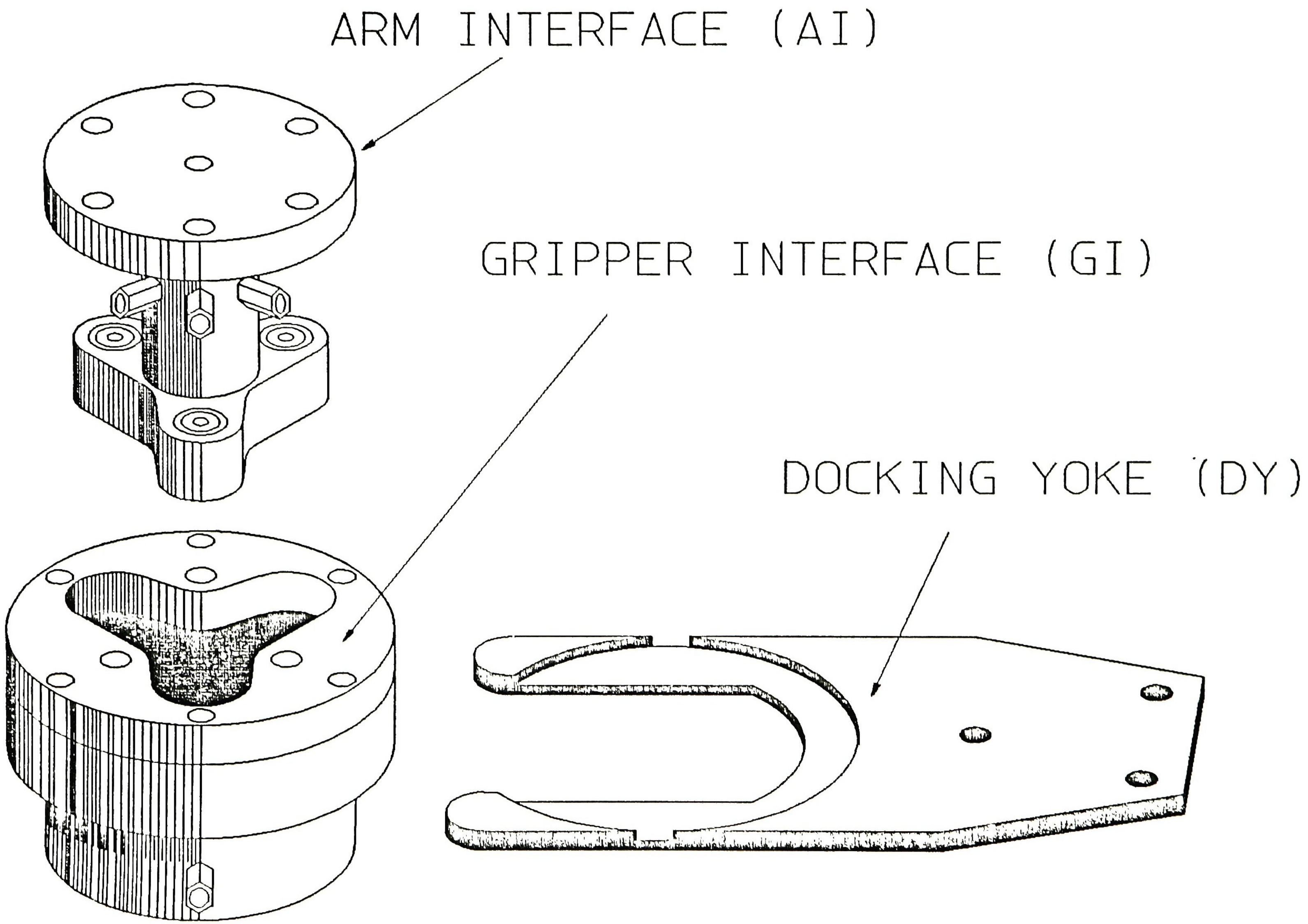

Figure 6. System Components

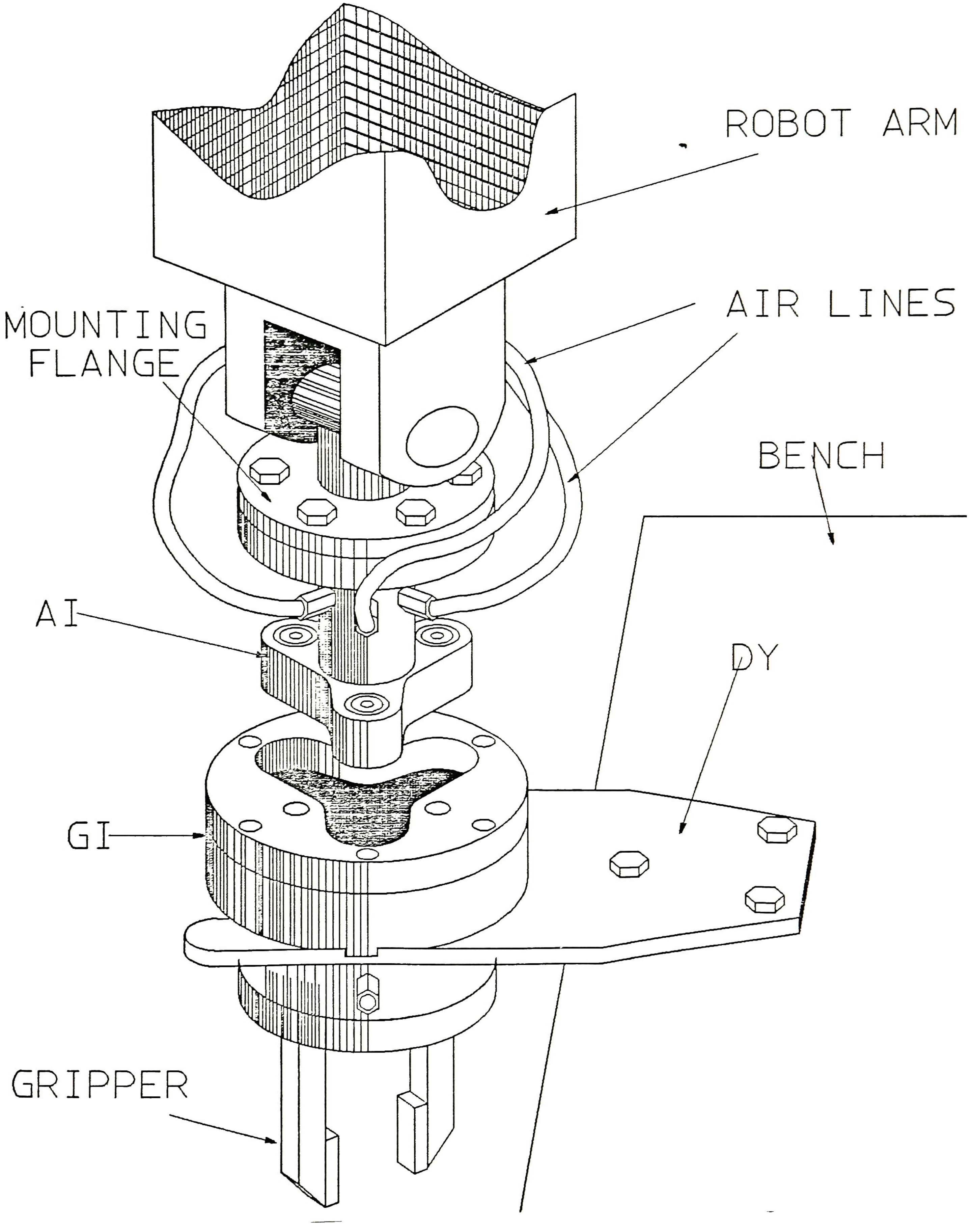

Figure 7. Example Configuration

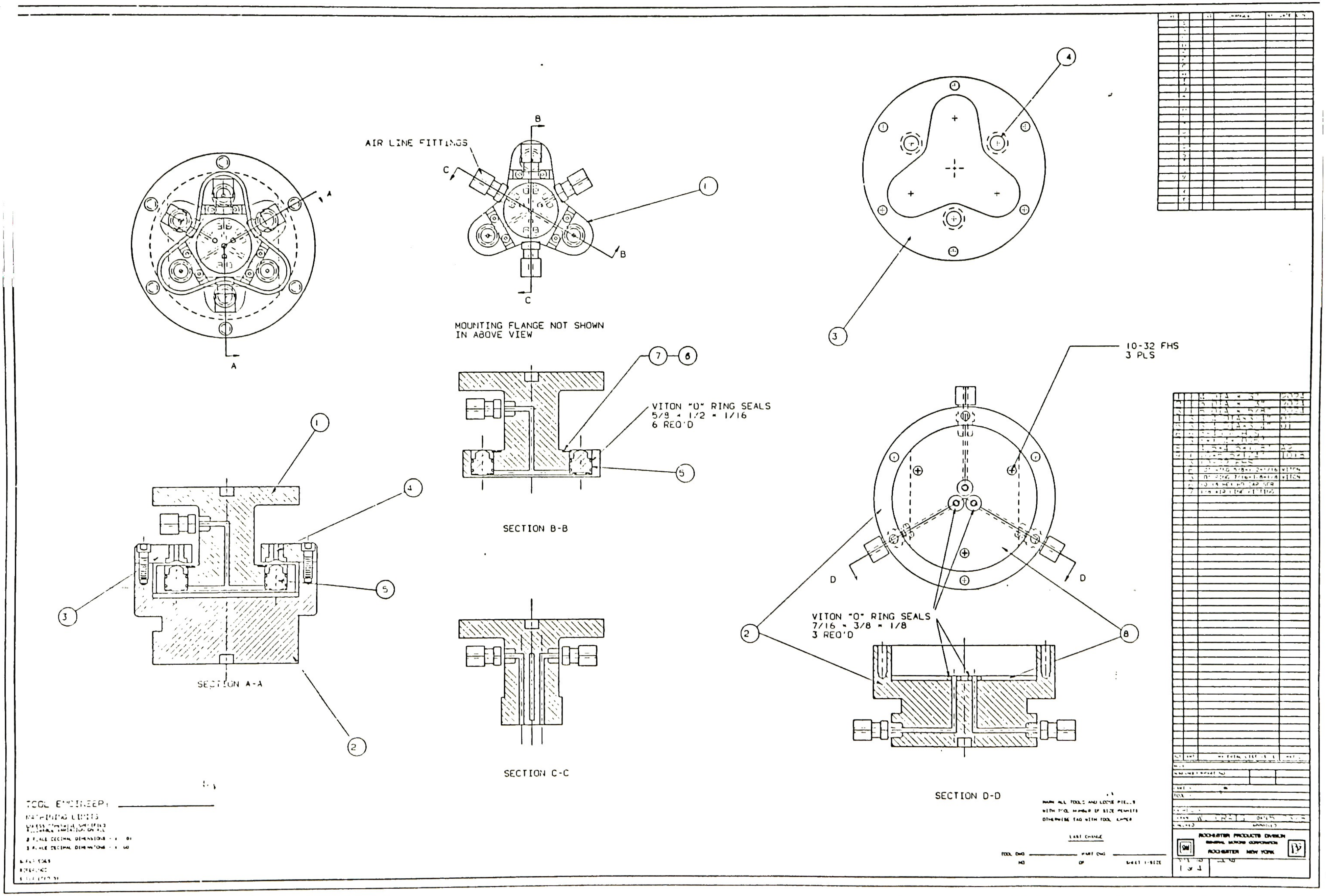

Figure 8. Engineering Diagram 1 of 4

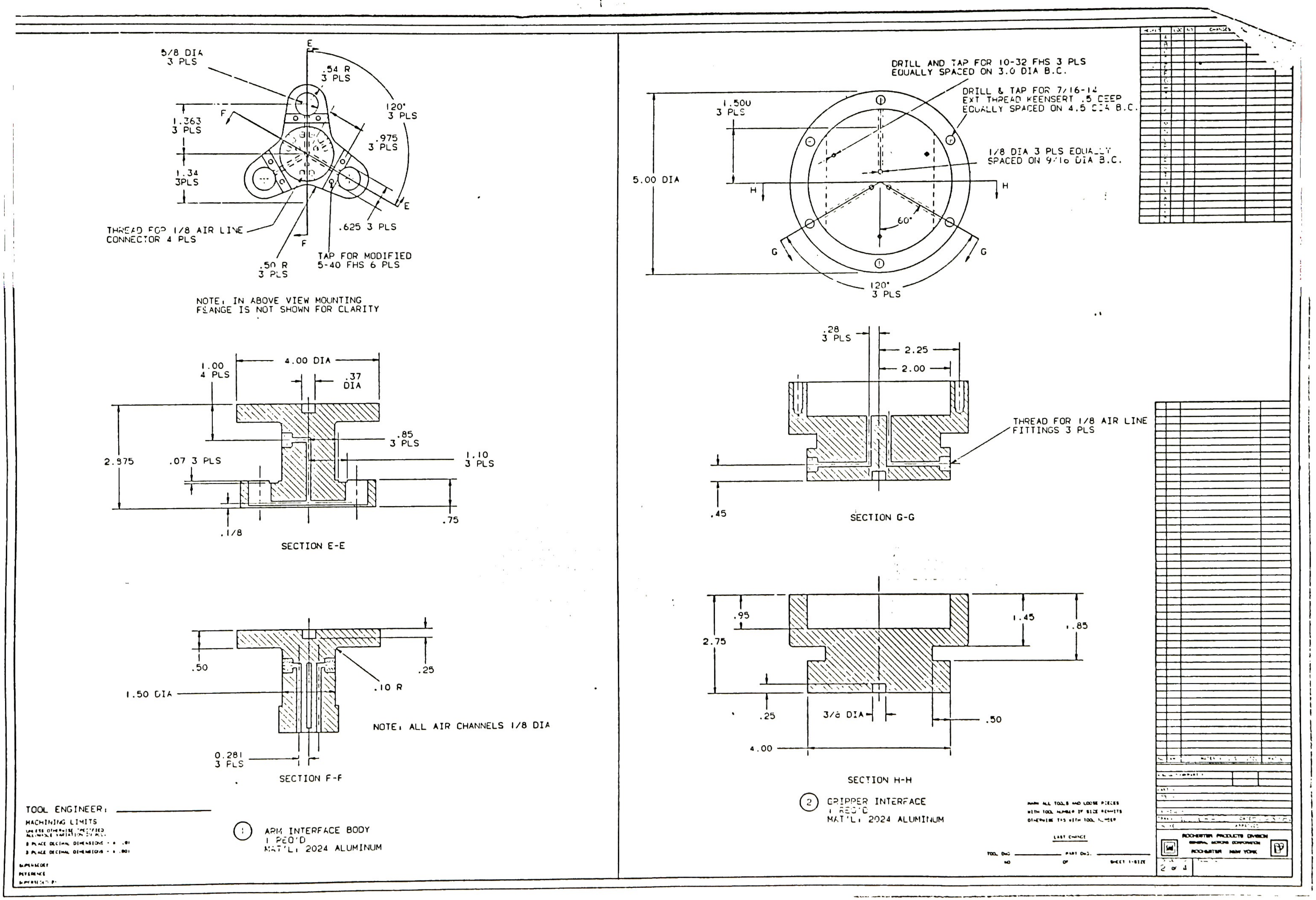

Figure 9. Engineering Diagram 2 of 4

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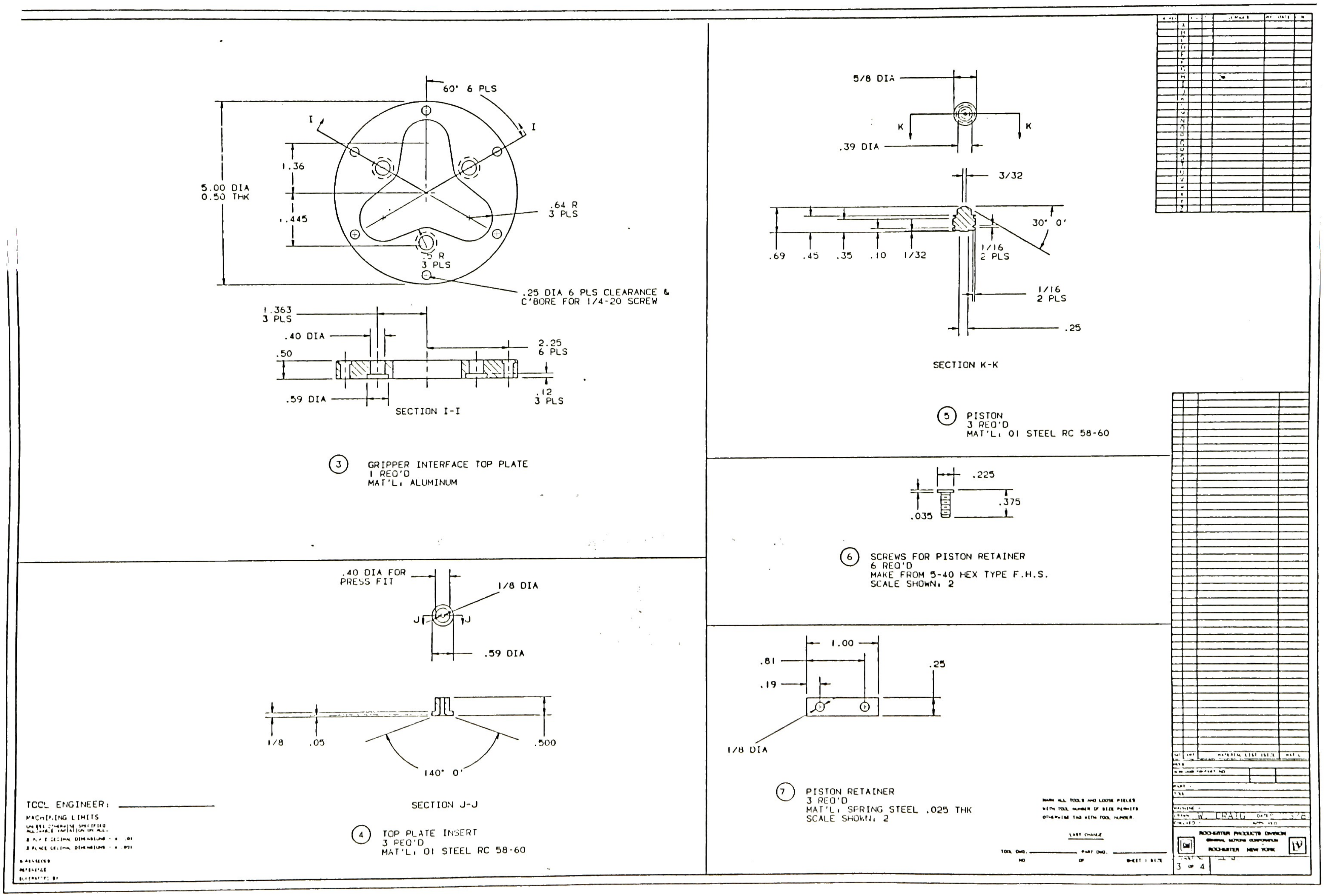


Figure 10. Engineering Diagram 3 of 4

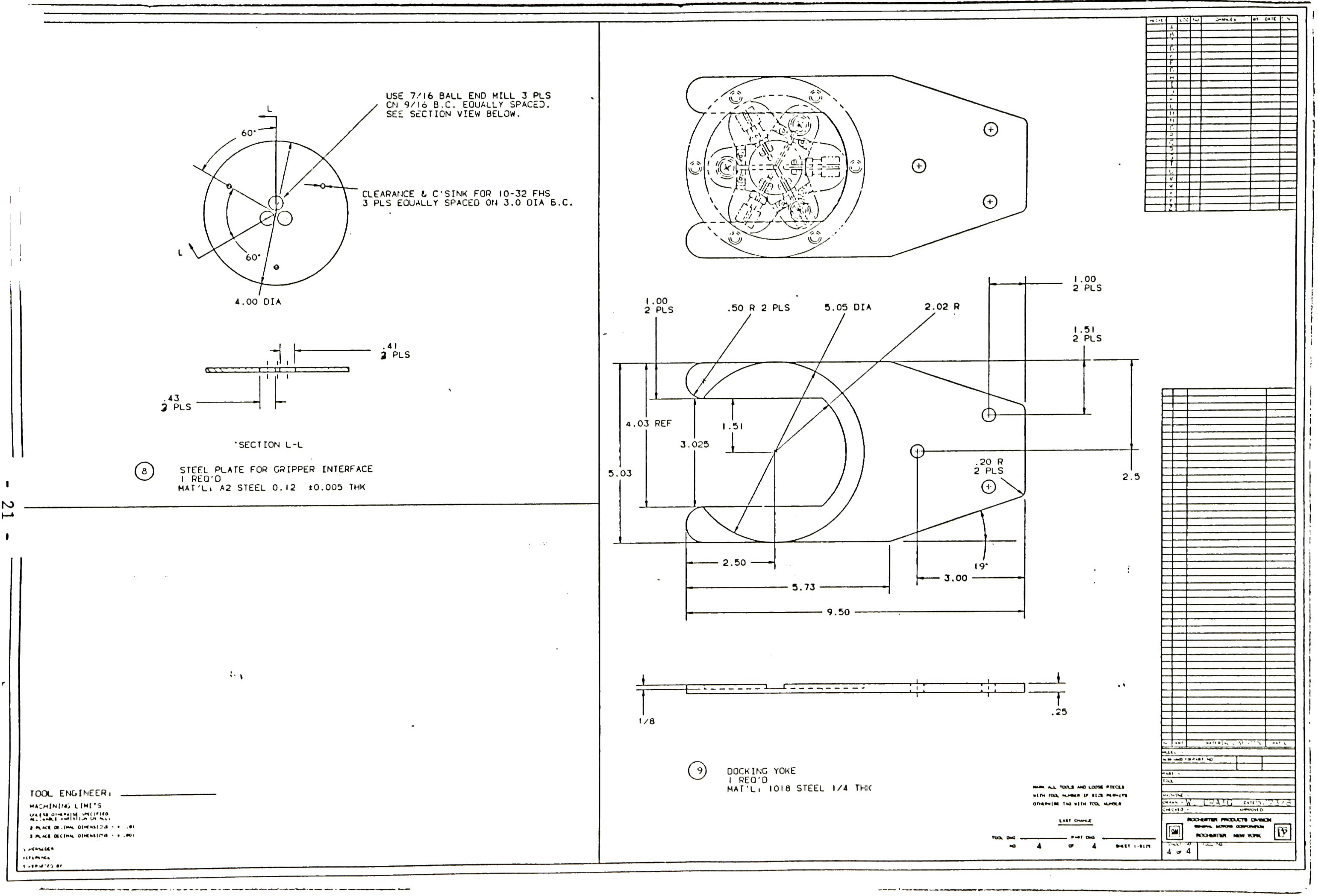


Figure 11. Engineering Diagram 4 of 4

IBM 81

3.1 Arm Interface. The arm interface bolts to the end of the robot arm. The pneumatic channels that will eventually be routed to the gripper are first terminated on the AI. The assembled AI as shown in Figure 12 on page 23, was machined from a 4" diameter round piece of 2024 aluminum. From the top view as shown in the engineering drawing Figure 9 on page 19, the AI appears to have three "spokes". At the end of each of these spokes is a pneumatically activated piston, 5/8" in diameter, that is used for locking the AI and the GI together. The pistons were machined from 01 steel and then hardened to a Rockwell number of 58-60 on the C scale. They are sealed in each cylinder by 2 Viton "O" rings. As can be seen in the piston detail shown in Figure 10 on page 20, the top surface is conical in shape. This allows the AI and the GI to be self aligning with respect to each other as will be described below. All three pistons are activated by a common air passage as can be seen from Figure 9 on page 19. Note that three air passages are provided for operation of whatever gripping mechanism may be attached to the GI described below. The hole pattern for the mounting flange is not shown as this varies with the particular machine the AI is used on.

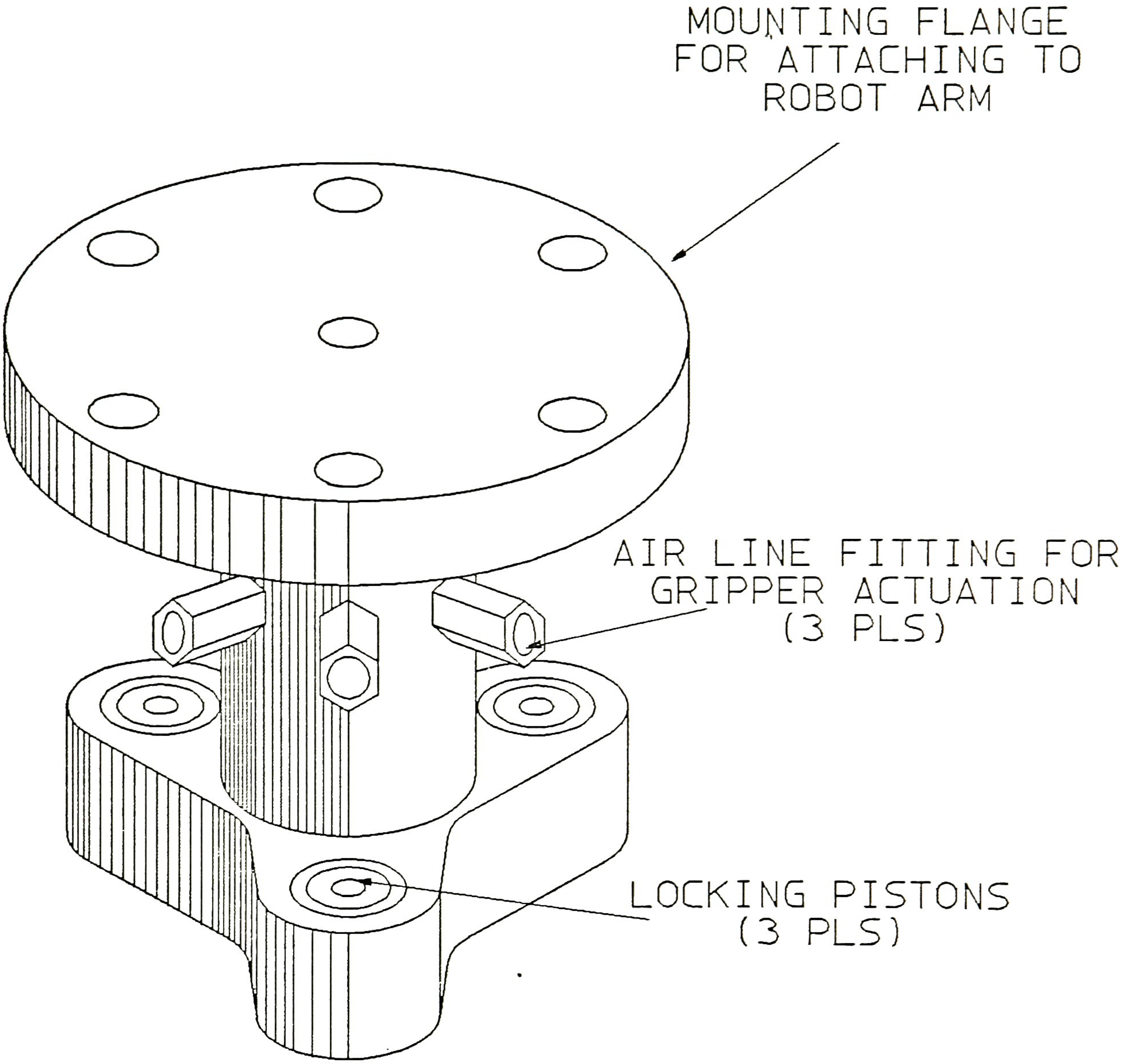


Figure 12. Arm Interface

3.2 Gripper Interface. As the name suggests, the gripper interface (GI) adapts the gripping mechanism, whatever it may be, to be accessible to the AI. The assembled GI is shown in Figure 13 on page 26. Pneumatic connections for gripper actuation are made between the gripping mechanism and the GI. As shown in Figure 9 on page 19 through Figure 11 on page 21, the GI consists of three main components, the body, the top plate and the base plate. The body and the top plate are machined from 2024 aluminum and the base is 01 steel. The selection of 2024 aluminum was based on the good strength to weight ratio of the material, its relatively low cost, and the ease with which it can be machined. The selection of the 01 steel was based on the fact that it is a cheap and readily available tool steel. The gripper bolts to the bottom of the GI body. Note that the body has grooves cut in it so that it may be received in the docking yoke which is described below. The top plate is attached to the body of the GI by six 1/4-20 hex head screws. Three 01 steel inserts are pressed into the top plate. These inserts are of the same hardness as the pistons in the AI. Referring to the detail of these inserts shown in Figure 10 on page 20, there is a concave area that receives the convex pistons described above. As the pistons move into these convex inserts, the two components will be aligned with respect to each other as the convex pistons seek the low point in the concave inserts. Three "O" rings are used to seal the air passageways between the AI and the GI. These "O" rings are retained in the base of the GI body by the steel base plate, which is indicated by balloon number 8 shown in section D-D of Figure 8 on page 18. Detail of the base plate is given in Figure 11 on page 21. The steel plate also provides

a suitable surface for the base of the AI to slide against when the two parts are mating. The use of the steel base plate in the GI also considerably reduces the friction between the AI and the GI since both the static and dynamic coefficients of friction for steel against aluminum are considerably less than those for aluminum against aluminum.

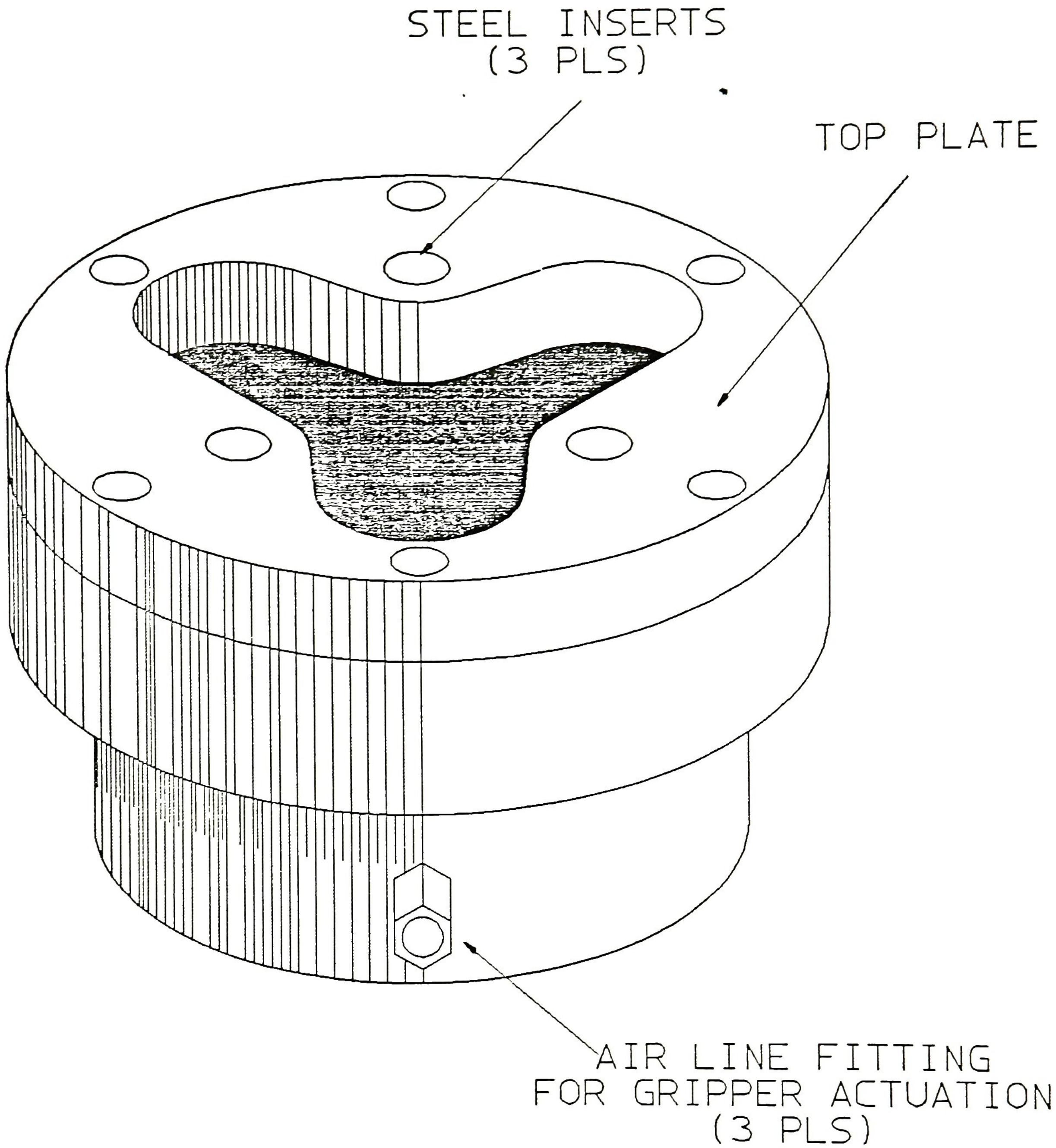


Figure 13. Gripper Interface

3.3 Docking Yoke. The purpose of the docking yoke (DY) is to provide a storage place for the GI and gripper when they are not in use. An isometric view of the DY is shown in Figure 14 on page 28. The docking yoke was machined from 01 steel. The DY retains the GI in a very specific orientation so that it may be reattached to the AI when needed. As can be seen in Figure 11 on page 21, the DY is merely a two blade fork into which the GI is translated. The GI is then released into an area which is recessed .05" so that the GI cannot slide along the fork once placed there. The yoke is attached to a stable bench or similar fixture using the three 1/2" holes. Obviously one DY is needed for each gripper used.

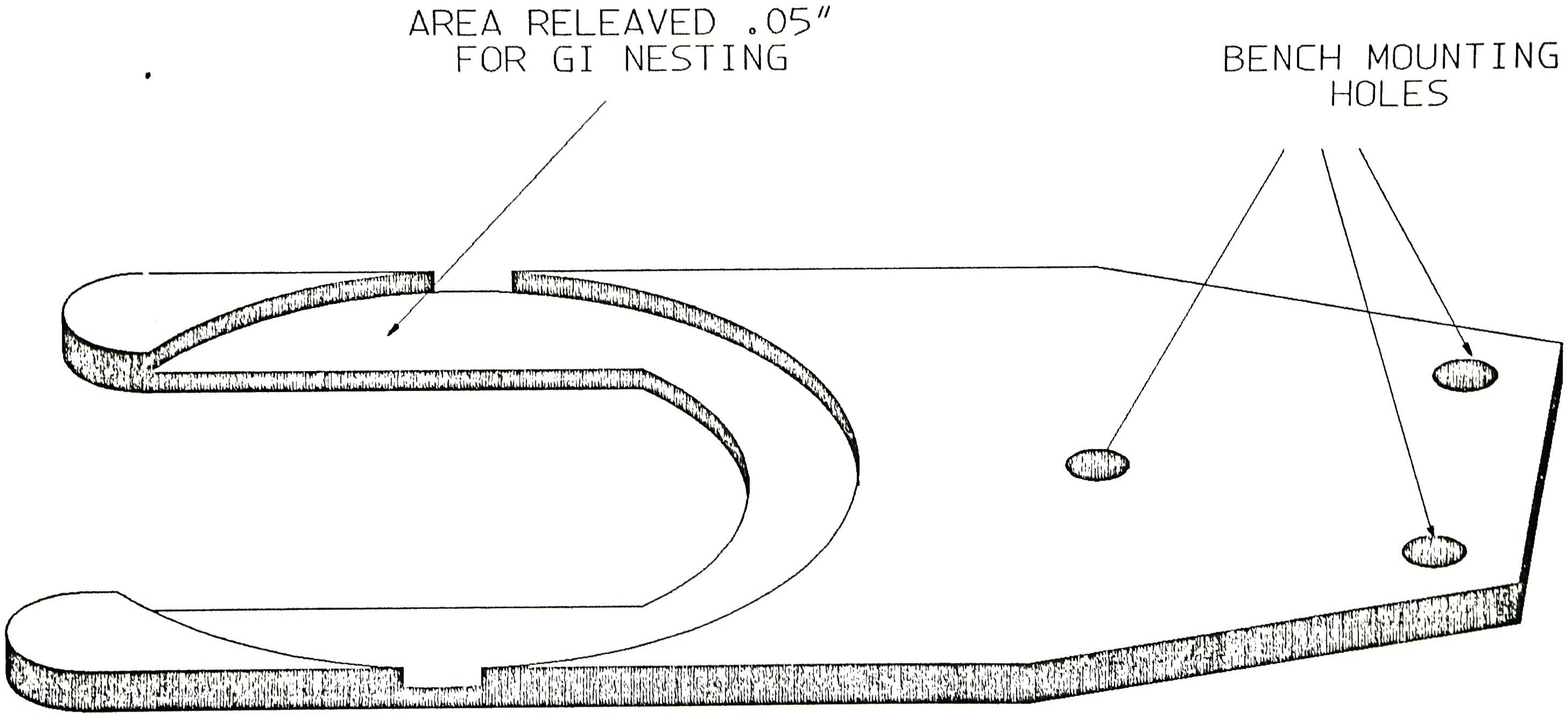


Figure 14. Docking Yoke

3.4 Force of Attachment Analysis.

The two components of the interface system are held together with a clamping force, Fc, as shown in Figure 15 on page 31. This clamping force is given by the following expression:

$$Fc = 3 * Pi * r^2 * Ps \text{ ....Eq(1)}$$

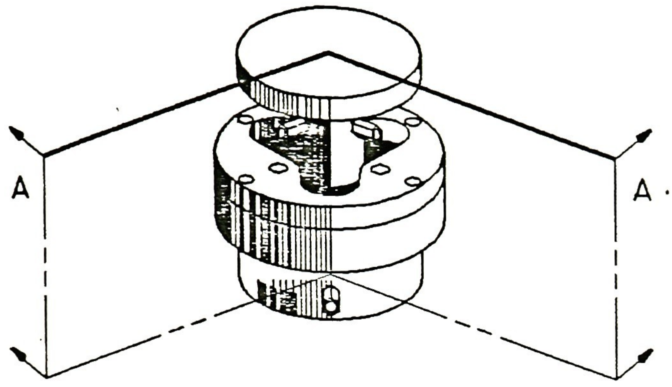
Where Ps is the supply pressure to the locking pistons in psi., r is the radius of the locking piston in inches, and Pi is the usual ratio of the circumference of a circle to its radius. If Ps is set to 50 psi and r is 5/16" then Fc would be 46.02 lb. Given that the maximum payload the QCEE was designed for is 15 lb., this clamping force is sufficient to hold the two components together. Because of the design of the QCEE, the weight of the payload Fw, as shown in Figure 15, subtracts from the total clamping force available. But even with the maximum payload of 15 lb. the clamping force would still be better than 25 lb.

3.4.1 Gripper Air Separation Force.

The channels that supply air to the gripper assembly produce a separation force between the AI and the GI. This force is equivalent to the cross sectional area of the supply channel multiplied by the air pressure in that particular channel summed over the number of active channels. Referring to Figure 15 on page 31, the force of separation, Fs, due to these supply lines is given by the following expression.

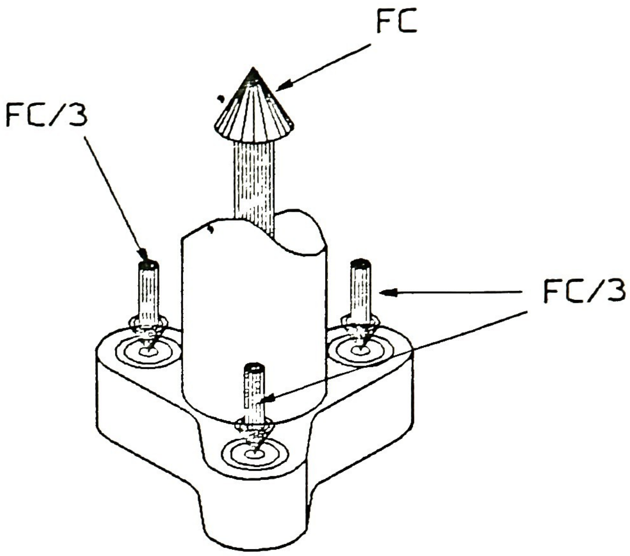
$$Fs = Na * Ps * (Pi * (Da/4)^2) \quad \text{Eq}(2)$$

Supply air for gripper actuation, Ps, is seldom at a pressure higher than 20 psi. The quantity "Na" is the number of pneumatic channels in use. Substituting in the known quantities for the diameter of the air channel, Da, which incidentally becomes the inner diameter of the "O" ring seals (3/8"), 20 psi for the supply air pressure and 3 for the number of pneumatic channels in use the maximum separation force due to gripper actuation air is 6.63 lb. Note that this worst case analysis assumes that all three air channels are in use simultaneously. For many applications only a single air channel is required and the separation force would be reduced accordingly.



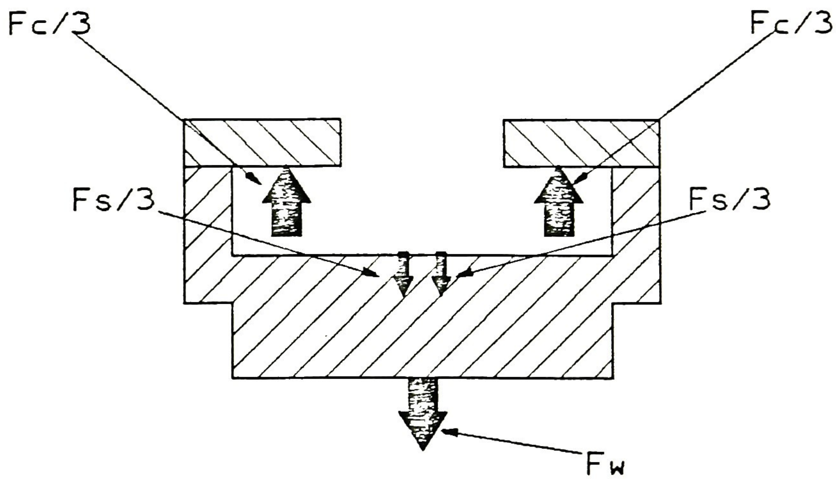
15-A

VIEW OF AI/GI ASSEMBLY WITH SECTION PLANES SHOWN



15-B

SIMPLIFIED FREE BODY DIAGRAM OF AI WITH CLAMPING FORCES INDICATED



15-C

SECTION A-A

FREE BODY DIAGRAM OF GI

(AI NOT SHOWN)

Figure 15. Force of Attachment Analysis

4.0 SYSTEM OPERATION

The QCEE requires two programmed subroutines for each gripper used, one for the attach cycle and the other for the detach cycle. Each routine must be individually programmed although the actions are very similar and certain portions of the basic routine are replicated. The following narratives assume that the docking yoke is bolted firmly to a stable fixture.

4.1 Attachment Cycle.

At the start of the following procedure it is assumed that the GI with the gripper bolted to it is residing in its associated DY. Refer to Figure 16 on page 34 for clarification of steps 1, 2 and 3.

1. The AI is positioned 2" directly above the GI. The three "spokes" of the AI are aligned with the cut out region of the same shape in the GI top plate. The bottom of the AI and the top plate of the GI are, of course, both parallel to each other at this point. This seems to be a trivial point but it requires a conscious effort on the part of the robot programmer to make sure the AI is level.

2. The AI is now translated downward into the GI until the top surfaces of the AI spokes are 0.075" below the bottom surface of the GI top plate as shown in Figure 16 on page 34 part A and B.

3. Now the AI is rotated sixty degrees until the pistons in the AI are directly below the concave receptacles in the GI top plate as shown in Figure 16 part C.

4. Air pressure is supplied to the pneumatically operated locking pistons. The conical top surfaces of the three pistons are forced into the concave receptacles of the GI top plate. If the pistons and the receptacles are slightly off center, they will align themselves in the manner described in section 3.2 above.

5. The mated assembly is now raised .07" so as to clear the recession in the DY.

6. The assembly is now translated out of the DY keeping the notches in the GI parallel to the blades of the DY to avoid jamming. The tool is now ready to use as shown in Figure 16 Part D.

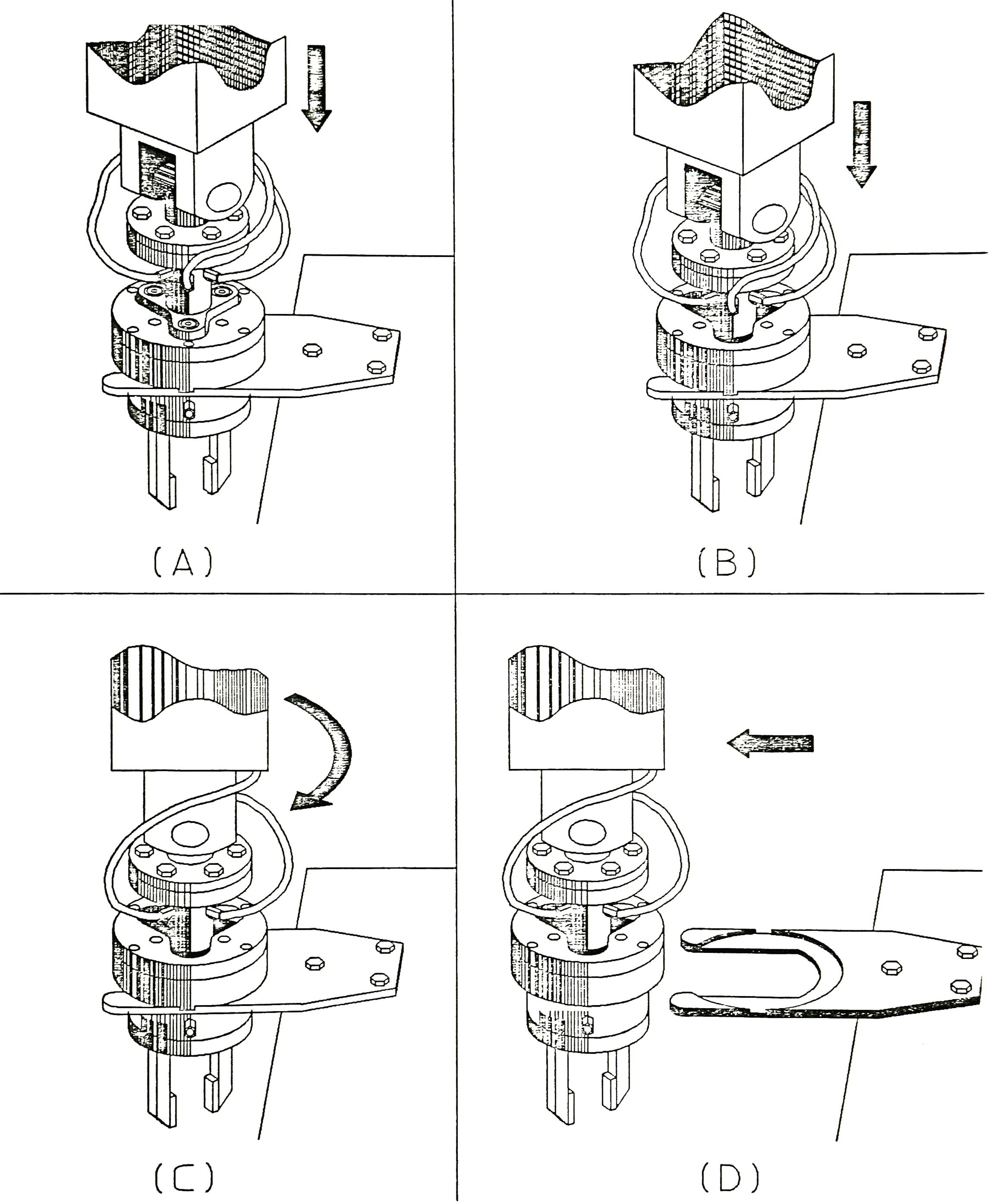


Figure 16. Attachment Cycle

4.2 Detach Cycle. The following sequence of steps are valid assuming that a gripper is attached. Refer to Figure 16 in reverse order for clarification.

1. The slots or notches in the GI are aligned with the blades of the DY.

2. The GI is translated into the DY until it is directly above the recessed area.

3. The GI is now lowered into the recessed region of the DY leaving about a paper thickness between the top of the notch in the GI and the top of the recessed area of the DY.

4. The pneumatic pressure is relieved in the circuit that fires the pistons. During testing, the pistons usually would settle down into the AI at this point. On occasion the pistons would stay in the higher position but this presented no problem as they would "cam" down when the AI was rotated as described in the step below.

5. The AI is now rotated sixty degrees until the "spokes" line up with their silhouette in the GI top plate.

6. The AI can now be translated upward out of the GI and is ready to access another tool.

4.3 Working Prototype Demonstration. A mock up automatic assembly work cell was demonstrated at RPD using the QCEE system. Two different grippers were used to assemble a two part throttle body (TB) unit. Each gripper was designed specifically for each TB part and consisted of an air cylinder which compressed a thick rubber cylinder along its longitudinal axis causing it to expand along the transverse axis as shown in Figure 17 on page 38. This rubber cylinder would be translated into a large hole in the throttle body component and then expanded thus latching on to the part. Notice that this expanding rubber cylinder must be custom made for the each component and is designed to exploit a particular geometric characteristic of the component. The input to the cell consists of the TB components arranged in a matrix format simulating a possible parts pallet layout. Note that the proposed TB test cell will require that the parts be delivered to the cell on pallets. The pallets will incorporate some means of accurately locating the parts carried thereon. The test cell system will also provide a means of determining if a parts pallet was present before work would begin.

The system is shown schematically in Figure 18 on page 39. A GMF Model A-1 industrial robot was used for the demonstration. The specifications for the robot are found in Appendix A. Implementation was accomplished with very little modification to the original design. The interchange system worked reliably and quickly with a Disconnect/Connect cycle of approximately 4.0 sec. The "O" rings proved very effective in sealing the air channels between the AI and the GI. Actual implementation work was done by Richard Forman, a Co-op student working at RPD. I was not

able to actively participate in the implementation process due to insurance problems Rochester Products has with non-employees working in the robotics lab. An implementation guide written by Richard Forman is found in Appendix B.

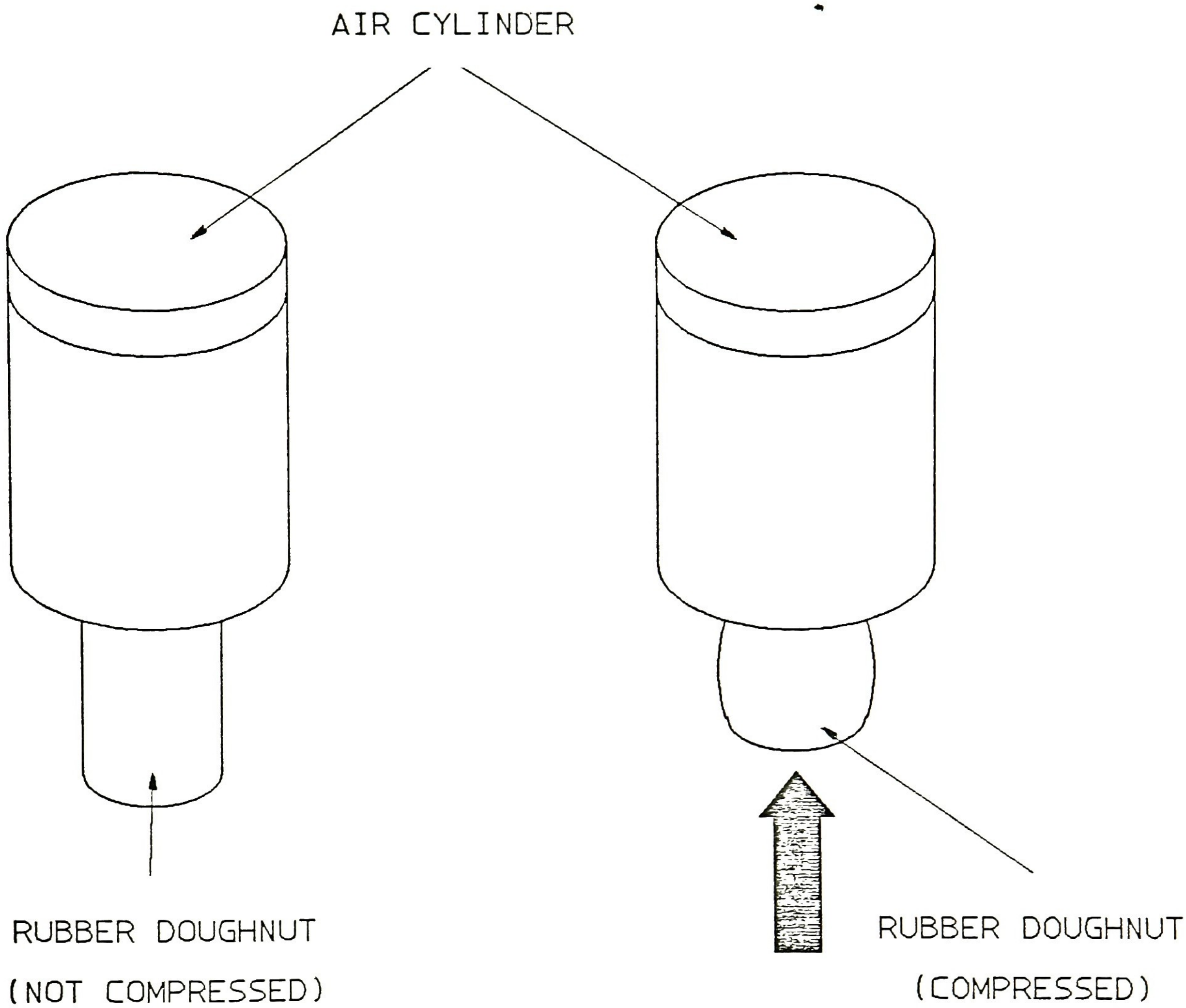


Figure 17. Throttle Body Gripper

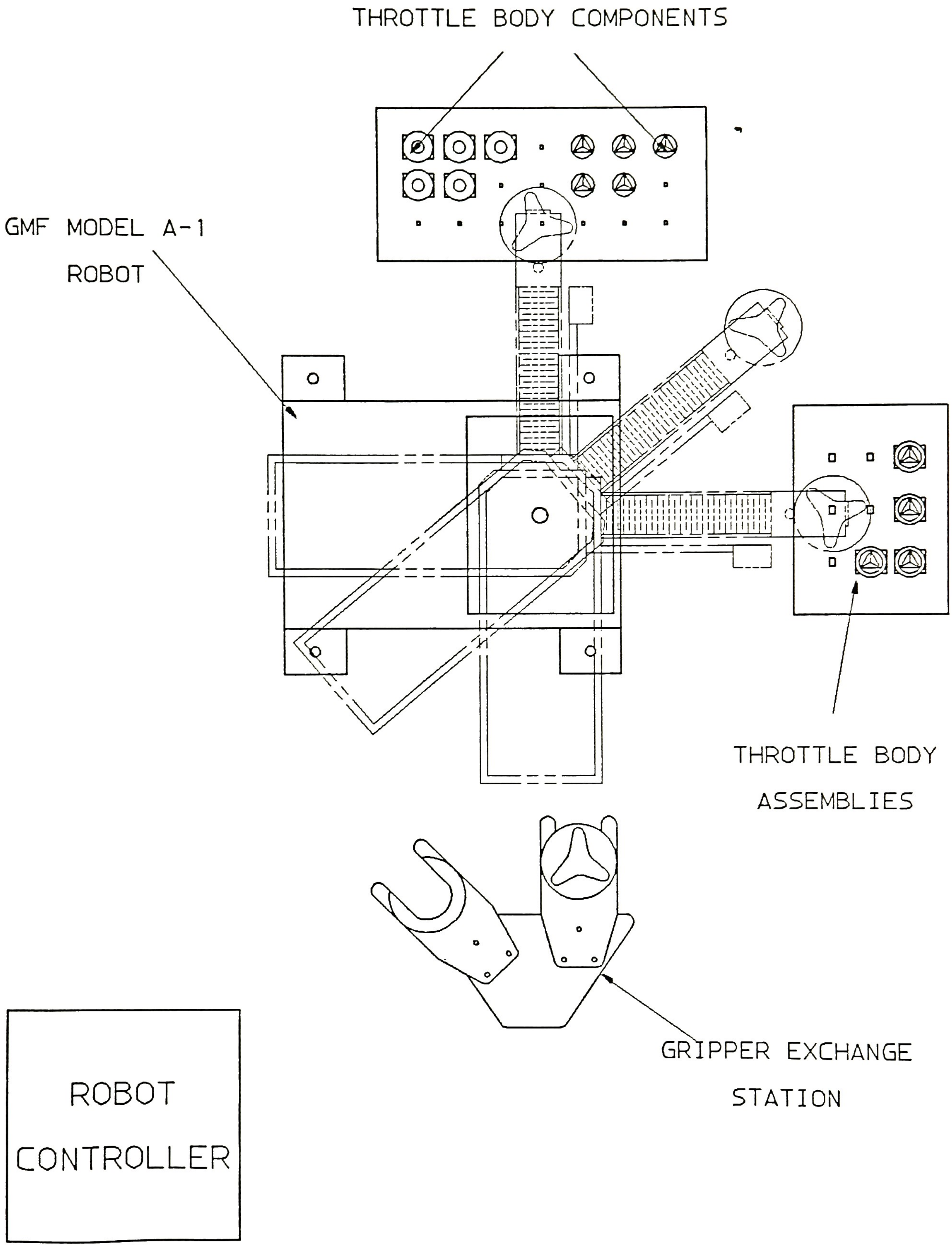


Figure 18. Test Cell Mock-up

5.0 EVALUATION OF THE SYSTEM AS DESIGNED

At the time that this project was started in the fall of 1983 there were relatively few similar devices in existence. GMF robotics at that time offered the only commercially available automatic gripper changing product, the "Auto Hand Changer" or AHC. General Motors evaluated the AHC and found it to be insufficiently sturdy and of little value in the industrial environment. The AHC was not very versatile in that it could connect a maximum of two air lines for use by the gripper mechanism.

The other auto gripper changing system that I found in the literature at that time was an experimental one developed by the Intelledex Incorporated (ref. [9]). This system was developed with similar objectives in mind although it is somewhat less robust for use on a smaller machine. This design incorporates a lead screw for attaching the male and female components of the interface. The lead screw of the male component, attached to the robot arm, screws into a threaded hole in the female component attached to the gripper. A locking system consisting of serrated clutch plates is used to keep the components from unscrewing. For tool removal, an air operated piston is used to separate the clutch plates. This is an effective means of joining the male and female parts but is somewhat complex and does not enjoy the self aligning feature of the QCEE presented here.

Early in 1984 EOA Systems of Dallas, Texas marketed an interchangeable end effector system (ref. [9]). This system consists a quick change

adaptor for the robot arm and several end effectors. A different design philosophy was employed here. The system does not use a general purpose gripper interface. Rather the company offers a line of dedicated end effectors covering a range of applications. EOA offers a large and small version of the system. The large version can handle payloads up to 150 lbs and the small one up to 25 lbs. The locking system is a pneumatically actuated locking pin. This seems to be a well designed system although its range of application is limited by the available grippers.

At the Robots 8 conference in April of 1984 an automatic gripper changing system was presented by J. M. Vranish (ref. [9]) of the National Bureau of Standards (NBS). This system is by far the most advanced of those disclosed to date. The system has the capability to connect not only electrical and pneumatic channels but high pressure hydraulic channels as well. The method of attachment incorporates a cam lock-pin assembly that forces close tolerance mating tapers between the arm and gripper interfaces together. According to the author, the design was adapted from a commercially available manual tool locking system marketed by the Younger Tool Company. The mating taper approach allows for a self aligning effect similar to that of the QCEE presented here. The cam locking-pin is acted on by a small air powered steel anvil because the tapers have a tendency to stick when it comes time to pull them apart. There is a potential problem in that the anvil may not generate the required kinetic energy to cause the tapers to come unstuck, but Vranish dispels any doubts with an analysis of the forces involved. Of the QCEE designs reviewed, this one has the most positive

locking mechanism. It also has the additional inherent quality of good repeatability.

Late in 1985 a quick change gripper system similar to that described in this report became commecially available. The product is the XChange (tm) system which is marketed by the Applied Robotics Corporation of Latham, N. Y. The XChange system allows for the interconnection of up to four pneumatic connections and/or up to 32 electrical connections between the XChange (tm) robot adapter and the XChange (tm) tooling adapter. The robot adapter is analogous to the AI described in this report and the tooling adapter is analogous to the GI. The robot adapter and the tooling adapter are held together by a mechanical toggling mechanism that is pneumatically operated and depends on the presence of air pressure to maintain attachment. Alignment between the robot adapter and the tooling adapter is accomplished by taper pins that must be carefully aligned before the two components are joined. The XChange system has more capability than the QCEE system described in this report which is the result of considerable development effort on the part of the Applied Robotics Corporation. The QCEE system described herein does, however, enjoy the unique advantage of self alignment between the AI and GI.

In summary, it is the opinion of the author that the QCEE presented here is simpler, cheaper and perhaps more reliable than those disclosed to date. It does not, however, incorporate all the features and capabilities of the NBS or XChange systems described above. I would assume,

however, that there are many real world applications that would not derive any benefit from the additional complexity of these systems.

6.0 RECOMMENDATIONS FOR FUTURE WORK

Considering the level of activity in the field of quick change end effectors, it seems that the technology will mature very rapidly. Since I first became involved with this project roughly two years ago, several disclosures have been made in the field of quick change end effectors. Of the designs disclosed it seems that different approaches have been taken to satisfy different requirements. Thus it would seem that the best approach to the design of future systems would be to give some consideration to the following constraints.

1. Type of machine(s) to use the QCEE over its expected life cycle.

2. Proposed application environments for the QCEE (i.e. pick and place, machine loading, assembly, ect.)

3. Cost

4. Any special features that are required for the proposed range of applications (i.e. hydraulic or fiber optic interconnections, ect.)

For the RPD environment, the current design could be improved by incorporating the additional feature of compliance into an integrated QCEE package. Compliance between the gripper and the robot arm is desirable in that it protects people and equipment from damage. Currently, a separate compliance device is used between the end of the

robot arm and the AI. The compliance device incorporates a continuity switch that detects relative motion between the gripper and arm. If motion is detected, the robot shuts down. Incorporating compliance into the QCEE package would reduce the weight and complexity of the end of arm tooling.

Speaking strictly in terms of maximizing flexibility in the factory, the anthropomorphic gripper designs offer the greatest number of possibilities. As indicated in section 4.3, the QCEE still requires specialized gripper tooling for a particular application or range of applications. Before anthropomorphic grippers become practical, however, a good deal of work is still required in the area of adaptive axis control algorithms for the robot and gripper. Such algorithms will process data from gripper mounted sensors and vision systems and make on line corrections in the position of the gripper "fingers" as well as the robot axes. This type of adaptive control would represent the ultimate in automation flexibility.

REFERENCES

[1] Jacobson, S.C.; Wood, W.F. and Biggers, K.B., "The Utah/MIT Dextrous Hand Work in Progress," Proc. 1st International Symposium on Robotics Research, 1983.

[2] Capoli, M. and Shahinpoor, M. "Design and Construction of a Five-Fingered Robotic Hand," Robotics Age Feb. 1984, pp 14-19.

[3] Lian, D.; Peterson, S. and Donath, M., "A three Fingered, Articulated, Robotic Hand," proc. 13th International Symposium on Industrial Robots and Robots 7, April 1983, pp 18-91 to 18-101.

[4] Nakano, Y.; Masakatsu, F. and Hosada, Y., "Hitachi's Robot Hand," Robotics Age, July, 1984, pp 18-20.

[5] Palm, W.J. and Datseris, P., "Pose Seeking Algorithms for the Control of Dexterous Robot Hands," 1985 IEEE International Conference on Robotics and Automation, pp 582-587.

[6] Lyons, D.M., "A Simple Set of Grasps for a Dextrous Hand," 1985 IEEE International Conference on Robotics and Automation, pp 588-593.

[7] Hirose, S. and Umetani, Y., "The Development of a Soft Gripper for the Veratile Robot Hand," Mechanism and Machine Theory, 1978, vol. 13, pp 351-359.

[6] Tella, R.; Birk, J.R. and Kelly, R.B., "General Purpose Hands for Bin-Picking Robots," IEEE Transactions on Systems, Man and Cybernetics, vol. SMC-12, No. 6, November/December 1982, pp 828-837.

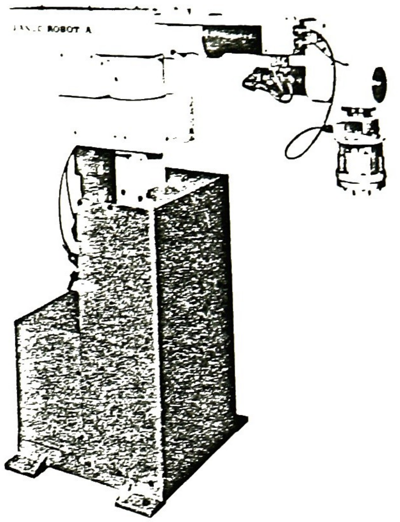
[8] Wright A. J., "End Effector Technology and Programmed Automatic Exchange," proc. 13th International Symposium on Industrial Robots and Robots 7, April 1983, pp 18-1 to 18-13.

[9] Vranish, J. M., " 'Quick Change' System for Robots," Proc. Robots 8 conference, April 1984, pp 17-74 to 17-97.

Appendix A. GMF A1 Robot Specifications

2 Robot Specifications

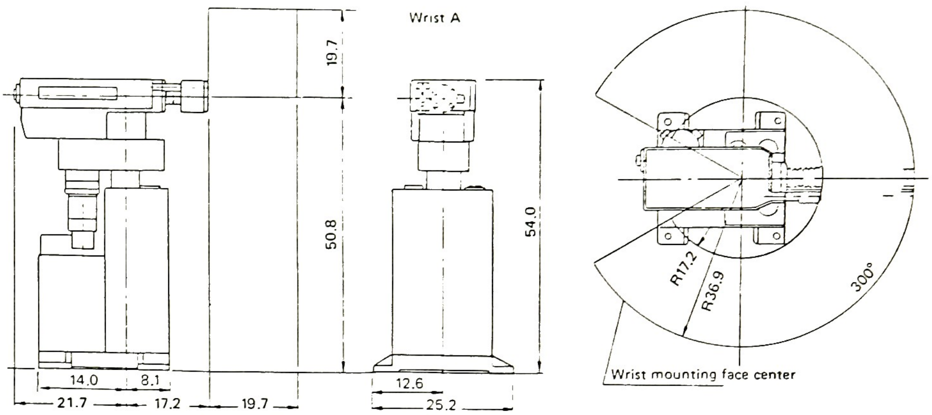
GMF
Model A-1



Manufacturer	GMF Robotics Corporation Northfield Hills Corporate Center 5600 New King Street Troy, MI 48098 (313) 641-4100
Classification	Controlled Path (Point-to-Point)
Price Range	$34,400 Base Price
Drive Type	Electric DC Servo
Load Capacity	20/33/66 lbs. (Depends on Wrist Selected)
Repeatability	± 0.002 in.
Reach	37 in. Standard 43 in. Optional

2 Robot Specifications

Work Envelope
GMF A-1



Specifications

Positioning Performance
Repeatability
± 0.002 in.

Manipulator
Drive Type
Electric DC Servo
Load Capacity
20/33/66 lbs.
(Depends on wrist selected)
Configuration
Cylindrical
Coordinate System
World (Cylindrical);
Tool (Cartesian); others
Degrees of Freedom
3 to 5 Axes
Gripper Actuation
Pneumatic, Electric, etc.

Power Requirements
220/380/440/etc. VAC; 3Ø;
50/60 Hz; 5000 W

Controller
Type
Minicomputer (System R, Model C)
Programming Methods
Teach Pendant and CRT;
Operator's Panel (option)
Memory Capacity
300 to 6000 Points
External Storage
Bubble Cassette (option)
I/O Interfaces
21 in/22 out
Cable Length
16 ft. Standard

Floor Space and Approximate Net Weight
Manipulator
22.0 X 25.2 in. Base
880 lbs.
Control Unit
24 w X 59 h X 28 d in.
550 lbs.
Power Unit
(Not a separate unit)

Environment
32 to 113° F
20 to 90% Relative Humidity

Special Notes/Options
- System R Model C controller is capable of directing 5 axes simultaneously
- 6 in/6 out interfaces are on wrist

Options
- Bubble cassette memory storage
- Sensor interface
- Software (e.g., palletize, straight line motion, easy program routines)
- Automatic gripper changer
- Wrist and gripper selection

GMF robots manufactured in Japan by Fanuc. Formerly marketed in the U.S. by General Numeric.

Appendix B. Implementation Guide

TITLE: Rochester Products Quick Change End Effector

DATE: August 13, 1984

REPORTED BY: Richard D. Forman

Co-op Student

University of Pennsylvania

APPROVED BY: Kurt Hertzog, Supervisor

Manufacturing Development and Engineering

Abstract

Evaluate and test the Rochester Products' QCEE (Quick Change End Effector) using a General Motors-Fanuc robot model A-1. An innovative design for the QCEE allows the robot to quickly change the tool that it is using.

Conclusions

The QCEE allows a robot that once performed only one operation, e.g. gripping or driving, to perform multiple tasks. It would reduce downtime and retooling costs when robot breakdowns occur or altering processes. By standardizing the connections, all robots used in one area or in all of General Motors could have interchangeable tools.

The concept of the QCEE is revolutionary and has many applications beyond those presented in this report. The Rochester Products design is a high quality implementation and rivals those units currently on the market. Its one shortcoming, to be discussed later, is unnoticeable when used with a majority of the tools currently available for robots.

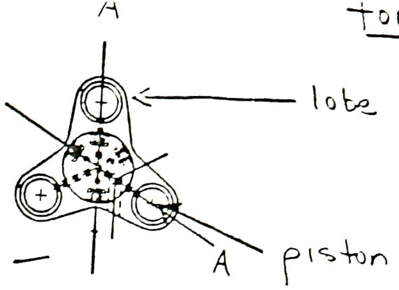
Introduction

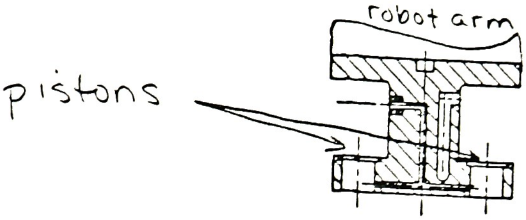
The QCEE was designed by Bill Craig as a masters thesis for a degree in mechanical engineering from Rochester Institute of Technology. It is composed of one male and one or more female components. The male end is permanently attached to the robot arm, and the female ends are attached to various tools that are intended to be used. The male is composed of three lobes spaced at intervals of 60 degrees. Each lobe has a pneumatic piston that is used to lock the male and female parts together. The pistons are triggered by a common air line and can be activated either manually or by robot service codes. Currently, only three other pneumatic lines are transmitted through the QCEE to the tool. A future development will allow electrical power to be transmitted as well as facilitating vision systems or sensor signals. This shortcoming did not affect its operation because all of the tools used with this robot required neither electricity nor feedback.

Refer to diagram on following page.

male end:
attached to the end of the robot arm.

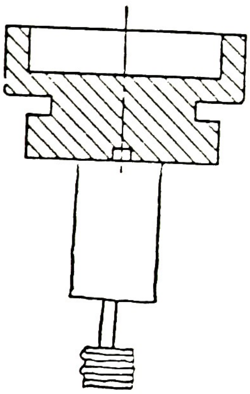
top view



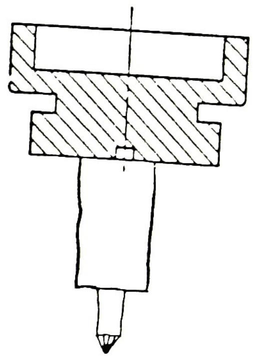


profile section view A-A

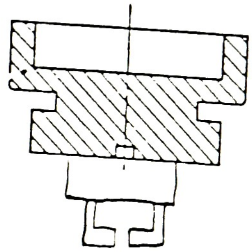
female end:
attached to tools



compressible rubber for gripping parts with hollow areas



torque wrench



grippers

Description of Work Cell

Work area layout is a very important consideration when deciding to use the QCEE, and depending upon the size and number of tools required, may require a large amount of forethought. Work spaces were investigated where the tools were placed in the Theta coordinate direction (waist rotation) of the robot and in the Radius coordinate direction of the robot. Tool receptacles must be placed level with the ground. The back edge of the tool holder should face the edge of the work envelope. The engineer should place the tool holder out of the way because of the space required to access the tools. The tools themselves might be unwieldy and it is difficult to maneuver them when placed in a crowded environment. Planning is required in deciding where the tool holders will be placed. Step through the processes and verify the fact that a position is acceptable.

Label the tools so that their placement in the tool holder is correct and alignment with the robot arm is correct. This will save time during programming and debugging.

Programming Procedures

The Robot was able to pick up new tools with relatively little difficulty. Running at a manual override speed of 8 (1=min., 8=max.), with the F codes presented in this report, there was no errors in fifteen consecutive operations.

However, when programming and debugging the robot, maintain a manual override speed of 3 or less and engage the single step mode using the teach pendant.

DO NOT EXECUTE PROGRAM AT HIGHER SPEEDS UNTIL ONE COMPLETE CYCLE HAS BEEN COMPLETED AT LOWER SPEEDS.

Even then, only increment speeds by steps of one (1) and repeat the entire program before changing the manual override speed. Problems, that were unapparent at slower speeds, often surfaced as the speed was increased.

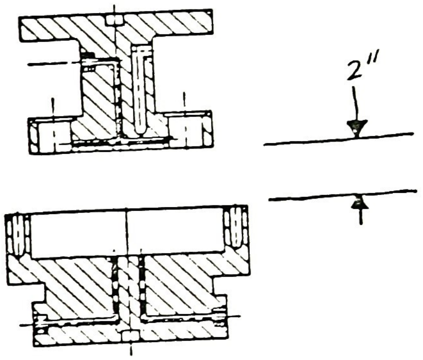
Each step in Tool Acquisition and Replacement is another programming point. The steps are merely guides that allow the programmer to easily to program the robot.

Tool Acquisition

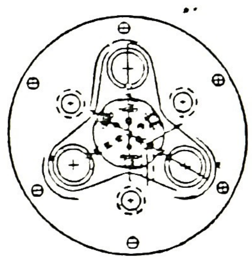
A new tool is loaded by the following procedure (after the robot has been programmed). Try to emulate this process in programming.

(1) The male QCEE is aligned 2" directly above the female and all pneumatic lines are turned off. The male lobes are aligned with and mirror the lobe arrangement on the female receptacle. Level out the male unit (parallel to ground) by changing the Beta coordinate.

two inch clearance

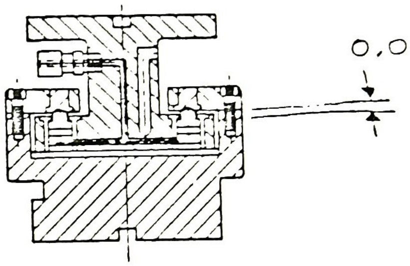


aligned lobes



(2) Lower robot arm until the male is 0.075" below the inside rim of female receptacle. Fcode=6

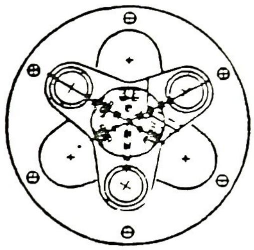
the male part is below the upper plate on female receptacle.

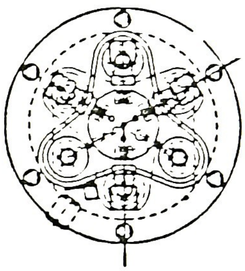


(3) Rotate robot arm 60 degrees by varying Alpha until lobes are 180 degrees out of phase with female slots. Fcode=8

visually simple representation.

actual representation with hidden lines.





(4) Activate pneumatic air line using robotic programming service codes that will raise pistons mating male and female parts of QCEE.

(5) Raise entire unit (including: robot arm, male, female and tool) 0.05" +until the female is able to clear the recession on the tool holder.

(6) Slide unit forward until the unit is at least 1.2" minimum distance from any point to any point on the tool holder. It will be necessary to vary Theta, Radius, Alpha and possibly the Z coordinate of the robot. Use linear hand control to keep the unit aligned while changing the coordinates (Gcode 01 and/or 15).

Note: It was unexpectedly necessary, when using Gcode=15, to program

G01,G15

and then delete G01 leaving

G15

The robot would not allow the programming of G15 directly.

Fcode=3 or 4 depending on ease of removal.

It was often necessary to break this one step into two or more programming steps. For instance, if the compliance emergency switch is activated while executing this step, remove the tool halfway, stop, and then remove it the other half. Doing this in steps allows the programmer to have more control and allows the tool to be aligned during the interim steps.

(7) With heavier tools it often occurred that even though the pistons fired they were unable to completely and securely mate the two parts. As an added measure of security, after step (6), deactivate and immediately reactivate the pneumatic pistons. This procedure should insure that male and female components are mated securely. Once free from the tool holder, the QCEE is no longer constrained from self alignment. In the deactivated state, the QCEE will go limp and, once reactivated, should be mated correctly subject only to the force of the pistons.

(8) The tool is attached and ready to be used.

Tool Replacement:

---

(1) Bring unit to within approximately 1.2" closest distance to tool holder and adjust the alpha angle so that the beveled tool edge is in alignment with tool holder. The height of the unit should be sufficient to allow beveled area of tool to straddle the tool holder.

(2) Move unit into a position that is aligned directly above the tool holder (0.1") and prepared for final placement. Do this by adjusting Radius, Theta, Alpha and possibly Z, always keeping beveled edge of female unit parallel to beveled edge of the tool holder.
Use linear hand control (Gcode=15) to keep the unit oriented in space.
Refer to (6) in Tool Acquisition.
Fcode=4.

(3) Lower unit to tool holder with a final clearance of 0.05" by changing Z. This should leave unit resting on the tool holder and applying negligible pressure to the end of the robot arm. To be safe, allow clearance to be paper thickness. Applying pressure will make demating difficult and possibly activate the compliance cut-off switch. Fcode=4

(4) Deactivate pneumatic lines which fire the pistons and the unit should fall into place on the tool holder.

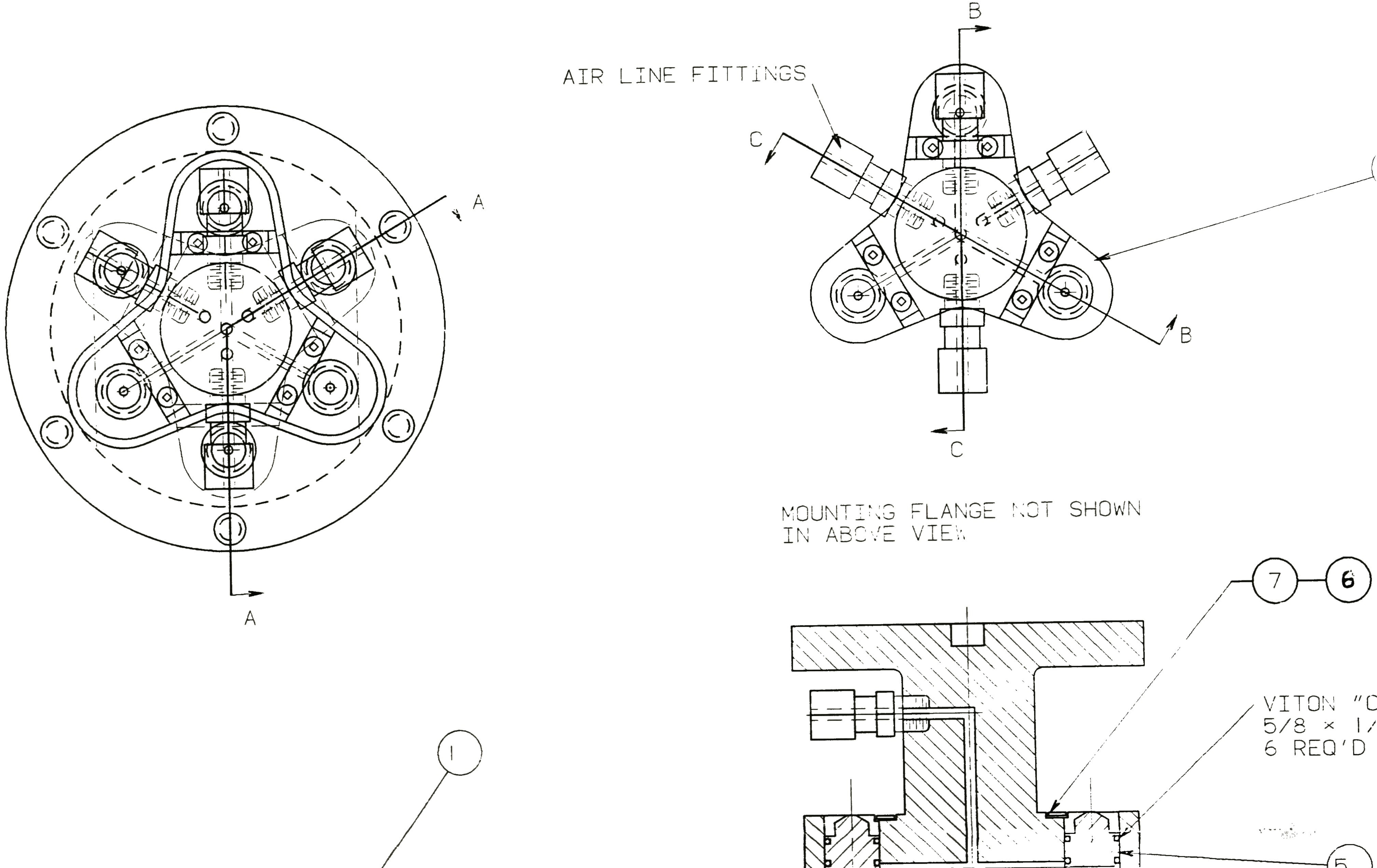
(5) Rotate robot arm 60 degrees by varying alpha until the male is aligned with the female parts. Fcode=8

(6) Raise the robot arm with male device by incrementing Z approximately 2". The male and female QCEE are now de-mated and the system is ready for another tool. Fcode=5

Compliance

A compliance unit is a device that allows slight misalignments to exert negligible effects on the operation of the robot. It is a free floating device under pressure that allows the orientation of the tool to be changed but returns to undeformed configuration after the external force is removed. If the tool gets stuck and forces the compliance unit to "yield" past a certain point, the emergency switch will be triggered and the robot will stop operating.

Most compliance units have an appreciable weight and this must be taken into account when designing tools. Not using one is normally a dangerous practice that becomes even more severe when using QCEE. It is rare that removal and replacement of a tool will occur without large forces being placed upon the tool by the tool holder. Compliance allow these forces to be reduced significantly without affecting the operational characteristics of the tool. Without compliance DAMAGE could occur to the tool, tool holder, robot and anything else in the work envelope of the robot (including people). The compliance unit that I used was an air pressure operated compliance unit. For lack of any quantitative values, the pressure was reduced to 40 p.s.i. from an air supply of 80 p.s.i. Newer compliance units are lighter, while retaining the strength and durability of earlier units.


AIR LINE FITTINGS
A
A
B
B
C
C
MOUNTING FLANGE NOT SHOWN
IN ABOVE VIEW
7
6
1
5
VITON "O
5/8 × 1/
6 REQ'D

CHECKED		LCC	NO	CHANGES	BY DATE	C.N.
	A					
	B					
	C					
	D					
	E					
	F					
	G					
	H					
	I					
	J					
	K					
	L					
	M					
	N					
	O					
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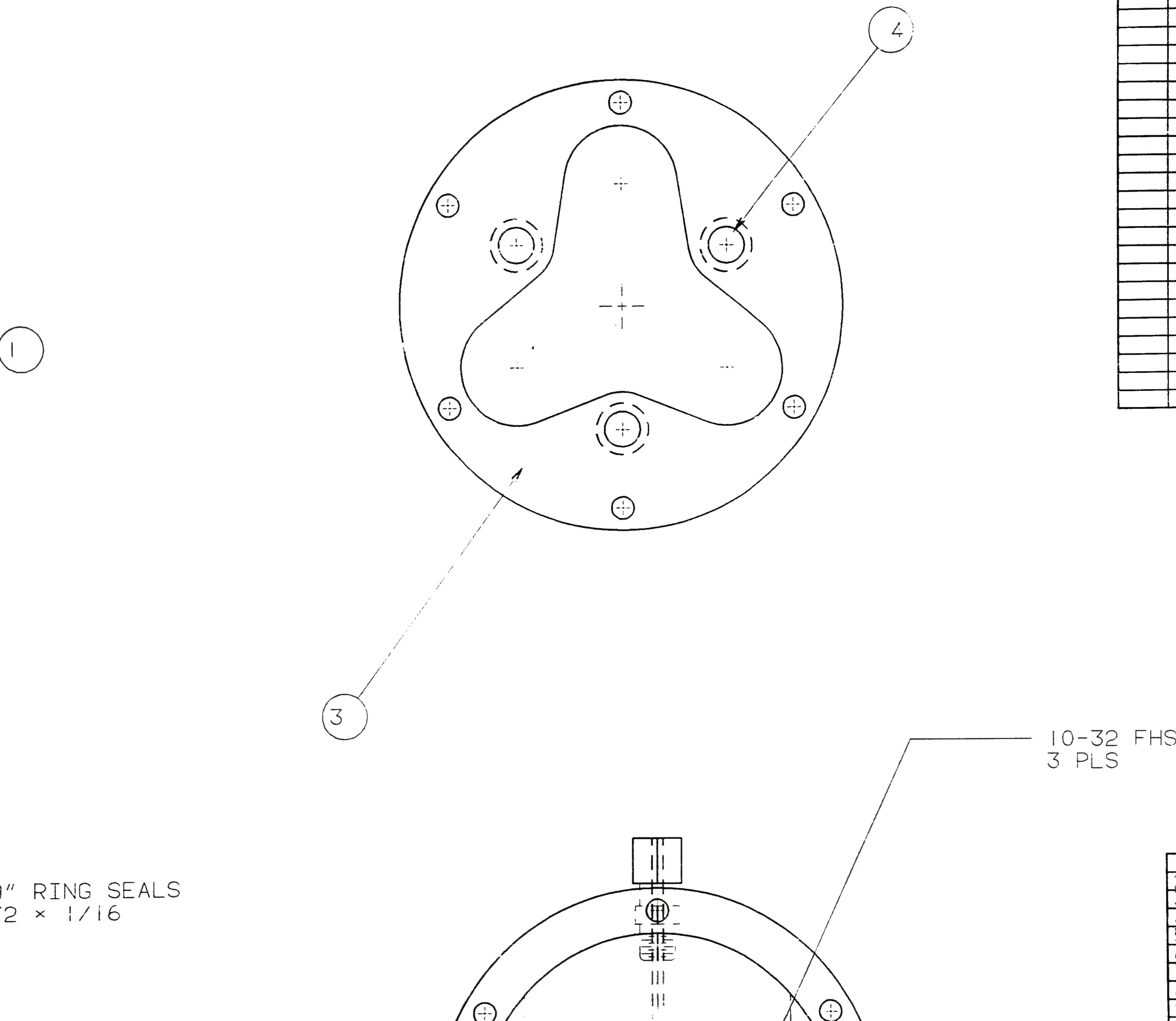
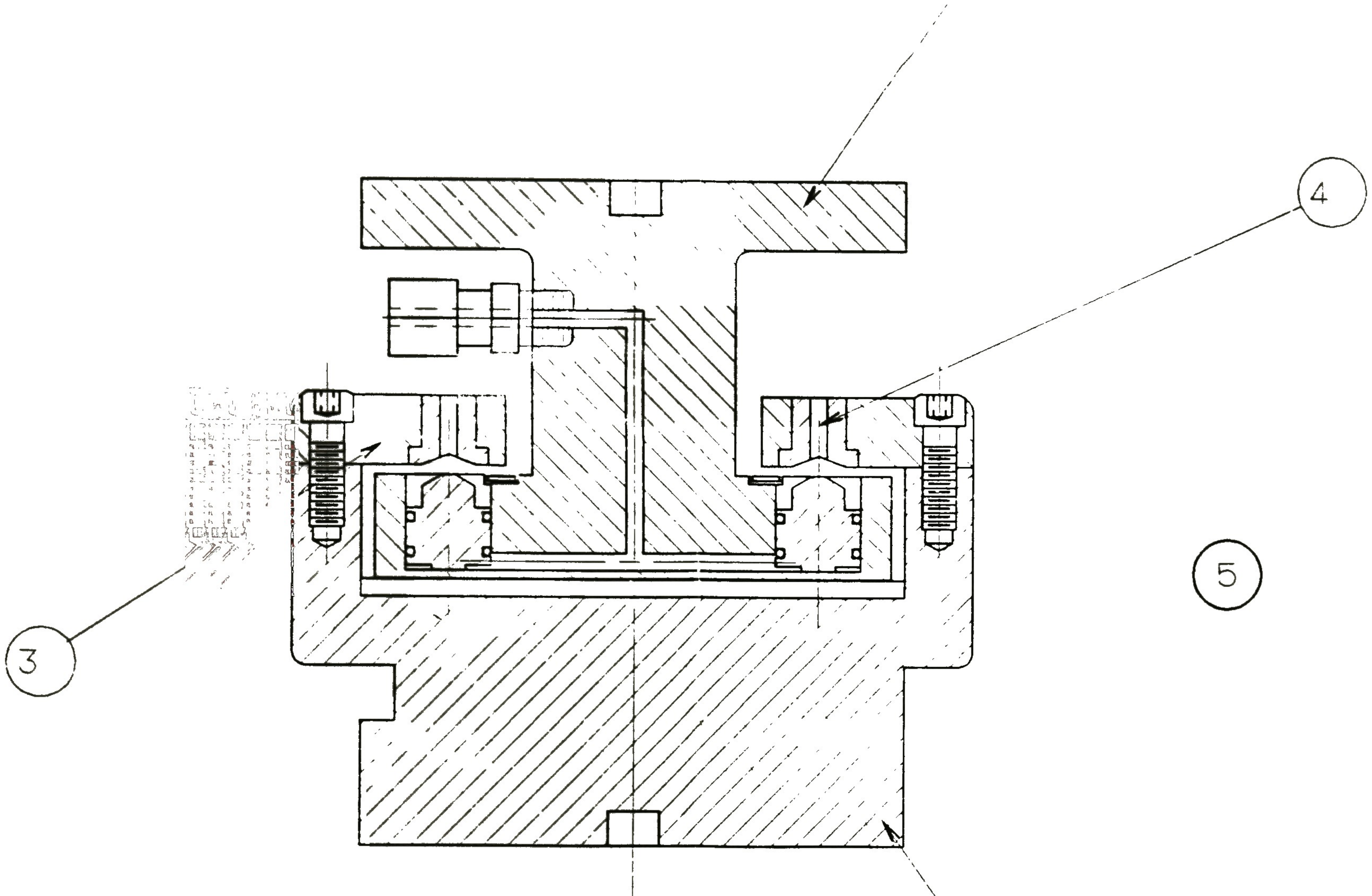
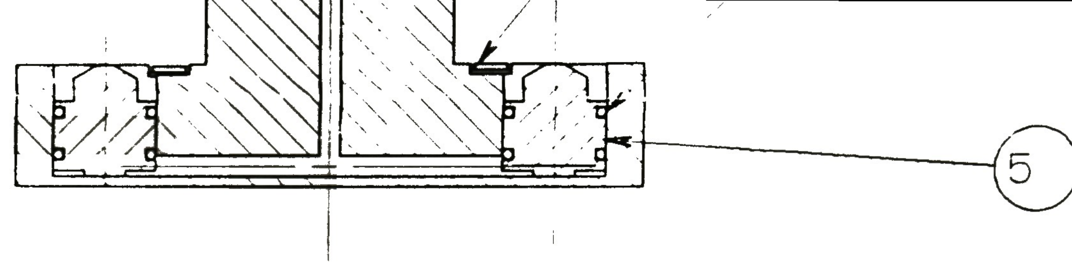
	S					
	T					
	U					
	V					
	W					
	X					
	Y					
	Z					



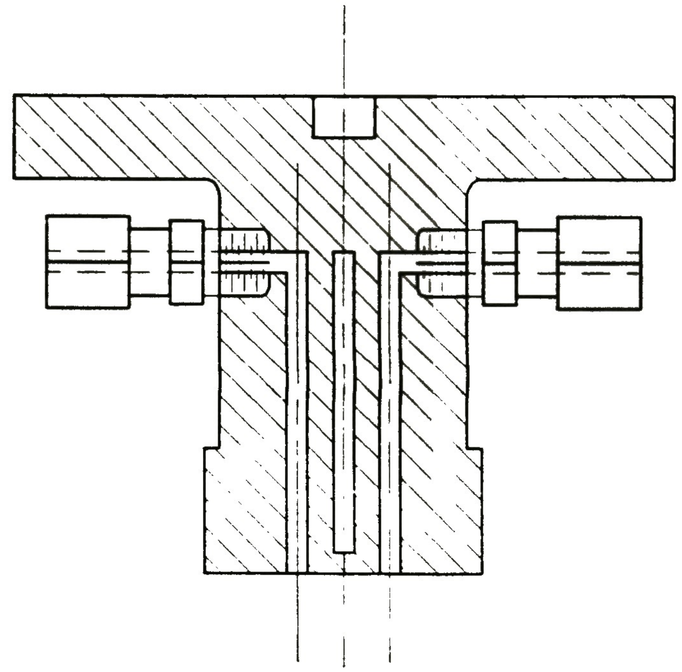
1	1	4 DIA × 3"	2024
2	1	5 DIA × 3"	2024
3	1	5 DIA × 5/8"	2024
4	3	3/4 DIA×3/4"	01
5	3	3/4 DIA×3/4"	01
6	6	5-40 F.H.S.	
7	3	1×1/4×.025"	
8	1	4.5×4.5×1/8"	A2
9	1	10×5.5×1/4"	1018
	3	10-32 FHS	



SECTION A-A



SECTION B-



SECTION C-C

TOOL ENGINEER: ____________

MACHINING LIMITS

UNLESS OTHERWISE SPECIFIED
ALLOWABLE VARIATION ON ALL:

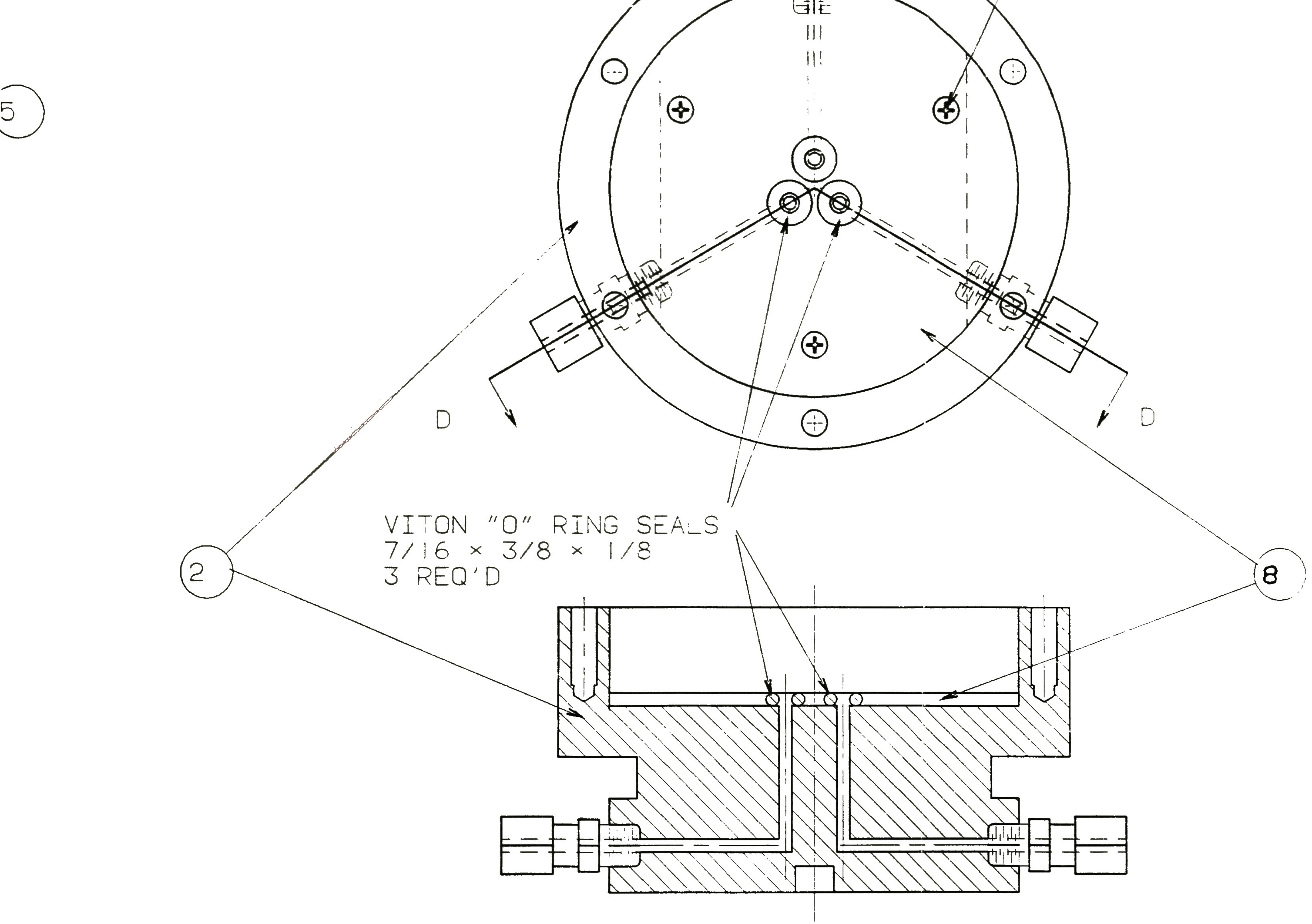
2 PLACE DECIMAL DIMENSIONS - ± .01

3 PLACE DECIMAL DIMENSIONS - ± .00

SUPERSEDES

REFERENCE

SUPERSEDED BY



SECTION D-D

NO	AMT	MATERIAL LIST (SIZE)	MAT'L
6	6	5-40 F.H.S.	
7	3	1×1/4×.025"	
8	1	4.5×4.5×1/8"	A2
9	1	10×5.5×1/4"	1018
	3	10-32 FHS	
	6	"O" RING 5/8×1/2×1/16	VITON
	3	"O" RING 7/16×3/8×1/8	VITON
	6	10-18 HEX HD CAP SCR	
	7	1/8 AIR LINE FITTING	

MODEL -
ALSO USED FOR PART NO
PART -
TOOL -
MACHINE -
DRAWN - W. CRAIG DATE 5/23/84
CHECKED - APPROVED

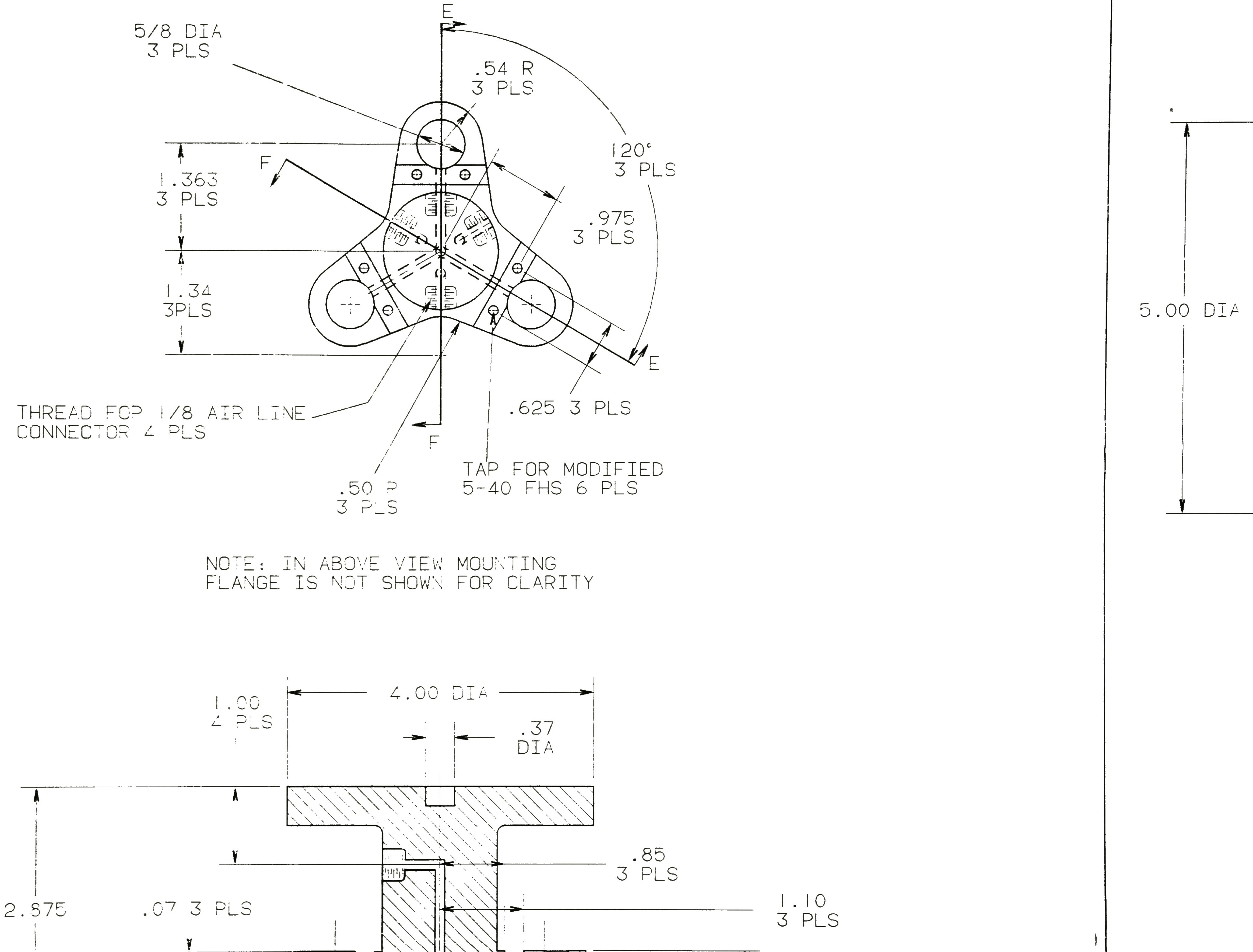
ROCHESTER PRODUCTS DIVISION
GENERAL MOTORS CORPORATION
ROCHESTER NEW YORK

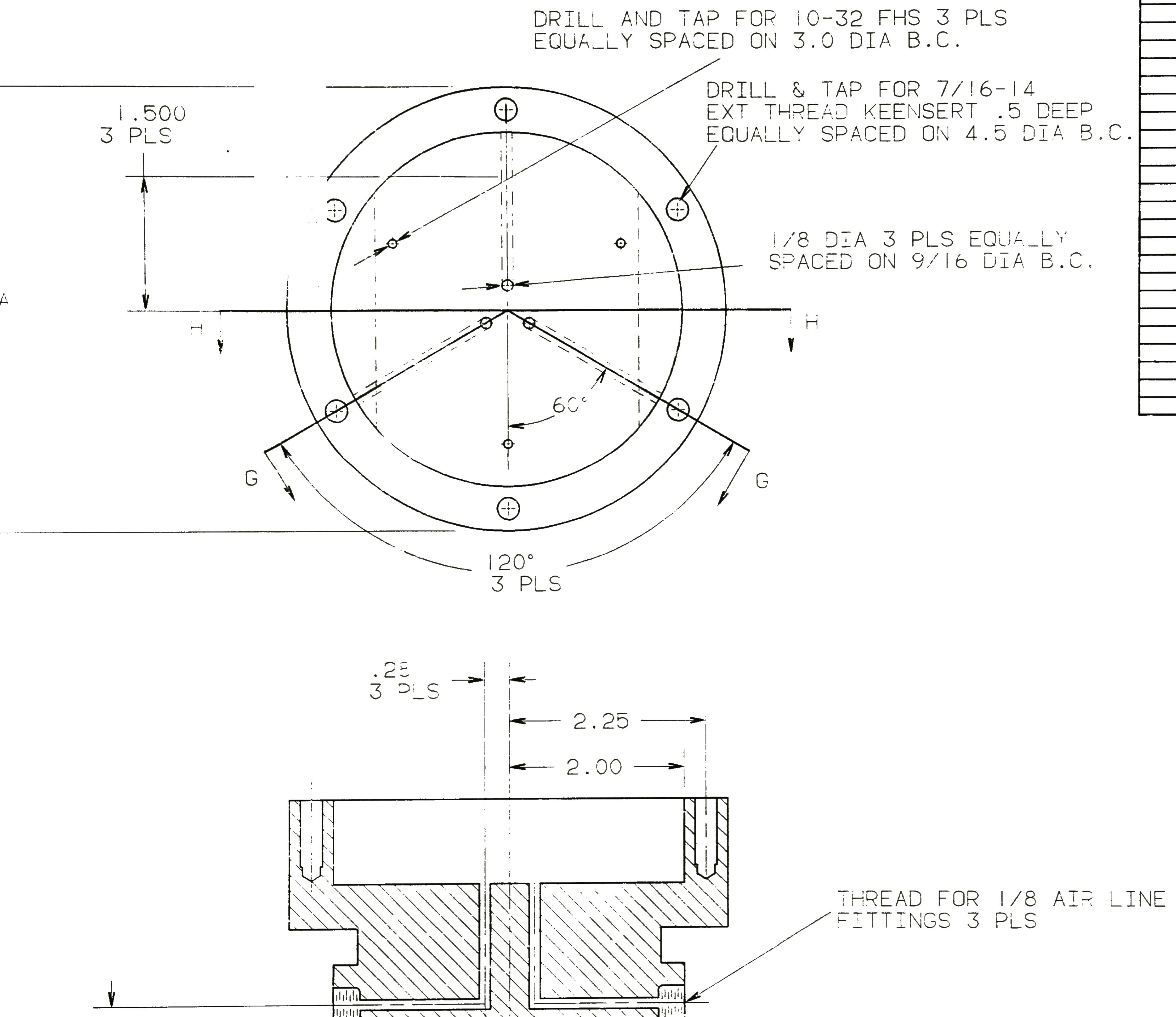
SHEET NO. 1 OF 4 TOOL NO.

MARK ALL TOOLS AND LOOSE PIECES
WITH TOOL NUMBER IF SIZE PERMITS.
OTHERWISE TAG WITH TOOL NUMBER.

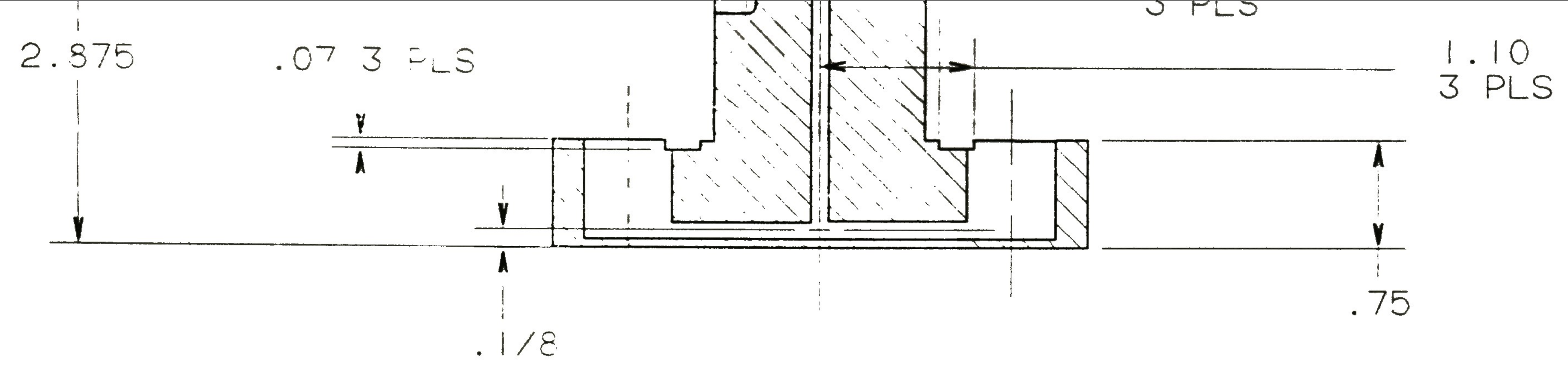
LAST CHANGE

TOOL DWG. NO ____ PART DWG. OF ____ SHEET 1-SIZE

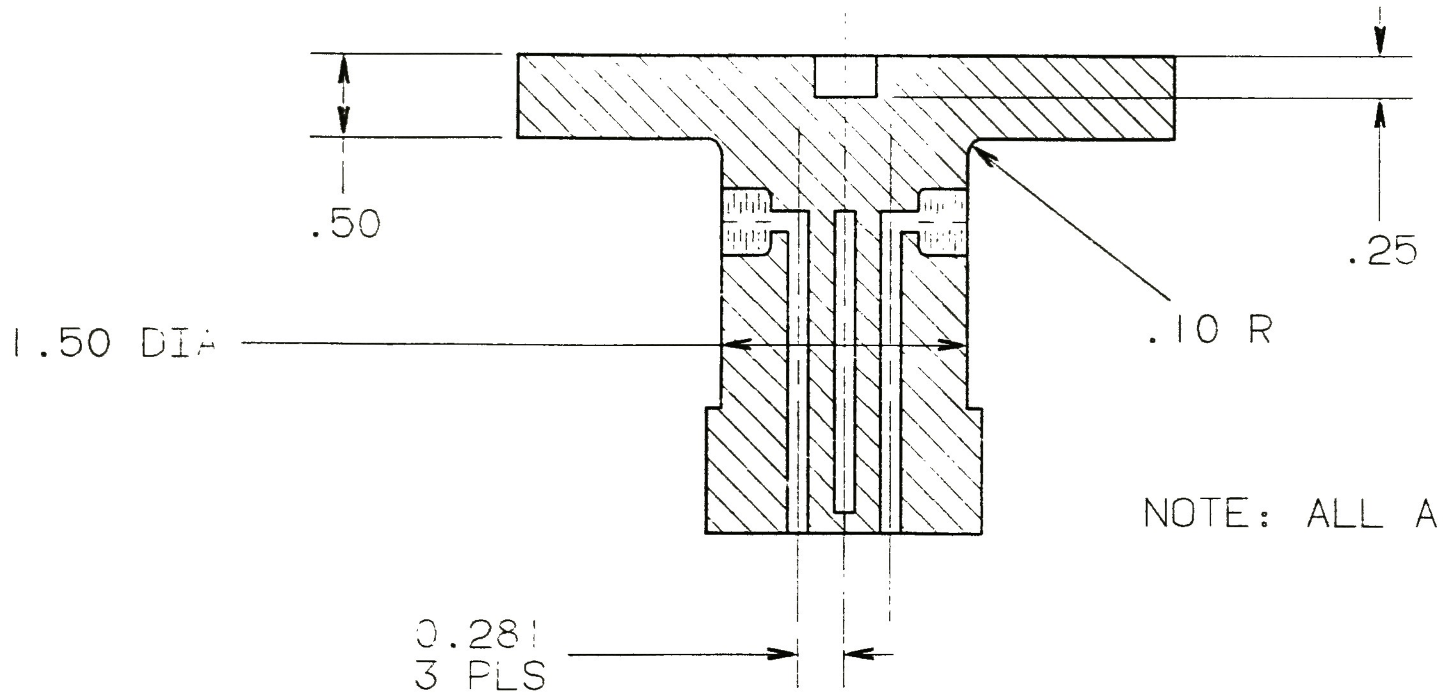

5/8 DIA
3 PLS
.54 R
3 PLS
E
120°
3 PLS
F
1.363
3 PLS
.975
3 PLS
1.34
3PLS
E
THREAD FOR 1/8 AIR LINE
CONNECTOR 4 PLS
.625 3 PLS
F
TAP FOR MODIFIED
5-40 FHS 6 PLS
.50 R
3 PLS
NOTE: IN ABOVE VIEW MOUNTING
FLANGE IS NOT SHOWN FOR CLARITY
4.00 DIA
1.00
4 PLS
.37
DIA
.85
3 PLS
2.875
.07 3 PLS
1.10
3 PLS
5.00 DIA



CHECKED		LOC	NO	CHANGES	BY	DATE	C.N.
	A						
	B						
	C						
	D						
	E						
	F						
	G						
	H						
	I						
	J						
	K						
	L						
	M						
	N						
	O						
	P						
	Q						
	R						
	S						
	T						
	U						
	V						
	W						
	X						
	Y						
	Z						



SECTION E-E



NOTE: ALL AIR CHANNELS 1/8 DIA

SECTION F-F

TOOL ENGINEER: ____________

MACHINING LIMITS

UNLESS OTHERWISE SPECIFIED
ALLOWABLE VARIATION ON ALL:

2 PLACE DECIMAL DIMENSIONS - ± .01

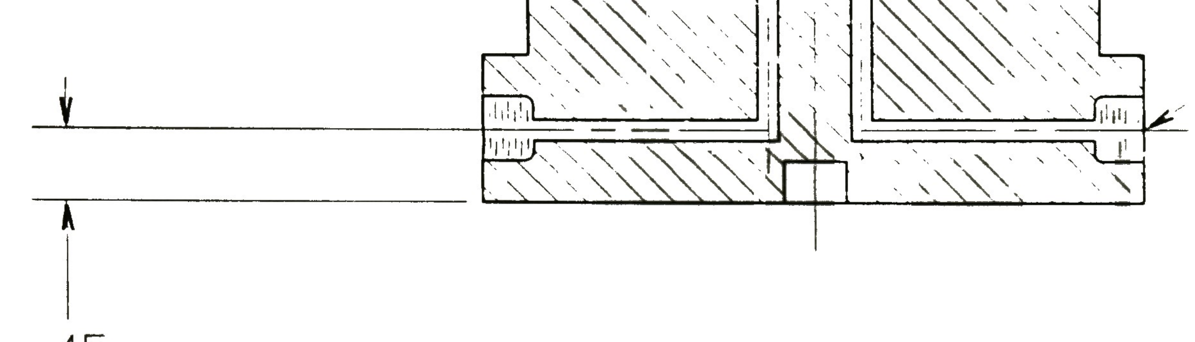
3 PLACE DECIMAL DIMENSIONS - ± .001

(1) ARM INTERFACE BODY
1 REQ'D
MAT'L: 2024 ALUMINUM

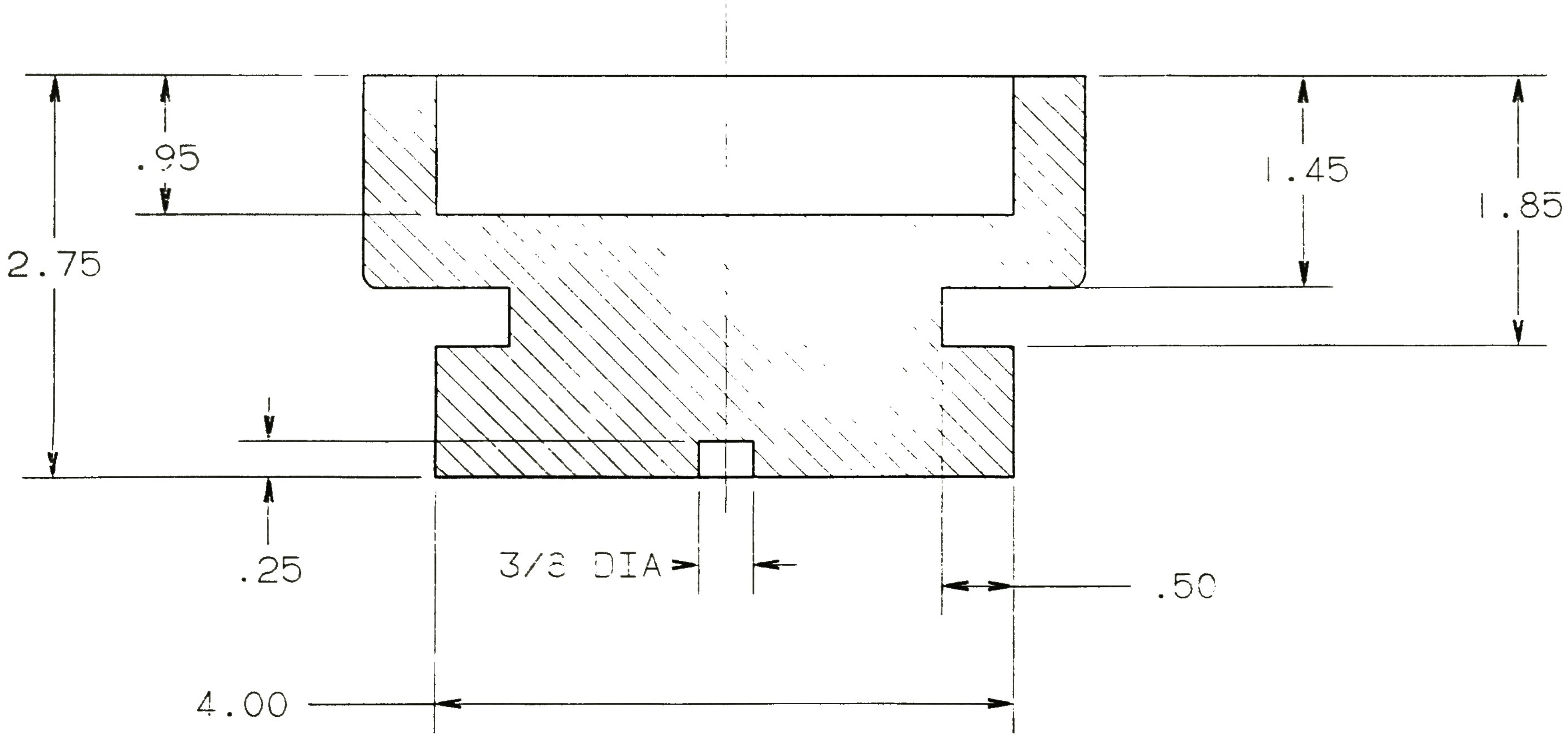
SUPERSEDES

REFERENCE

SUPERSEDED BY



SECTION G-G



SECTION H-H

(2) GRIPPER INTERFACE
1 REQ'D
MAT'L: 2024 ALUMINUM

MARK ALL TOOLS AND LOOSE PIECES
WITH TOOL NUMBER IF SIZE PERMITS.
OTHERWISE TAG WITH TOOL NUMBER.

LAST CHANGE

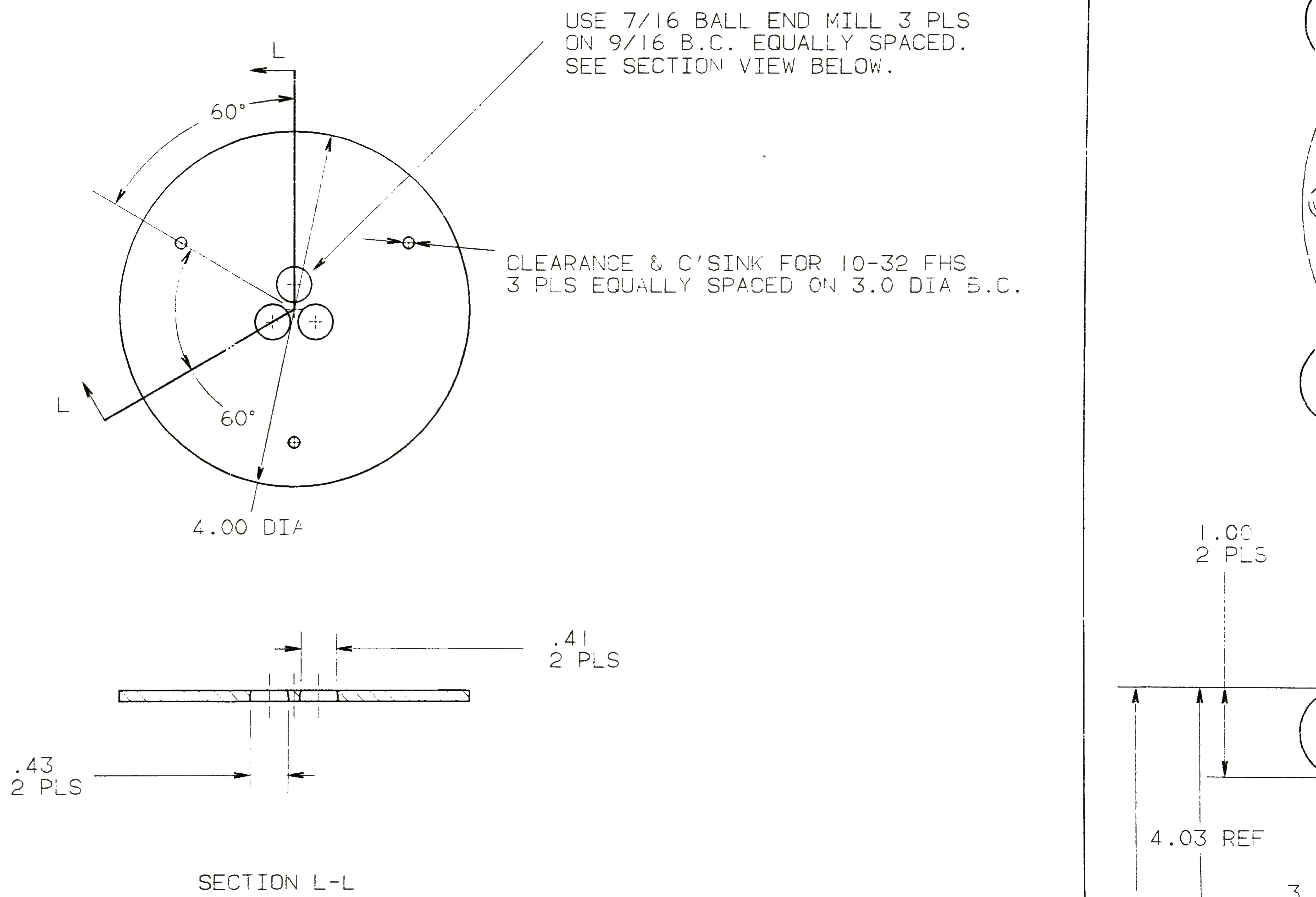
TOOL DWG. NO ______ PART DWG. OF ______ SHEET I-SIZE

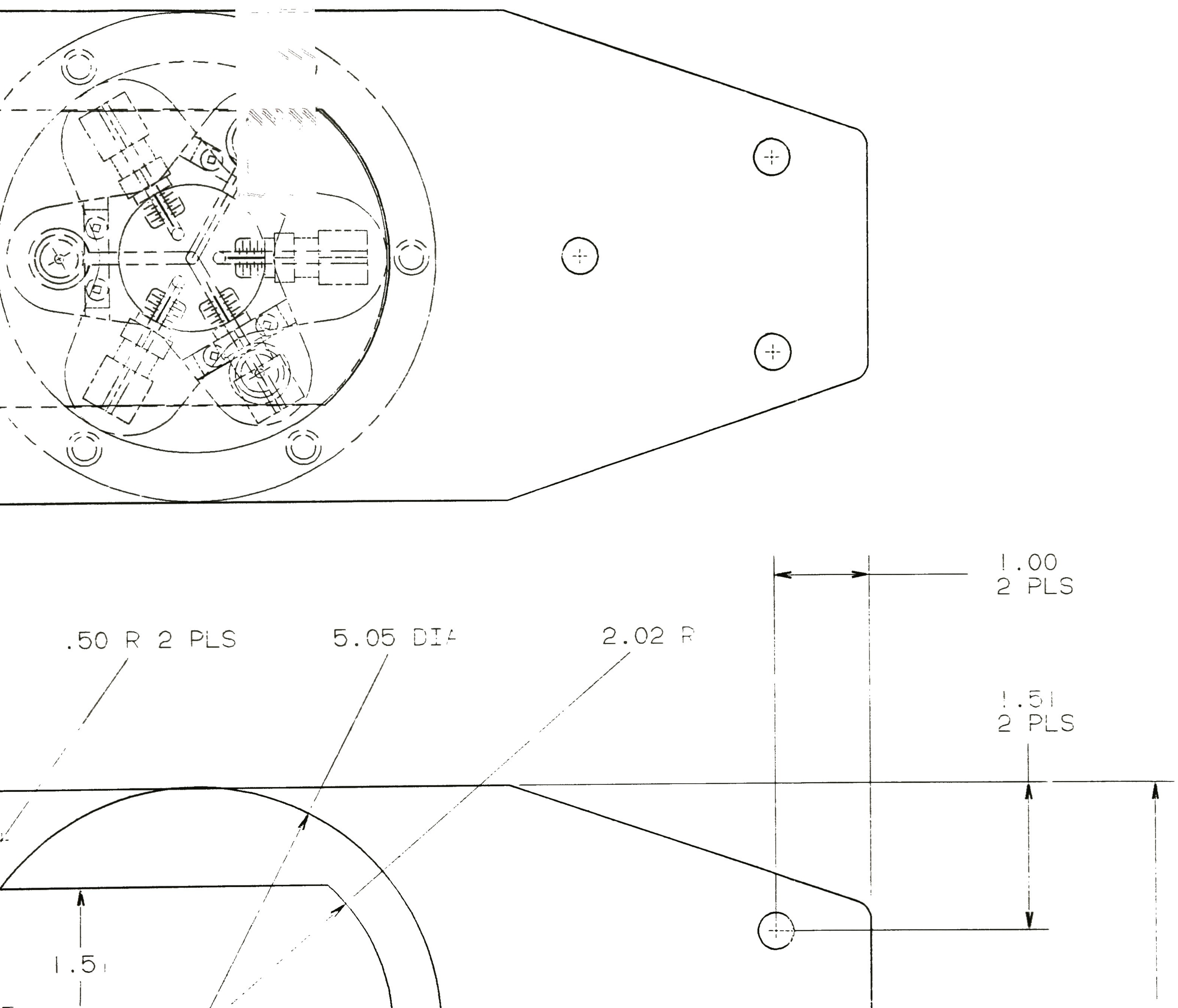
NO	AMT	MATERIAL LIST (SIZE)	MAT'L

MODEL -
ALSO USED FOR PART NO
PART -
TOOL -
MACHINE -
DRAWN - W. CRAIG DATE 5/23/84
CHECKED - APPROVED

ROCHESTER PRODUCTS DIVISION
GENERAL MOTORS CORPORATION
ROCHESTER NEW YORK

SHEET NO. 2 OF 4
TOOL NO.


USE 7/16 BALL END MILL 3 PLS
ON 9/16 B.C. EQUALLY SPACED.
SEE SECTION VIEW BELOW.
L
60°
60°
CLEARANCE & C'SINK FOR 10-32 FHS
3 PLS EQUALLY SPACED ON 3.0 DIA B.C.
4.00 DIA
.41
2 PLS
.43
2 PLS
SECTION L-L
1.00
2 PLS
4.03 REF



CHECKED		LOC	NO	CHANGES	BY	DATE	C.N.
	A						
	B						
	C						
	D						
	E						
	F						
	G						
	H						
	I						
	J						
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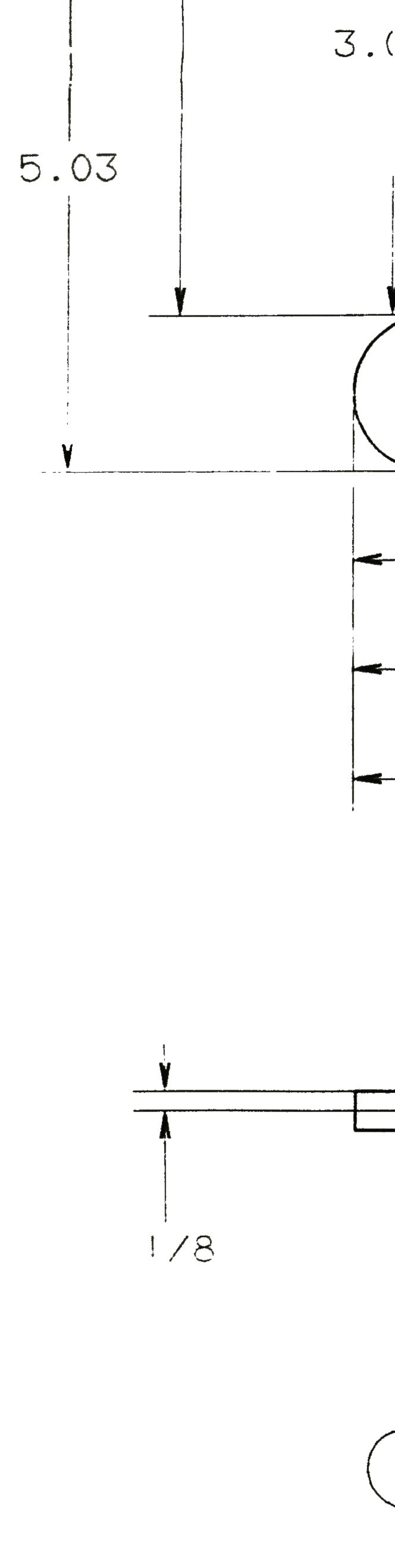
	W						
	X						
	Y						
	Z						

SECTION L-L

(8) STEEL PLATE FOR GRIPPER INTERFACE
1 REQ'D
MAT'L: A2 STEEL 0.12 ±0.005 THK



TOOL ENGINEER: ______________

MACHINING LIMITS

UNLESS OTHERWISE SPECIFIED
ALLOWABLE VARIATION ON ALL:

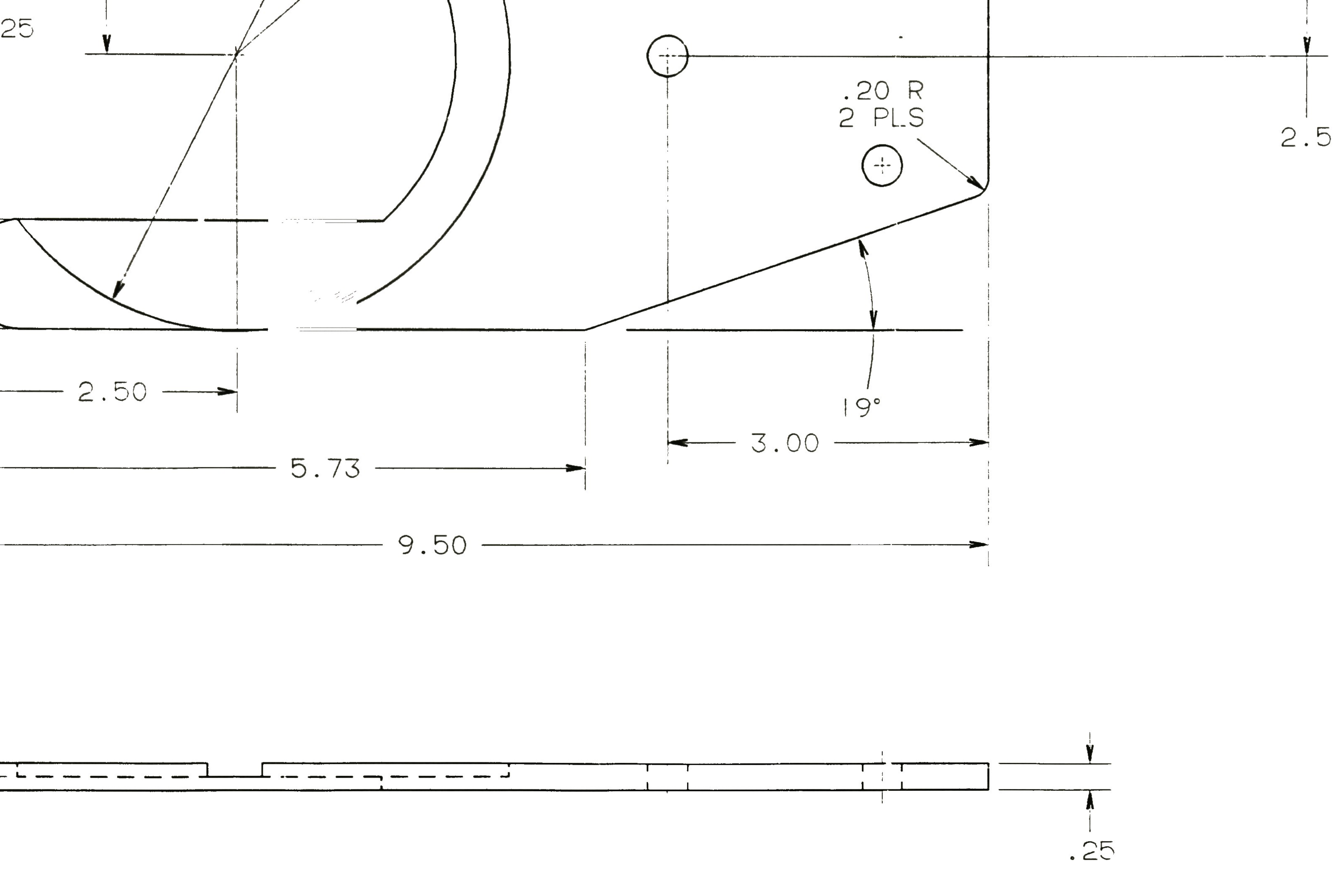
2 PLACE DECIMAL DIMENSIONS - ± .01

3 PLACE DECIMAL DIMENSIONS - ± .001

SUPERSEDES

REFERENCE

SUPERSEDED BY



DOCKING YOKE
1 REQ'D
MAT'L: 1018 STEEL 1/4 THK

MARK ALL TOOLS AND LOOSE PIECES WITH TOOL NUMBER IF SIZE PERMITS. OTHERWISE TAG WITH TOOL NUMBER.

LAST CHANGE

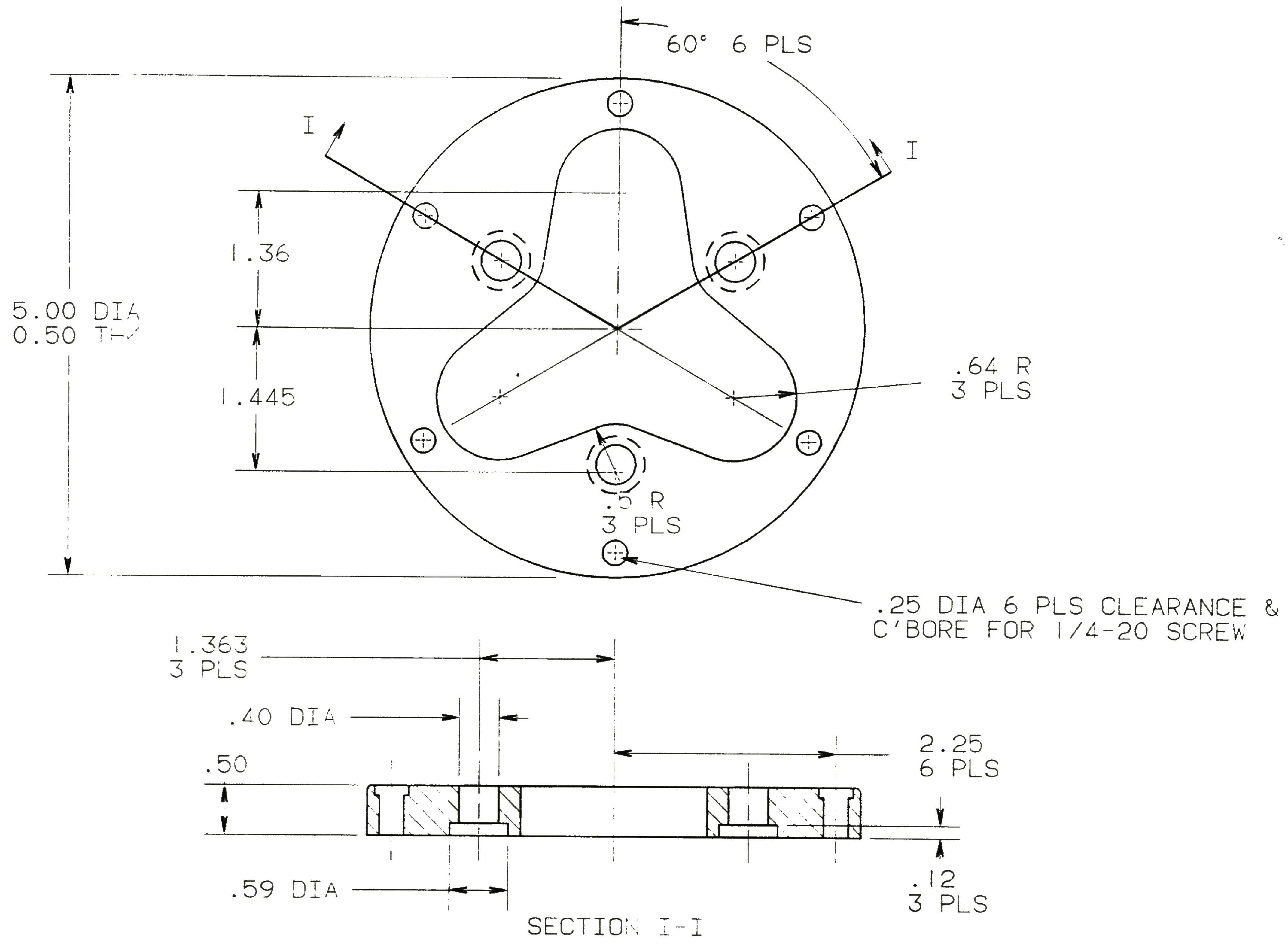
TOOL DWG. NO 4 OF 4 PART DWG. SHEET 1-SIZE

NO	AMT	MATERIAL LIST (SIZE)	MAT'L

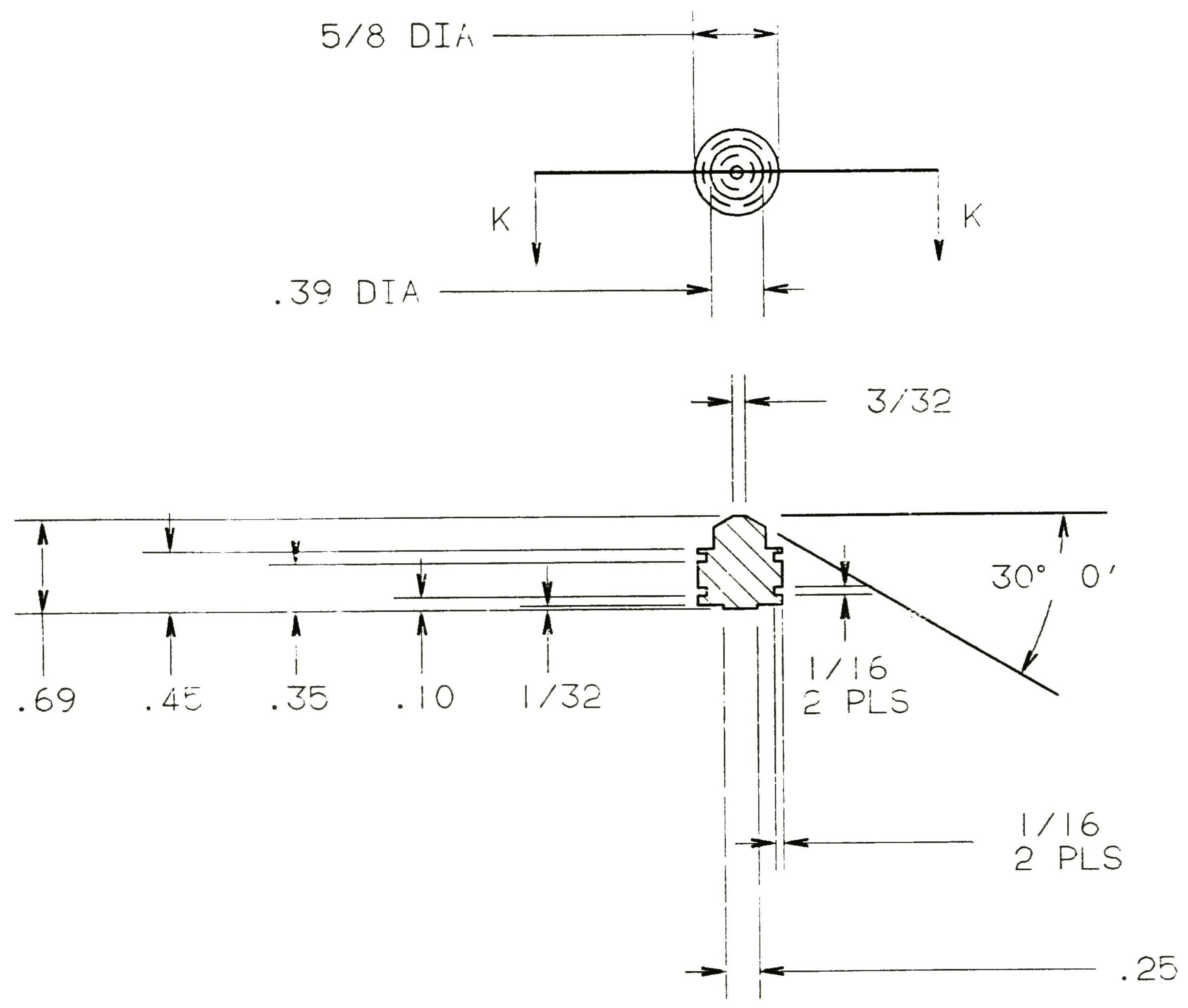
MODEL -
ALSO USED FOR PART NO
PART -
TOOL -
MACHINE -
DRAWN - W. CRAIG DATE 5/23/84
CHECKED - APPROVED

ROCHESTER PRODUCTS DIVISION
GENERAL MOTORS CORPORATION
ROCHESTER NEW YORK

SHEET NO. 4 OF 4 TOOL NO.



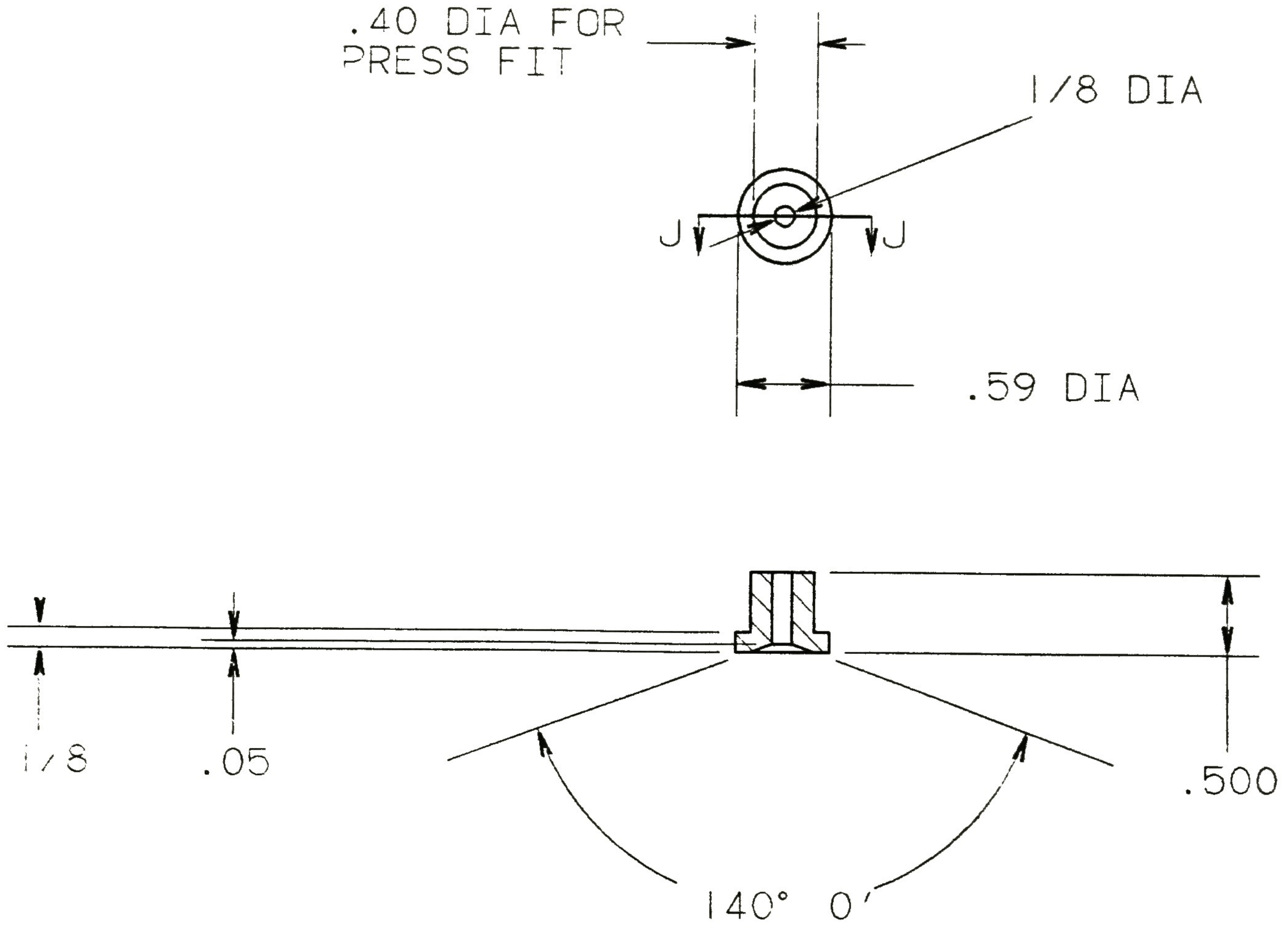
(3) GRIPPER INTERFACE TOP PLATE



SECTION K-K

(5) PISTON
3 REQ'D
MAT'L: O1 STEEL RC 58-60

(3) GRIPPER INTERFACE TOP PLATE
1 REQ'D
MAT'L: ALUMINUM



SECTION J-J

(4) TOP PLATE INSERT
3 REQ'D
MAT'L: O1 STEEL RC 58-60

TOOL ENGINEER: ____________

MACHINING LIMITS

UNLESS OTHERWISE SPECIFIED
ALLOWABLE VARIATION ON ALL:

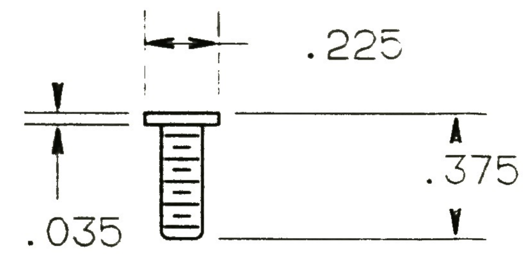
2 PLACE DECIMAL DIMENSIONS - ± .01

3 PLACE DECIMAL DIMENSIONS - ± .001

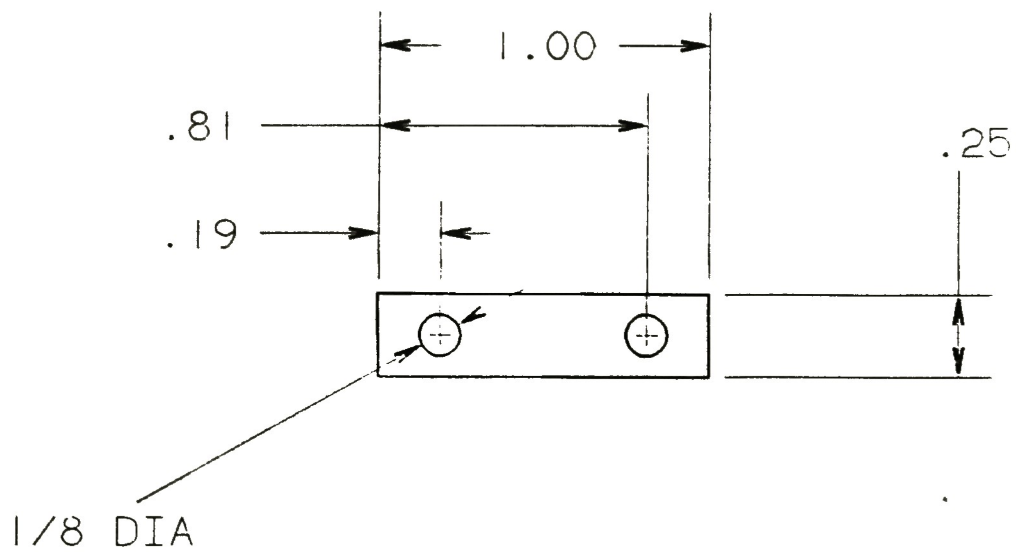
SUPERSEDES

REFERENCE

SUPERSEDED BY



(6) SCREWS FOR PISTON RETAINER
6 REQ'D
MAKE FROM 5-40 HEX TYPE F.H.S.
SCALE SHOWN: 2



(7) PISTON RETAINER
3 REQ'D
MAT L: SPRING STEEL .025 THK
SCALE SHOWN: 2

MARK ALL TOOLS AND LOOSE PIECES
WITH TOOL NUMBER IF SIZE PERMITS.
OTHERWISE TAG WITH TOOL NUMBER.

LAST CHANGE

TOOL DWG. NO ______ PART DWG. OF ______ SHEET I-SIZE

NO	AMT	MATERIAL LIST (SIZE)	MAT'L

MODEL -
ALSO USED FOR PART NO
PART -
TOOL -
MACHINE -
DRAWN - W. CRAIG DATE 5/23/84
CHECKED - APPROVED

ROCHESTER PRODUCTS DIVISION
GENERAL MOTORS CORPORATION
ROCHESTER NEW YORK

SHEET NO. 3 OF 4 TOOL NO.