Design, Fabrication, and Evaluation of a Pick-N-Place Robot

by

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Approved by:

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Dr. Oren Masory

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Abstract

In present day American industry the majority of robotic systems being implemented are servo robots. Non-Servo or Pick-N-Place robots have many qualities suitable for industry, however, are usually considered not flexible enough for industrial application. This research project was therefore created to design a Pick-N-Place robot which would be flexible enough for industrial application, and evaluate its performance in comparison with a servo robot of similar configuration. The mechanical structure was successfully designed, however the fabrication process was not completed because of budget complication. The control system developed utilized a GE Series Three Programmable Controller and an interface board composed of air valves and solenoids. A control program was written which effectively simulated the robot motion, however, the evaluation of the mechanical structure could not be completed because of the delay in the fabrication process. Steps have been addressed to assure the complete fabrication of the mechanical structure once sufficient funds are acquired.

Acknowledgement

For the opportunity to participate in this program, I would like to thank Dr. Lawrence Cress. I would especially like to thank Dr. Oren Masory for devoting so much of his valuable time for the success of my project. Without his support the project would not have been as enlighting or rewarding.

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Introduction

I. Background

As our technology increases there is more of an inclination to lean towards automation. Many jobs are now being performed faster, more accurately, and more economically by robots. For this reason it is essential that a good understanding of what a robot system consists of be developed. Robots being implemented for today's automation are called industrial robots. Industrial robots are defined by the Society of Manufacturing Engineers as, "A programmable, multifunction manipulator designed to move materials, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks." This basically means that some mechanical arm, through programming, is used to move a specific part to a different location to execute some function. This definition is very broad but lays down the foundation for a robot system.

To understand a robot system, the most logical approach is to study the interconnecting subsystems. The subsystems of a robot are comprised primarily of two main components: mechanical structure and control system.

The mechanical structure is considered the body or outer frame of the robot system and is commonly referred to as the manipulator. The mechanical structure can be divided into three areas corresponding to the coordinate system, drive system, and gripper. The coordinate system determines the path a robot will follow as it moves from one position to another. The three coordinate systems are cartesian, cylindrical, and spherical. Figure 1 is an illustration of the three different coordinate systems. The drive system is considered the power source for

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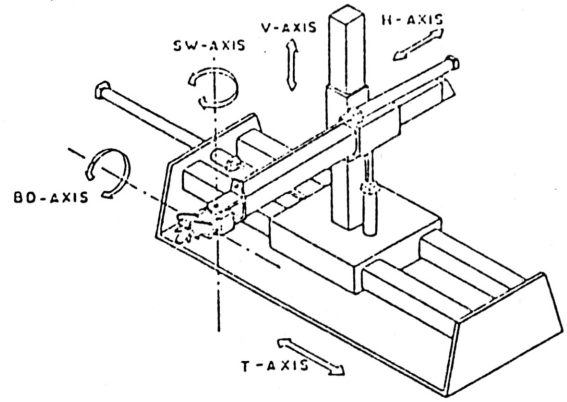
Citation and format follow the style of ASME Journal of Dynamic System, Measurement, and Control

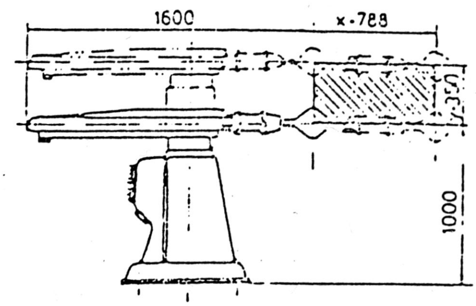
CARTESIAN COORDINATES

- 3 Linear Axes



CYLINDRICAL COORDINATES

- 2 Linear Axes
- 1 Rotary Axis



SPHERICAL COORDINATES

- 1 Linear Axis
- 2 Rotary Axes

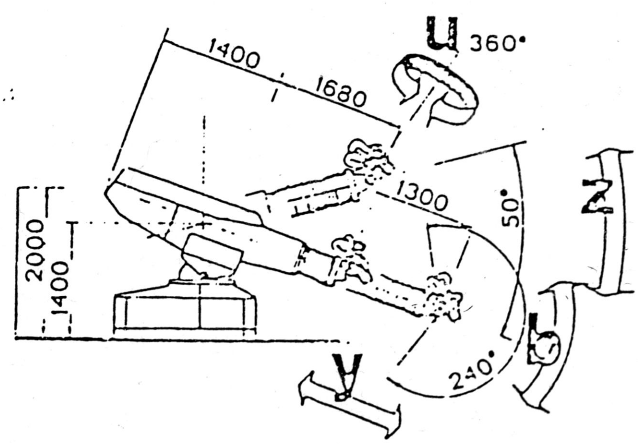


FIGURE 1. Three Dimensional Coordinate Systems

the robot which actually creates the motion. The three main power sources are electric motors, hydraulics, and pneumatics. The gripper is the most important element of the mechanical structure because it is the interface between the robot and the particular object being handled. The gripper is analogous to the human hand and wrist.

The control system is responsible for directing the mechanical structure to various locations required to execute a particular task. The brain of the control system is some type of computing device. The computer can be a large main frame, personal computer, or a microprocessor. The computer is usually not located on the mechanical structure but in the near vicinity. Sensors are mounted on the mechanical structure which are used as feedback for the computing device. The computer can thus use the feedback to better control the mechanical structure. Some of the more common types of sensors are limit switches (position), cameras (sight), and strain gauges (load).

The previous discussions have been on robot subsystems. On a larger scale is the classification of a robot into the category of servo or non-servo. The primary difference between the two types of robots is the number of positions the mechanical structure can reach. A servo model can move to an infinite number of positions within its range. A location is determined by three dimensional coordinates, and the robot proceeds to the position on command. On the contrary, non-servo robots can only obtain a finite number of positions determined by the robot's number of degrees of freedom. A degree of freedom is an axis of rotation. If a robot has three degrees of freedom, it can obtain eight and only eight different positions. The eight positions are specified by mechanical stops. An understanding of the difference between servo and non-servo is necessary to appreciate the goals and justification of this research project.

II. Objective

The research project that was undertaken had three main goals. The first goal was to design and fabricate a Pick-N-Place (non servo) robot. A detailed design of a mechanical structure would be developed followed by fabrication at the Intelligent Machinery Laboratory at TAMU. The second goal was to interface and control the mechanical structure with a programmable controller. A GE Series Three Programmable Controller was previously purchased and readily available for such a task. The last goal was to evaluate the performance of the robot in terms of repeatability and accuracy. A test set up would be constructed and the robot would be programmed to carry out a particular operation.

The justification for such a project is embedded in the theory that Pick-N-Place robots have some qualities superior to servo robots allowing them to be better suited for industrial application. Pick-N-Place robots are theoretically faster and more accurate than servo models. The cost of a Pick-N-Place robot is approximately $10,000 compared to a $50,000 servo robot. Therefore Pick-N-Place robots can be more economical to implement than servo robots. However Pick-N-Place robots are usually not flexible enough for industrial application. To compensate for this problem, the design developed in this research project will incorporate a mechanism allowing greater flexibility.

Research

To effectively complete the goals developed in the objective section, a time table was created to efficiently budget appropriate time to each research area. The time table is located on the following page as Figure 2. The first semester was designated for developing the mechanical design, while the second semester was used for the control system and the performance evaluation. The research results will therefore be presented in three sections corresponding to the three research areas of mechanical design, control system, and performance evaluation.

I. Mechanical Structure

The research for the design of the mechanical structure began with a literary review of common industrial robots. Catalogs and specifications of robots were obtained and reviewed from the following corporations: *Mobot, Auto-Place, Seiko, Robomation, Mack, and ASEA*. Appendix C contains a small sample of robots reviewed. In light of the time allotted for research, it was decided to model the mechanical structure after an existing robot but alter the design to meet the specific predetermined project goals. An *ASEA* robot was selected for its efficient and effective design. A complete set of working drawings for the *ASEA* robot is located in Appendix B. A detailed study of the design of the *ASEA* robot was then performed.

To help understand the complex motion of the robot, a wooden model was constructed. A photograph of the model is located in Appendix D. The model was constructed to scale allowing critical dimensions to be calculated for later design purposes. It was also an excellent reference as the design process developed.

Once a sound understanding of the *ASEA* robot design was established the preliminary design of the mechanical structure began. The *ASEA* robot is a servo

FALL SEMESTER 1985

Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	SEMESTER WEEKS														
1. Survey	*	*	* R												
2. Conceptual Design				*	*	* R									
3. Detailed Design							*	*	* R						
4. Parts Fabrication										*	*	*	*	*	* R
5. Supervision										*	*	*	*	*	*
6. PC study										*	*	*	*	*	*
7. Test Setup													*	*	*

SPRING SEMESTER 1986

Task	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
	SEMESTER WEEKS														
1. PC wiring	*	* R													
2. Testing			*	*											
3. Task Programming					*	*	* R								
4. Eveluation								*	*	*	*	* R			
5. Documentation													*	*	* R

R – Indicates reporting

FIGURE 2. Fall and Spring Research Time Table

robot and the project goal is to develop a non-servo robot. The motion for the *ASEA* robot is acquired through DC motors which are servo devices. Therefore, pneumatic pistons, which are non-servo elements, were chosen to replace the DC motors. Another major alteration was the decision to replace the parallel links, which are used to control the gripper, with a sprocket/chain assembly. Another task completed during the preliminary design was the research of the availability of the above selected parts. A *Clipped Minimatic* catalog was consulted for the feasibility of pneumatic pistons for robot applications. A *Winfied M. Berg Inc.* catalog was utilized to determine if a sprocket/chain assembly suitable for the design requirements existed. Both components were available and would satisfy the requirements that had been established thus far by the preliminary design. After completion of the preliminary design, the detailed design for the mechanical structure could then be addressed.

The detailed design entailed finalization of the predetermined preliminary design by deciding on final dimensions and part selections. The *Winfied* catalog was used extensively for part selection and dimensional analysis. The final design is presented in the form of an assembly drawing, two half sections, and concluding remarks on the interconnections. A full set of working drawings have been placed in Appendix A.

Figure 3 is an assembly drawing of the final design. One quarter inch aluminum was selected for the framework because of its high strength to weight ratio. The robot stands 19.75 inches tall and has an arm span of 15.5 inches. The base is 7 inches wide, 4.438 inches deep and 11 inches tall. The shoulder is 1.5 inches wide and 8.75 inches tall. The arm has an overall length of 15.5 inches and a constant width of 1.5 in. The pistons are shown secured to the base by a clamping device which is allowed to swivel. The pistons can be moved within the clamps allowing

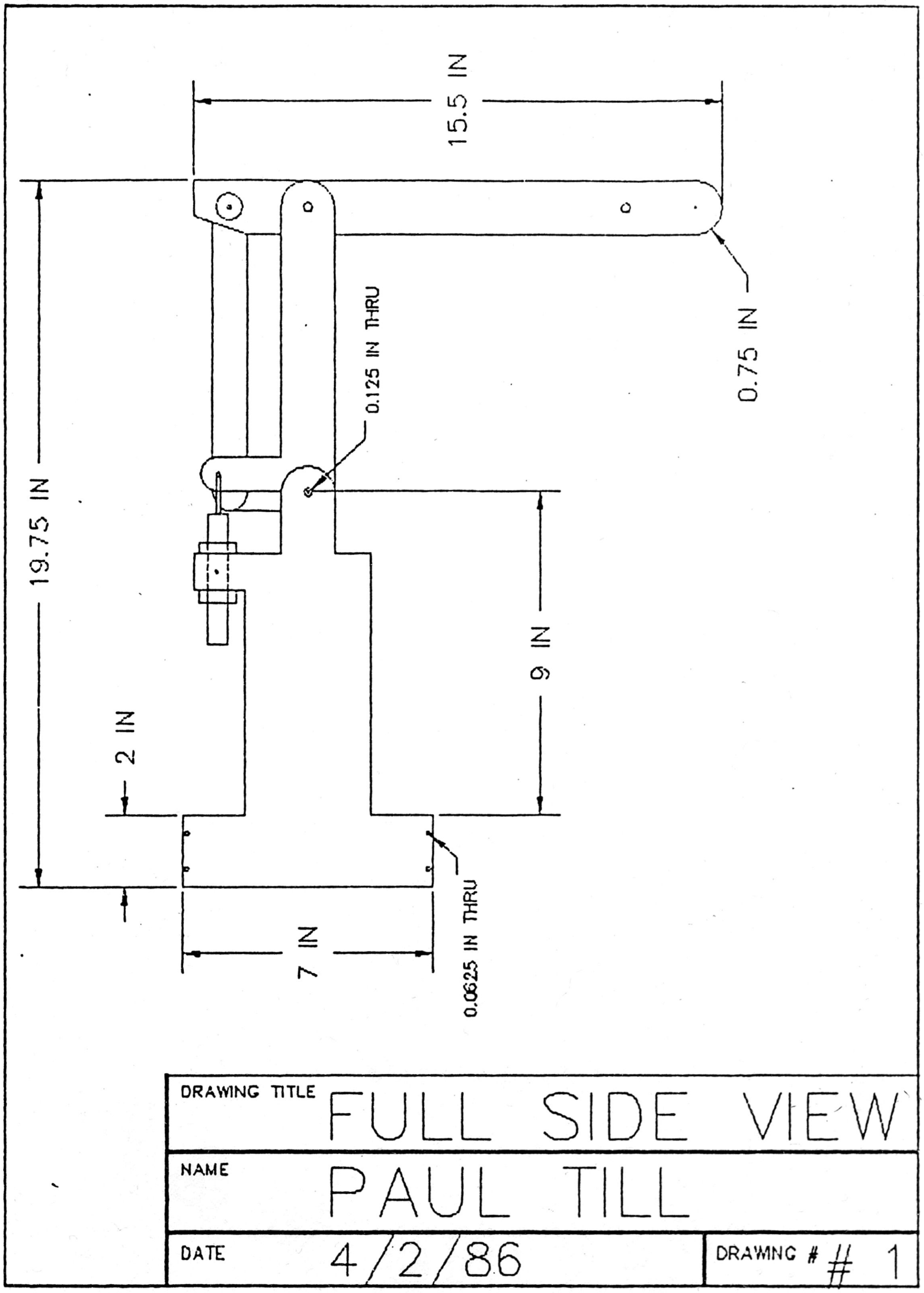


FIGURE 3. Full Assembly Side View

greater flexibility by accommodating several different test set ups. Thus making the non-servo robot flexible enough for industrial application. The robot has a theoretical calculated horizontal reach of 18.5 in. and a total vertical reach of 29 inches from the ground.

A full vertical section has been taken through the middle of the mechanical structure resulting in Figure 4. The two most important features revealed in this view are the chain/sprocket assembly and the parallelogram which controls the upper arm. The chain/sprocket assembly is represented in red. The function of the assembly is to create the up and down rotation of the gripper as shown in the figure. The piston is attached to the chain which runs over sprocket 1A to a fixed spring. As the piston is retracted, sprocket 1A rotates. Fixed to sprocket 1A is sprocket 1B which will also rotate. Sprocket 1B is attached to sprocket 2B through a looped chain. Sprocket 2B is fixed to 2A but both are free to rotate on the shaft. The motion of 1B causes both 2A and 2B to rotate correspondingly. Sprocket 2A is attached to 3A in a similar manner. Sprocket 3A is fixed to the gripper which rotates the gripper in the desired motion. As the piston pressure is released, the spring recoils returning the gripper to its original position.

The parallelogram assembly is represented in Figure 4 in blue. The function of this mechanism is to control the arm motion. Motion of the arm is acquired through the following sequence. The connecting piston is pressurized extending the rod represented in yellow. The vertical link represented in blue is forced to move upward. This upward motion applies a force on the back of the arm link which forces it to rotate about the shaft connecting the arm and shoulder. The horizontal blue link supports the piston rod and the vertical link while forcing them to travel a prescribed arc motion. The piston is retracted to return the arm in a horizontal position.

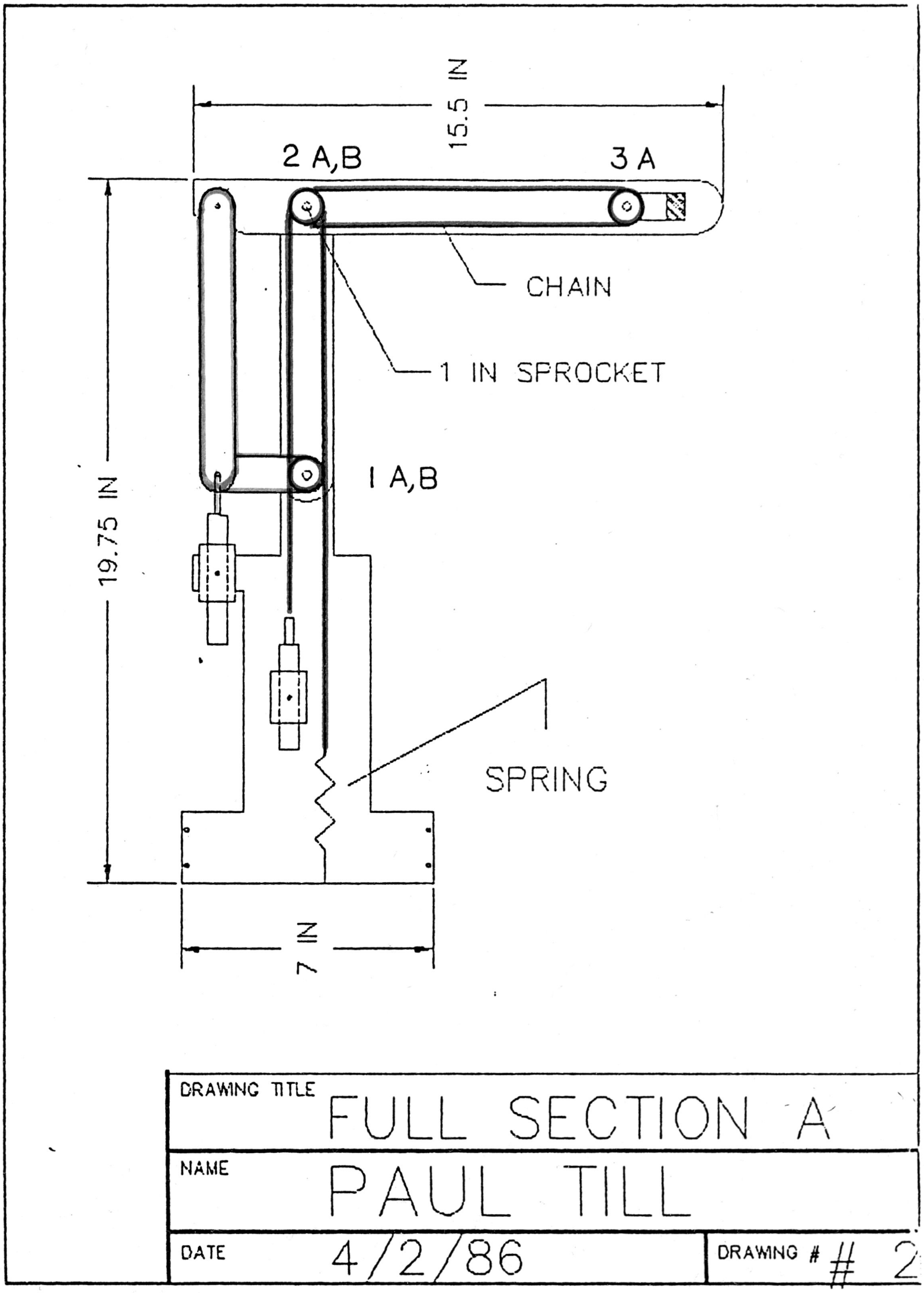


FIGURE 4. Inside View of Section A

Figure 5 shows the counter part of Figure 4. It is the internal section view of side B. Once again two important features are revealed which are the chain/sprocket assembly and the shoulder rotation mechanism. The chain/sprocket assembly represented in red is very similar to the one previously discussed. However, the function now desired is a pure rotation rather than an up and down motion of the gripper. The rotation from sprocket 3A is transformed through a bevel gear set to a rotation about the perpendicular axis. The top view of the gripper assembly shows clearly the interaction between sprocket 3A and the bevel gear resulting in the desired rotation. The shoulder rotation is developed through the piston and shoulder represented in blue. As the piston rod extends it applies a force on the extended shoulder blade rotating it around the shoulder/base shaft. As the piston is retracted, the shoulder returns to its vertical position.

In concluding on the design of the mechanical structure, reference should be made to the interconnecting parts. Appendix A includes a detailed representation of the placement of bearings and bushings. An internal view of the shoulder/base and arm/shoulder shafts is presented along with detailed views of the machined parts. Also contained within Appendix A is a complete parts list with references.

II. Control System

The control system is the mechanism that is responsible for directing the motion of the mechanical structure. The control system developed for the mechanical structure previously discussed includes a progammable controller with an interface board. A GE Series Three Programmable Controller was utilized and is represented in Figure 6. Part 1 of Figure 6 is considered the CPU/Programmer which is the key board for entering software commands. Part 2 consist of six modules, three for reading in input voltages and three for outputting voltages. The PC

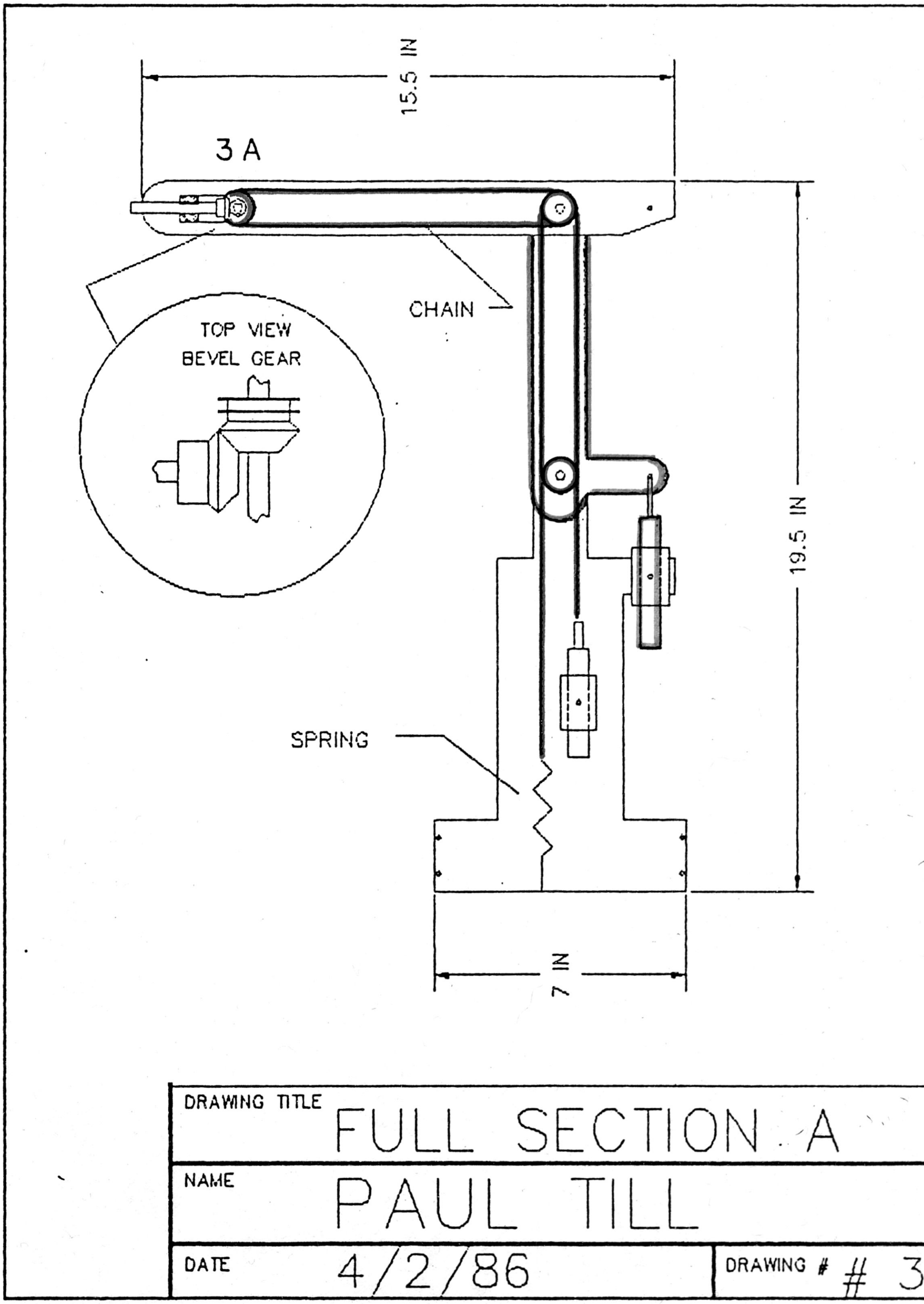


FIGURE 5. Inside View of Section B

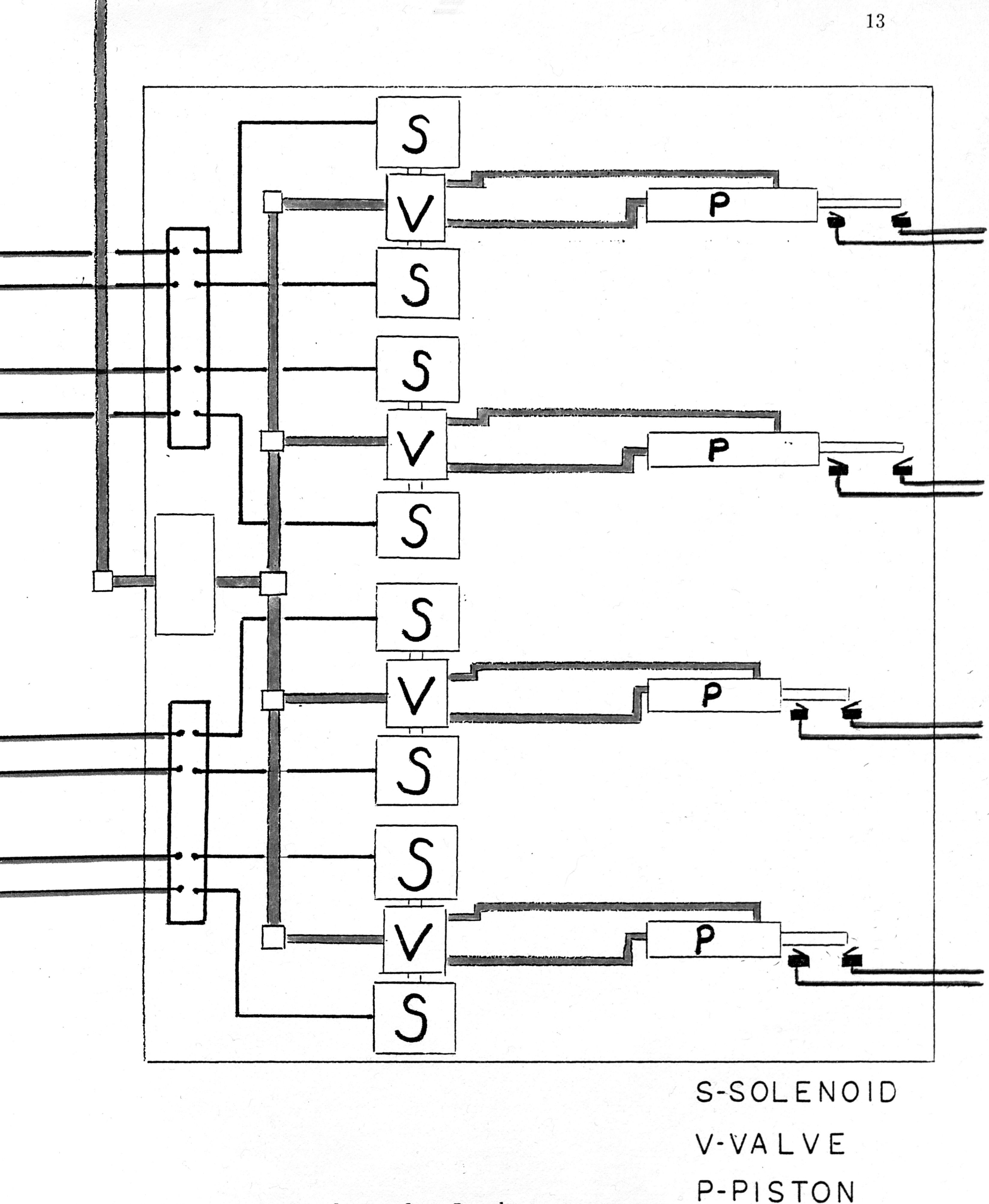
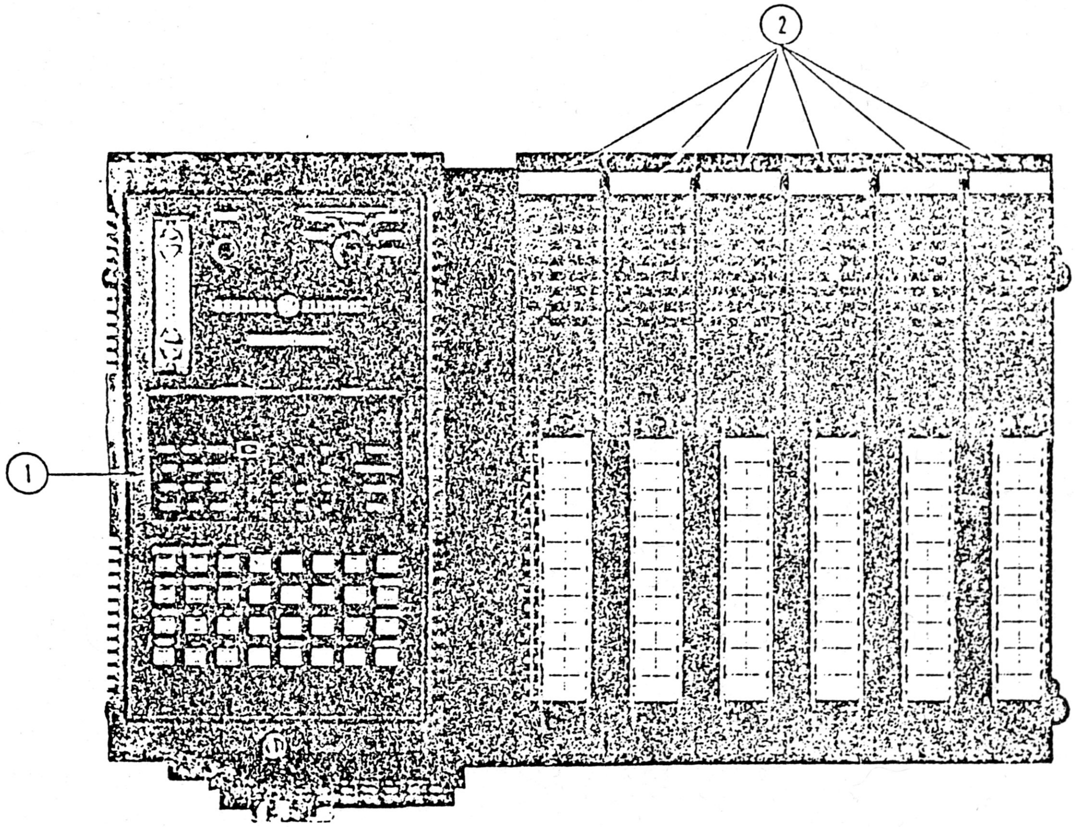


FIGURE 7. Schematic of Interface Board

(Programmer Controller) is essentially a microprocessor which can detect input voltages and produce output voltages. The software, entered in part 1, determines which output modules to energize (output voltage) corresponding to the voltages detected on the input modules.

The interface board is responsible for converting the output voltage of the PC to piston motion. A schematic of the interface board is presented in Figure 7. The hardware of the interface board consist of pistons, valves, solenoids, and limit switches which are represented in the schematic. The blue lines represent the flow of air pressure through the valves to the pistons from some external air pressure source. The black wires from the solenoids are connected to the red output wires from the PC. The limit switch wires, represented in green, are fed back to the PC for input voltages. The interface board performs its function in the following manner. The output voltage from the PC is transferred across its corresponding solenoid. Resulting from the energizing voltage, the solenoid acts on the valve. The valve controls the flow of air to the piston which controls the position of the stroke. The overall effect is to control the position of the piston with the voltage outputted from the PC. Note: The pistons are only temporarily mounted on the interface board until the fabrication of the mechanical structure is completed.

The software necessary for the GE Programmable Controller is written in Ladder Diagram logic. Ladder Diagram logic is not a high level computer language (i.e. FORTRAN, Pascal, etc.). On the contrary it is most often used by technicians or machinists. The language is processed in a parallel fashion contrary to most languages which are executed sequentially. It is therefore very difficult to program a robot task which is performed in a sequential manner. However, techniques have been developed which enables such programming to be performed. The ladder diagram logic is entered into the PC via the CPU/Programmer. Figure 8 is a



(1) CPU/Programmer

(2) I/O Modules (4, 6 or 8 slots)

FIGURE 6. GE Series Three Programmable Controller

detailed photograph of the CPU/Programmer used for the GE Series Three PC. The ladder diagram logic is entered into the address location with the instructional and numerical keys. An example of a program and the steps necessary to enter the code into the PC is located in Appendix F.

III. Evaluation

The original conceived plan for evaluating the Pick-N-Place robot was to construct a test set up and have the robot perform a particular task. The accuracy and repeatability would be calculated and compared to the specifications for the *ASEA* industrial robot. The results would be evaluated to determine if the non-servo robot did possess characteristics superior to the servo model. However, due to budget cuts the complete fabrication of the Pick-N-Place robot was delayed. For this reason the mechanical structure was not tested, but the controller was programmed to carry out the task.

To test the controller a particular task consisting of relocating a material part from one position to another was simulated. If the controller could perform this simple task, it could be extrapolated to more complex applications when the mechanical structure was completed. Figure 9 is a schematic representation of the kinematics necessary to perform the task. To program the PC a flow chart was constructed and is presented in Figure 10. From the flow chart a Ladder diagram program was written and entered into the PC. A copy of the program can be found in Appendix G. The program was executed and the controller successfully generated the piston strokes necessary to simulate the robot motion.

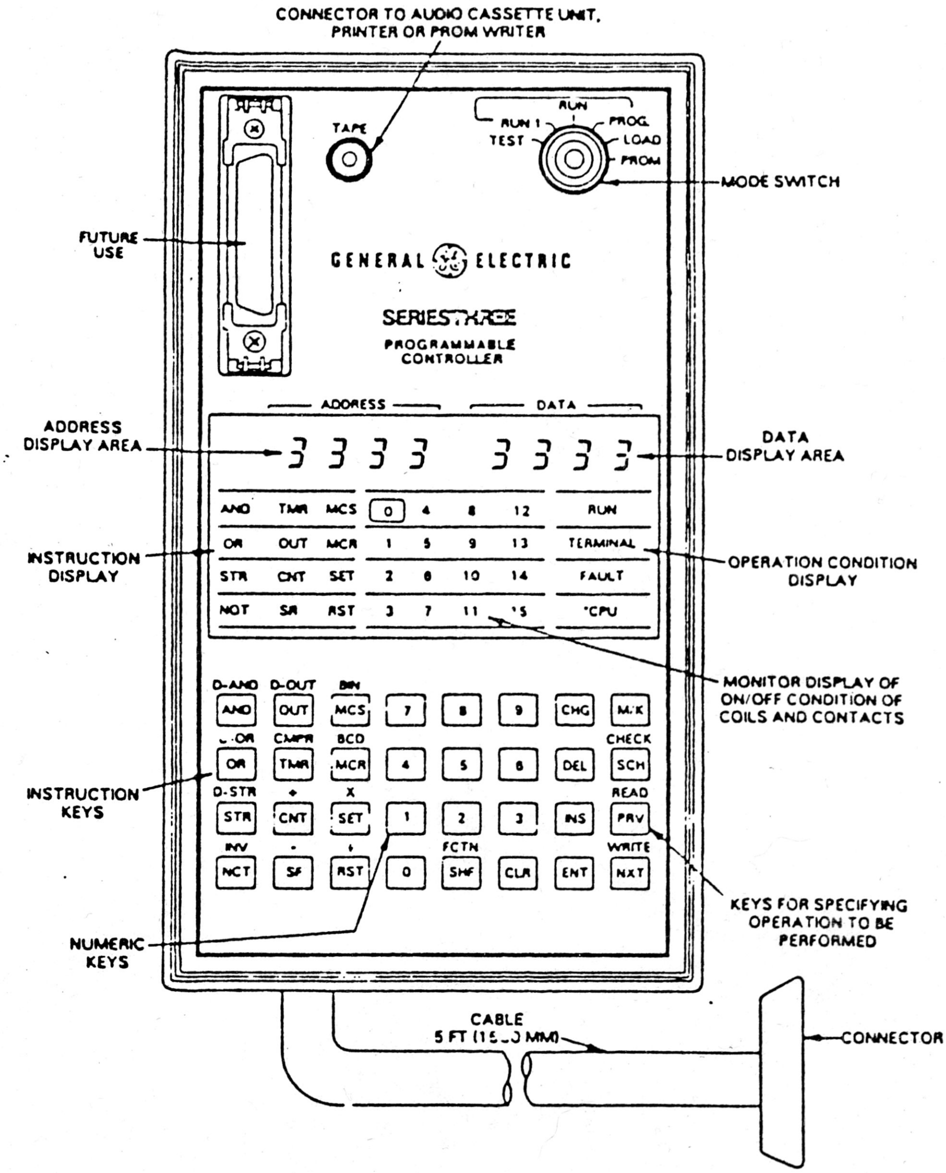


FIGURE 8. CPU/PROGRAMER For A GE Series Programmable Controller

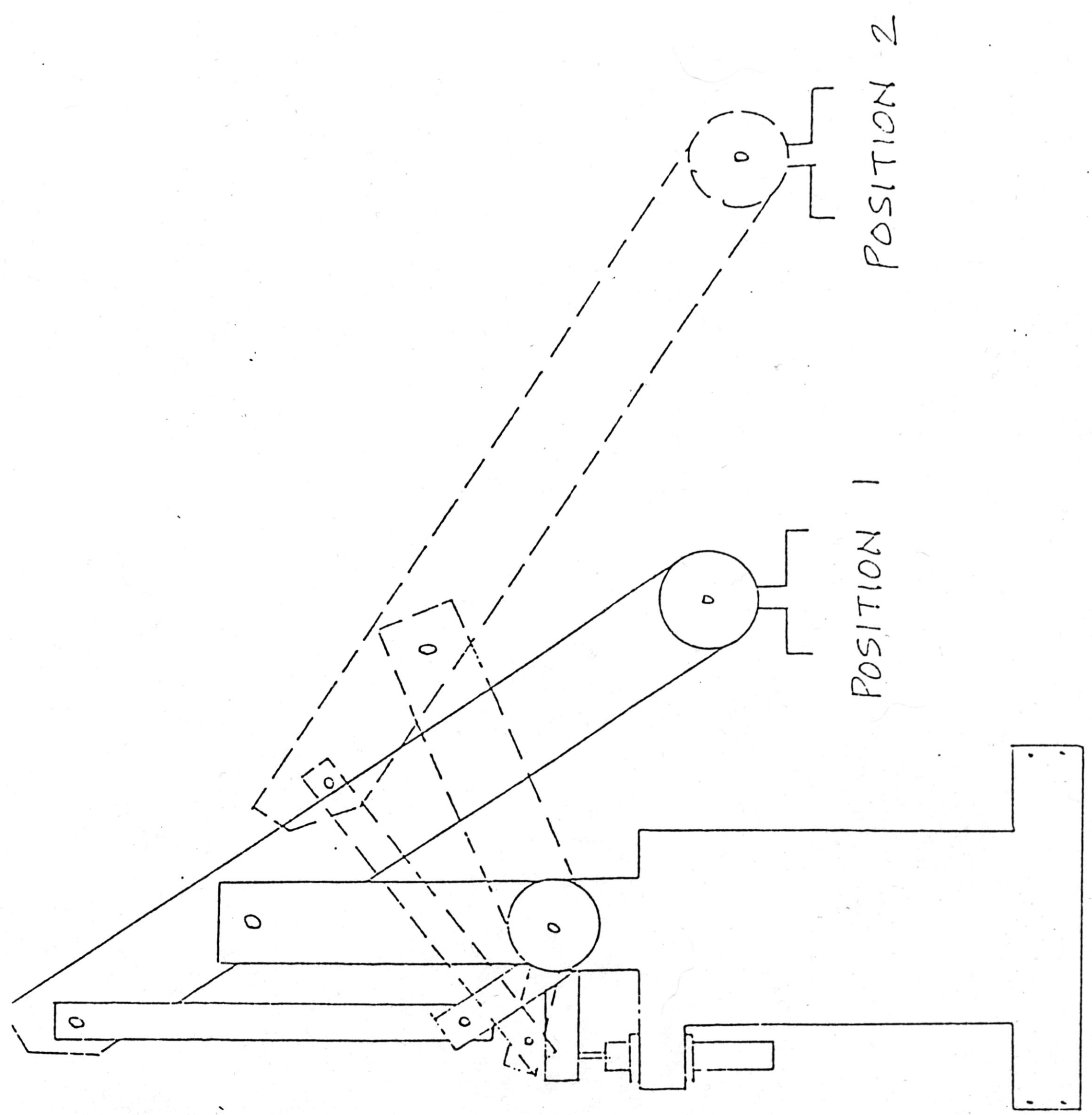


FIGURE 9. Kinematics For Mechanical Structure For Simulation

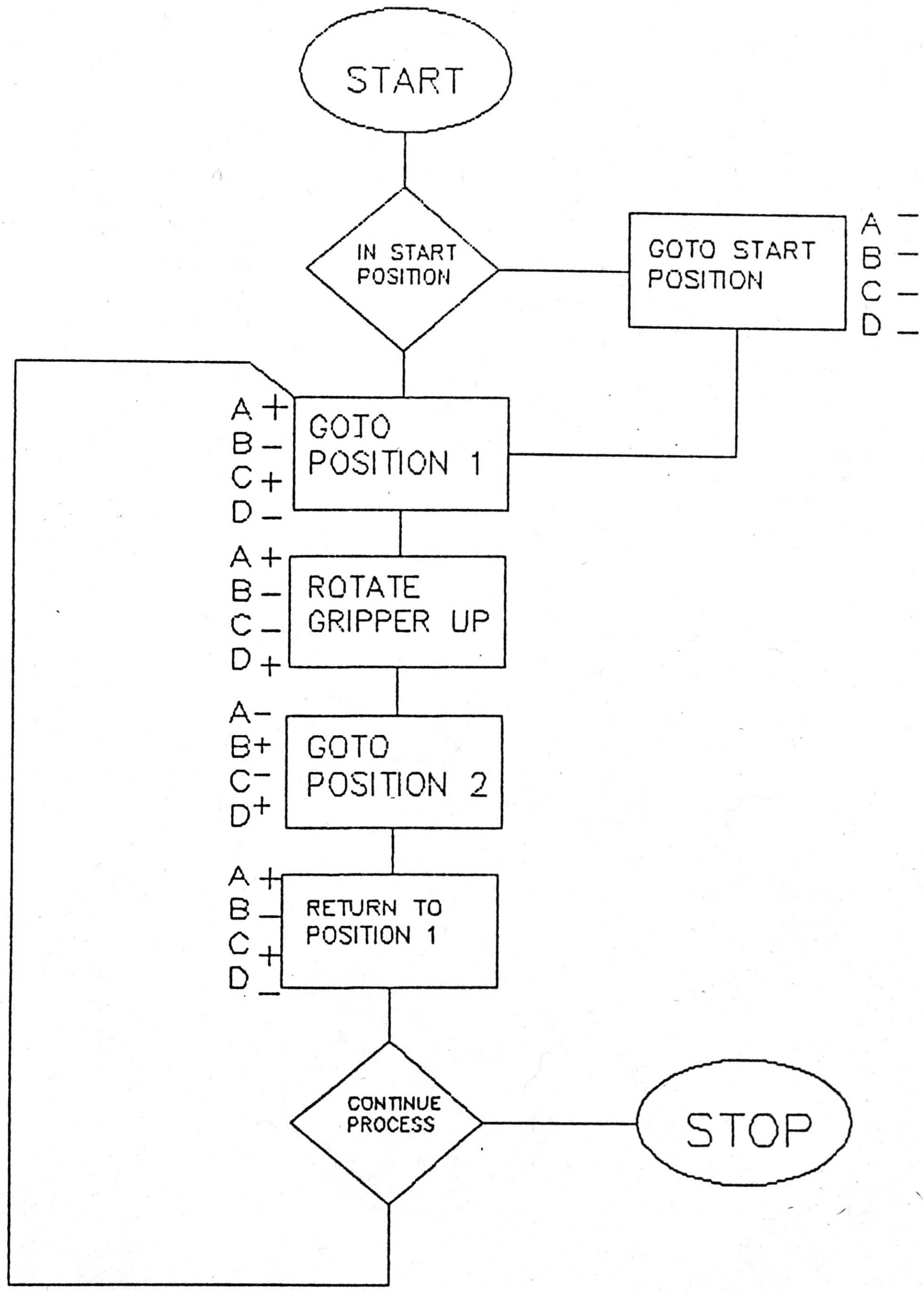


FIGURE 10. Flow Chart for Simulation Program

Conclusions

Referring back to the objective section, goal number one, the design of a mechanical structure, was successfully accomplished. However, due to budget complication the entire fabrication process was not completed. The second goal was to develop a control system for the mechanical structure. The control system was developed utilizing a GE Programmable with an interface board. A program was written that effectively controlled the pistons which simulated a particular task. The third goal, evaluation of the robot performance, was not performed because of the incomplete fabrication process. To ensure the completion of the fabrication process, steps have been taken to allow the process to be executed when sufficient funds are acquired.

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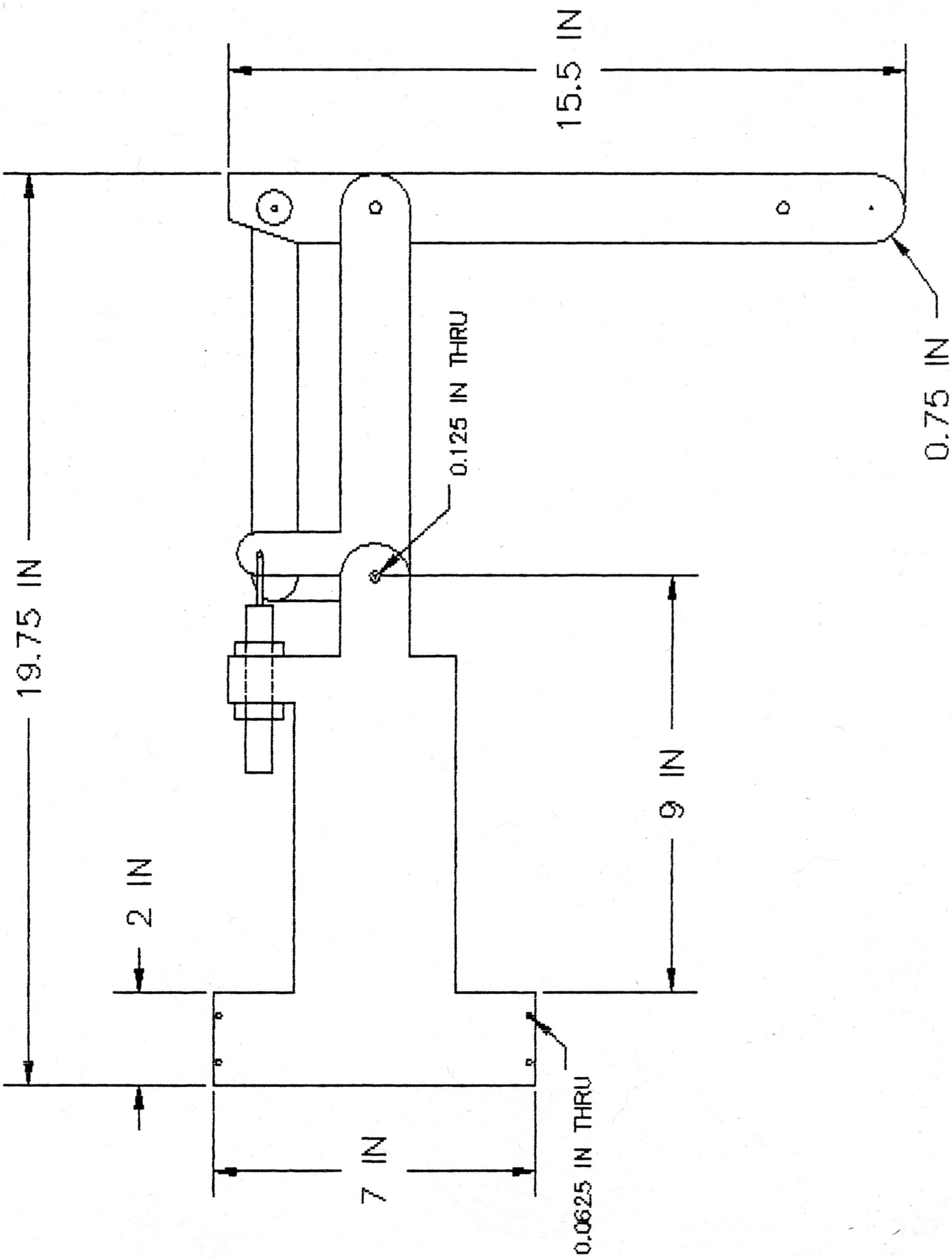
Appendix A

Working Drawings



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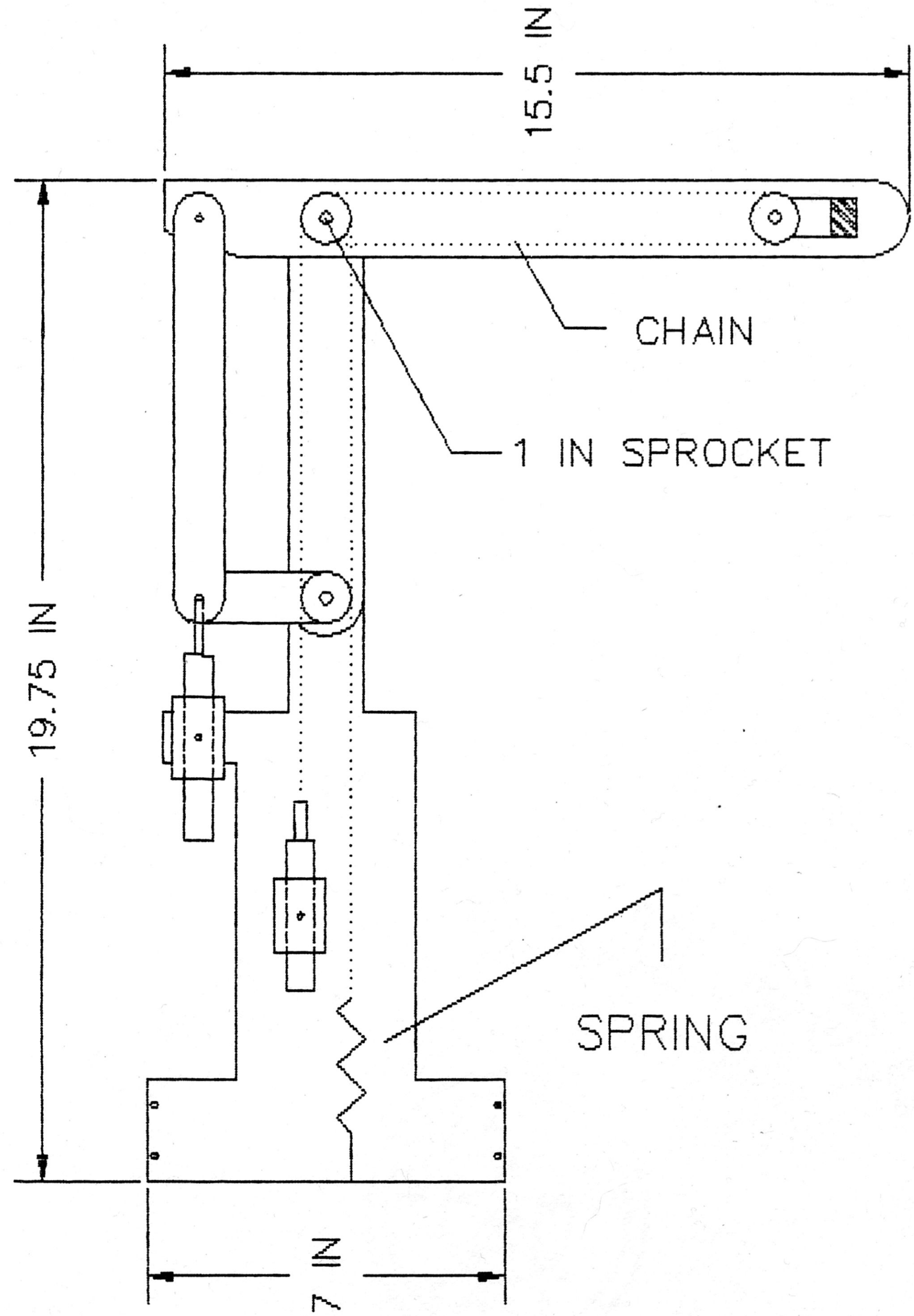

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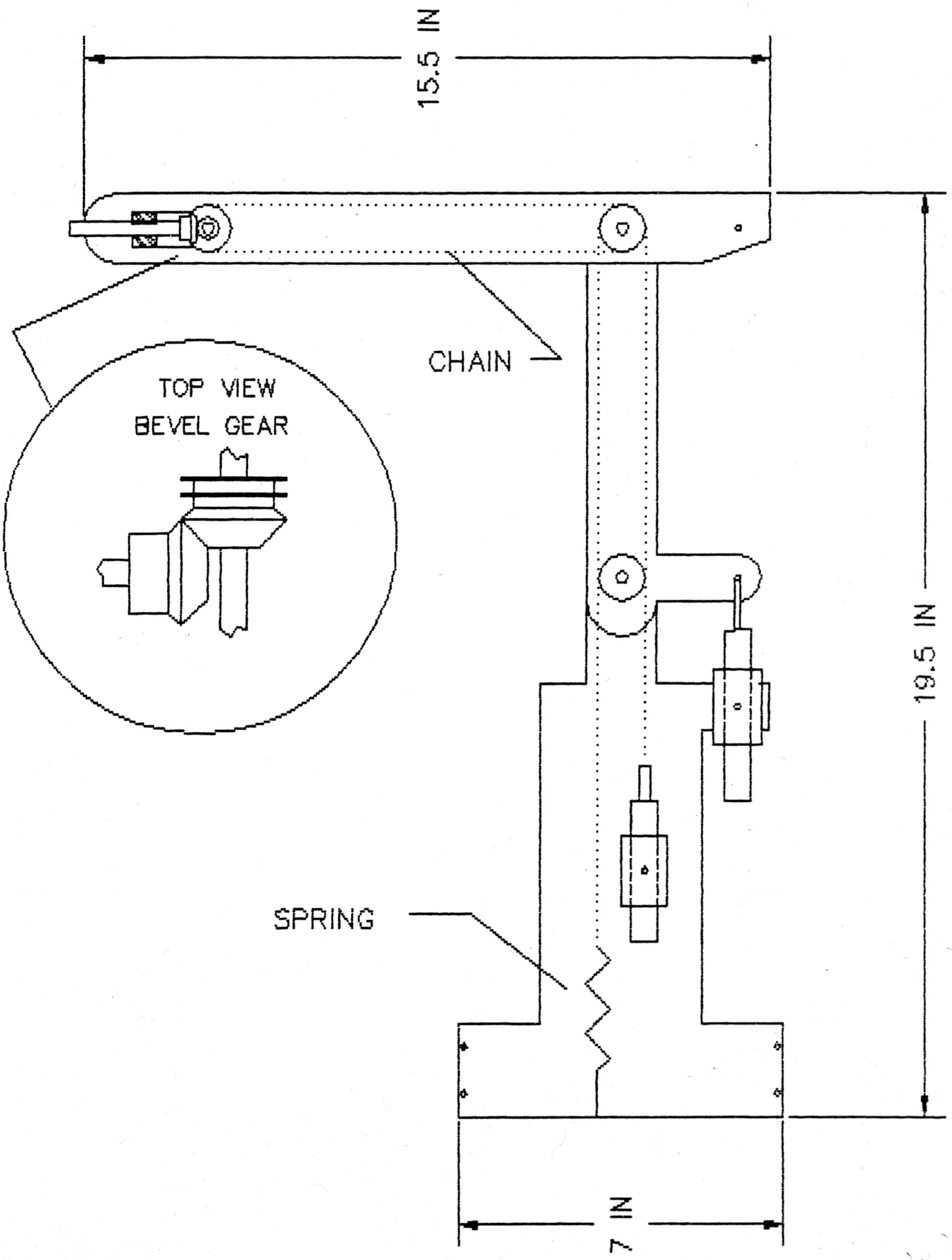

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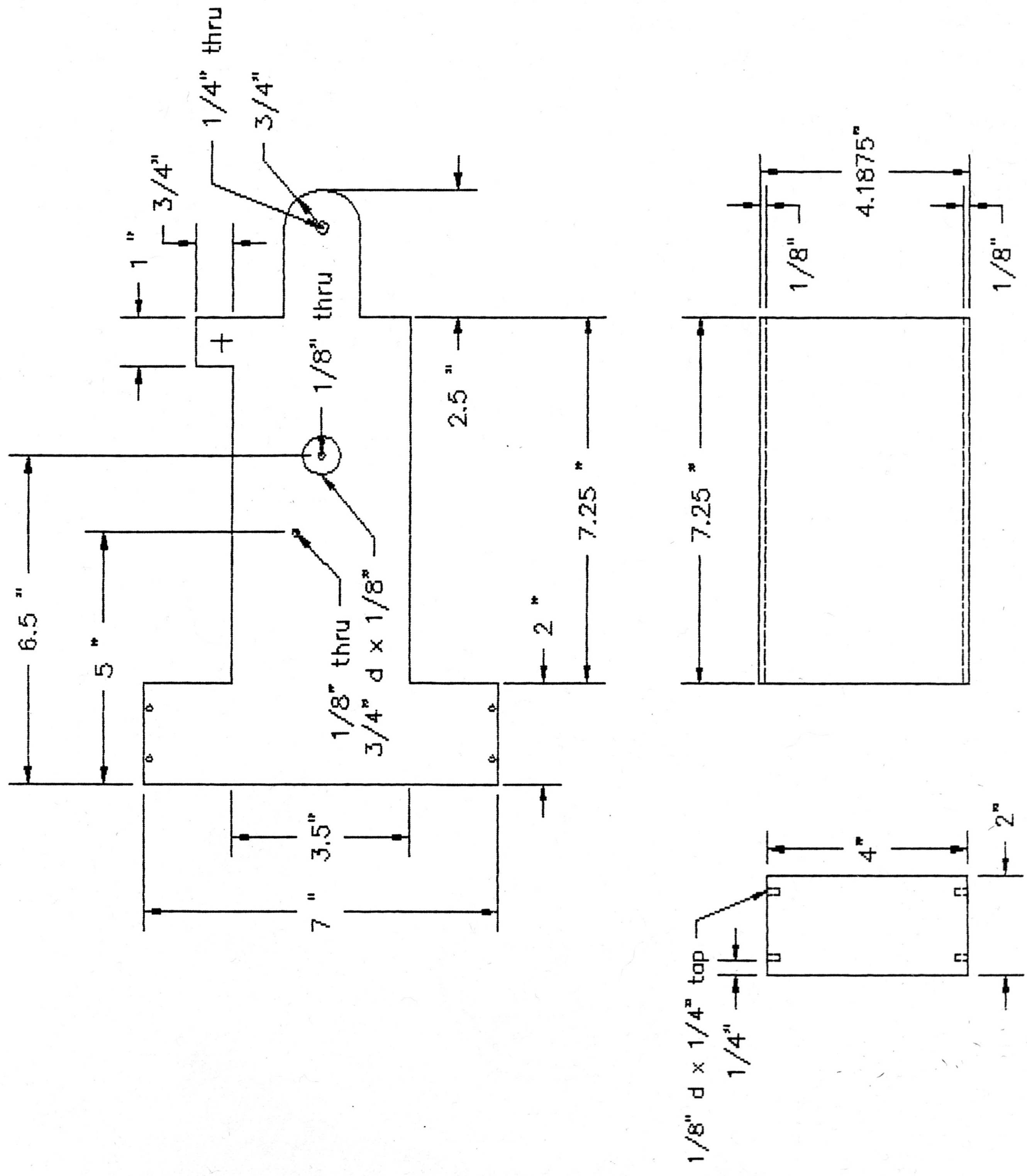

NOTE: All thicknesses are 1/4"

MATERIAL ALUMINUM

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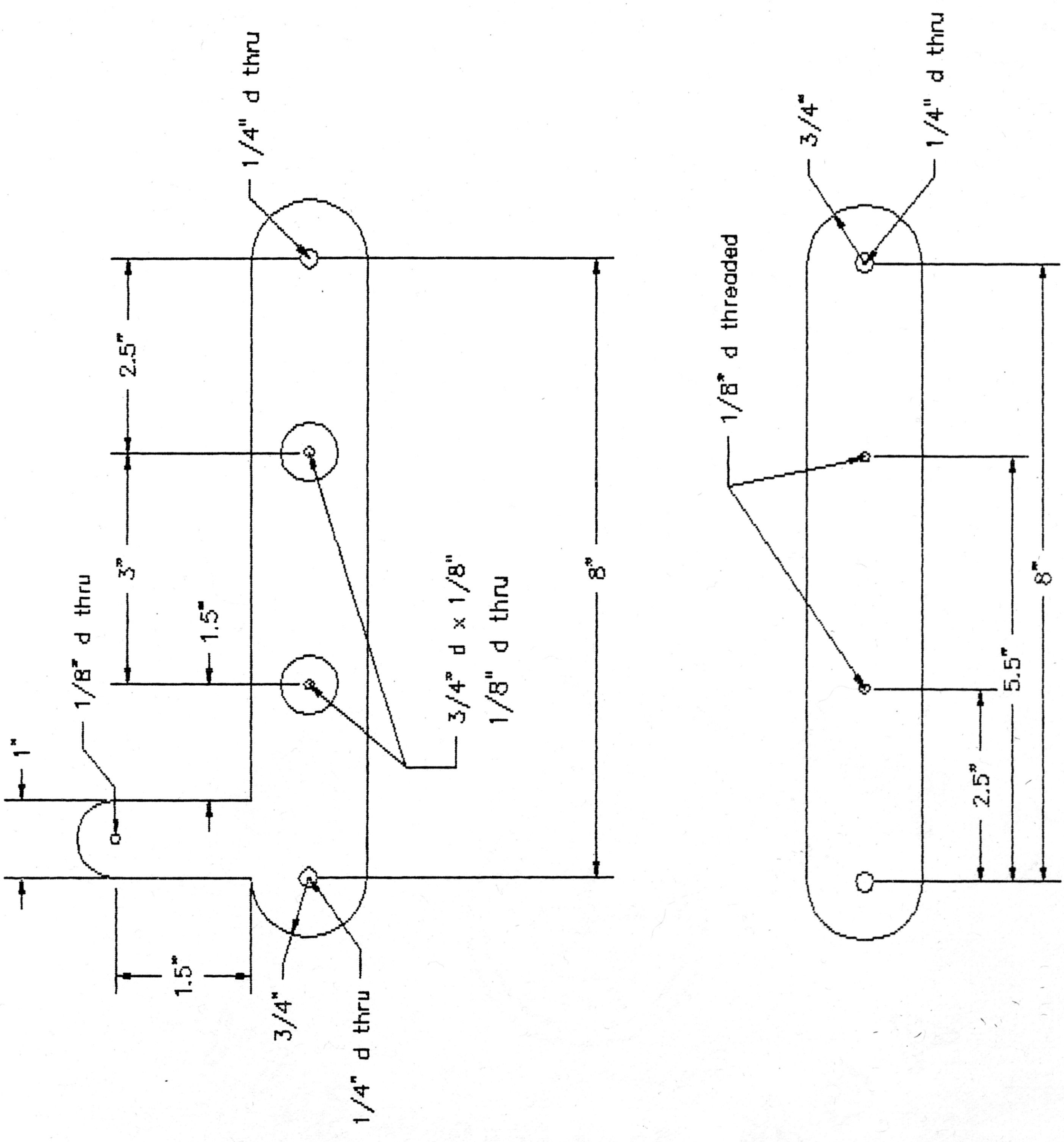
NAME PAUL TILL

DATE 4/2/86

DRAWING # # 4

EXTERIOR VIEWS



NOTE: All thicknesses are 1/4"

MATERIAL ALUMINUM

DRAWING TITLE	SHOULDER A AND B		
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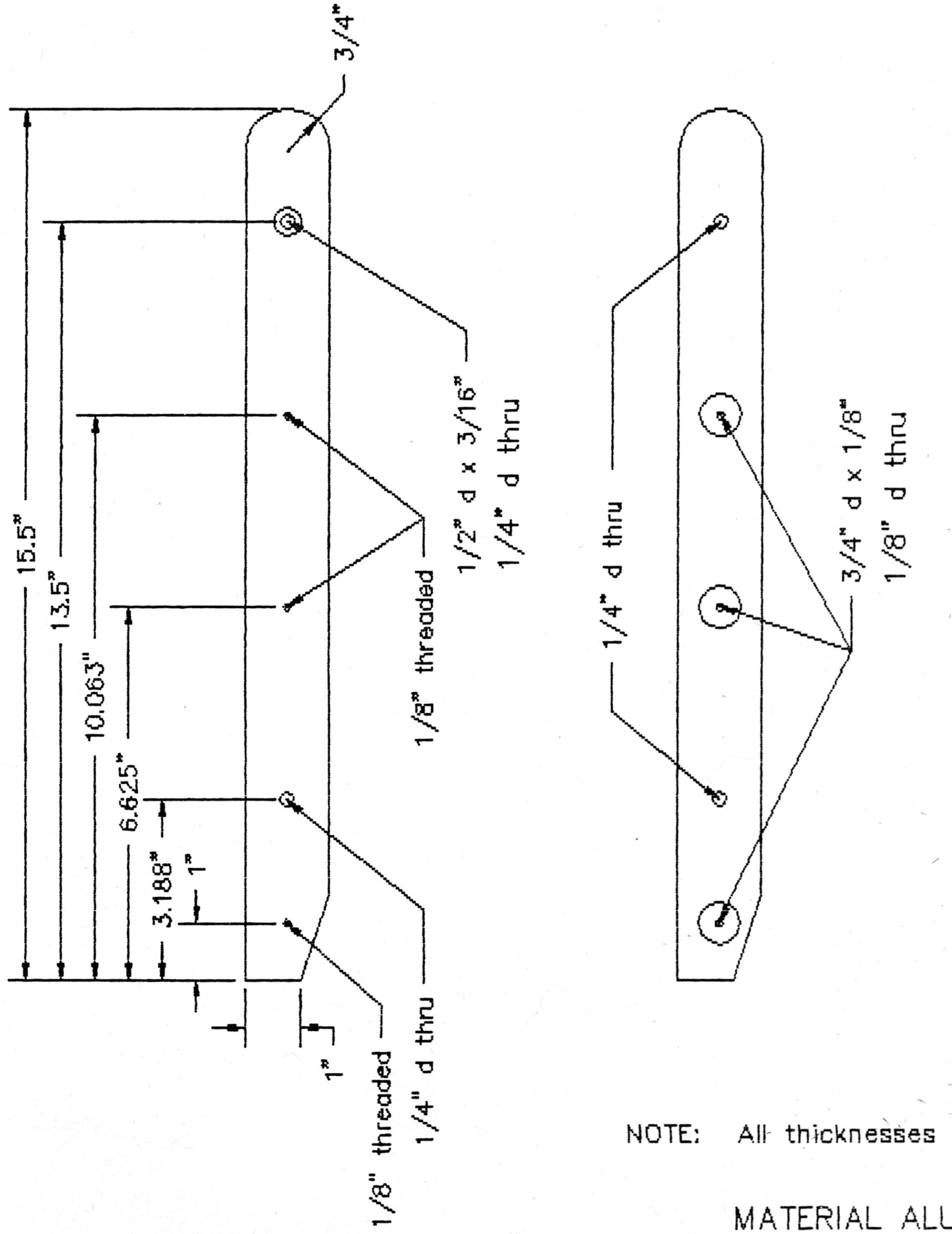
DATE	4/2/86	DRAWING #	# 5

INSIDE VIEW OF A   OUTSIDE VIEW OF B



NOTE: All thicknesses are 1/4"

MATERIAL ALUMINUM

DRAWING TITLE	BOTH SIDE ARM VIEW
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DATE	4/2/86
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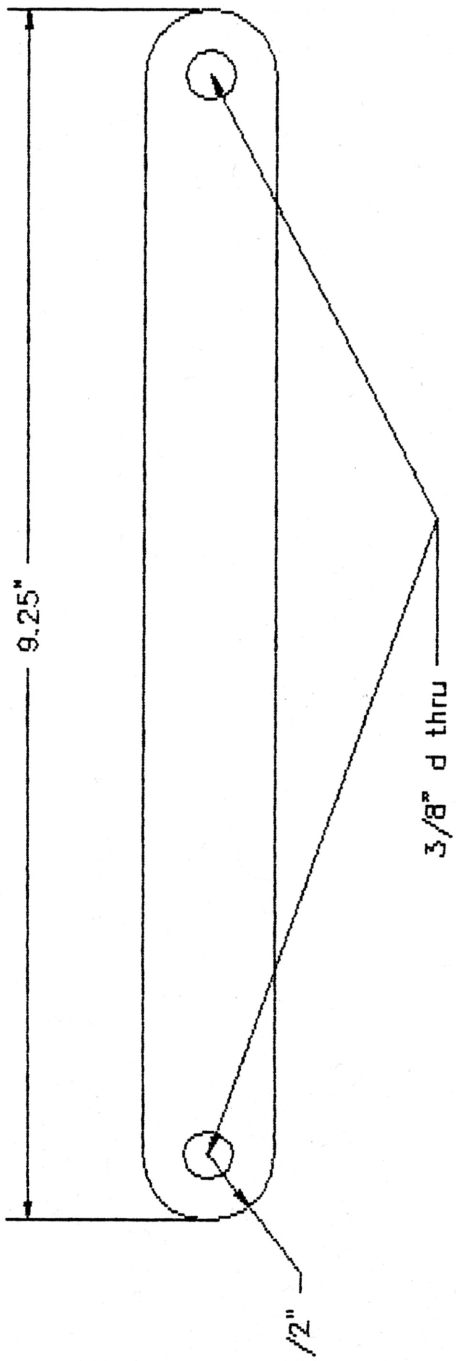
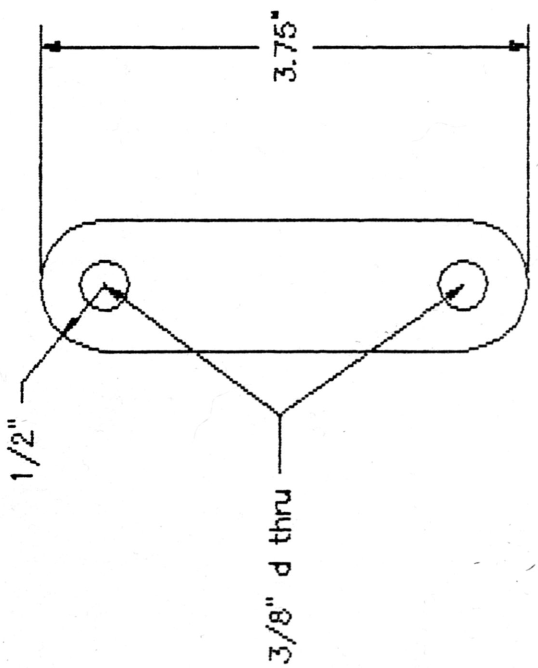
NOTE: All thicknesses are 1/4"

MATERIAL ALUMINUM





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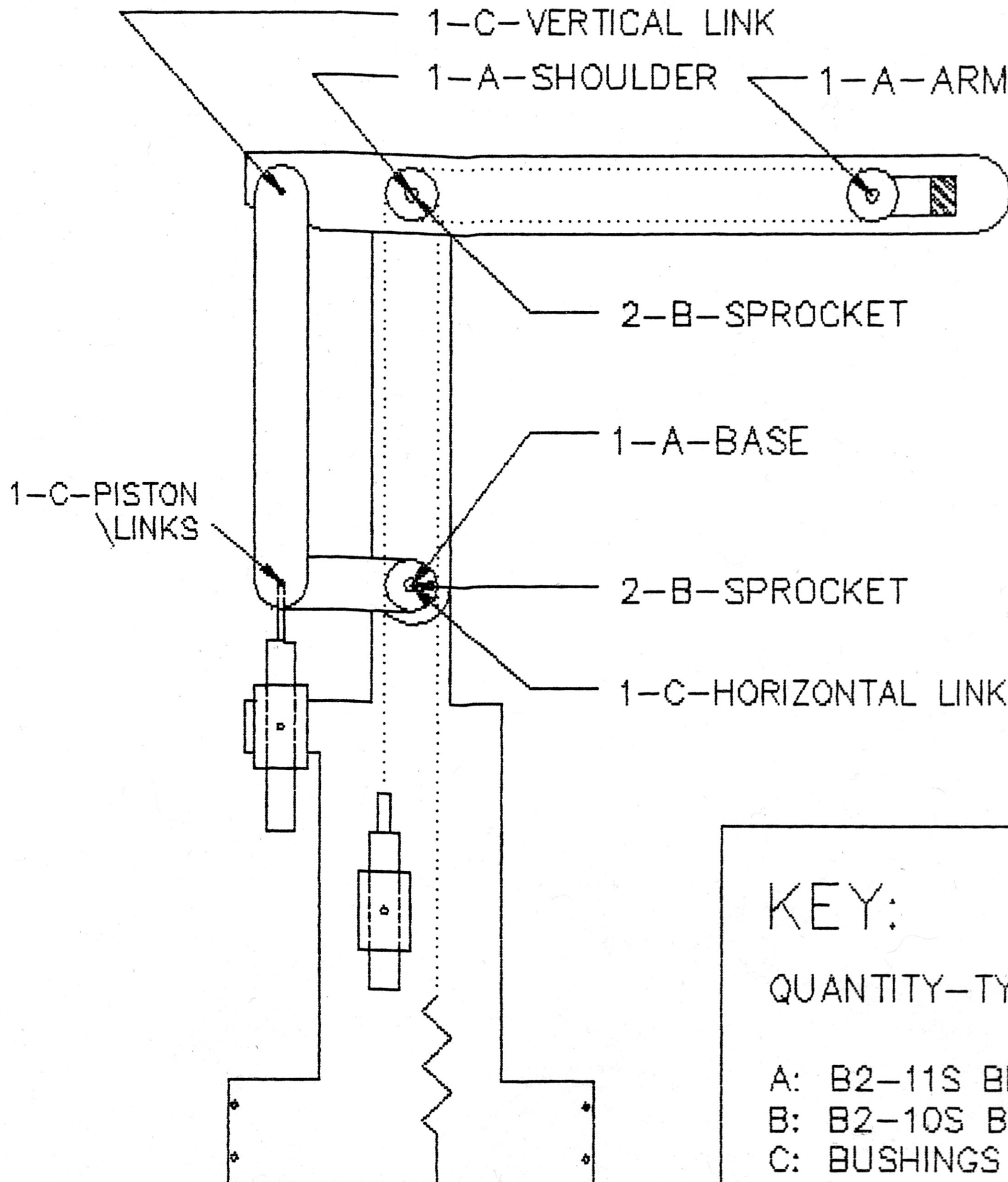

KEY:

QUANTITY-TYPE-LOCATION

A: B2-11S BEARING
B: B2-10S BEARING
C: BUSHINGS

NOTE: SEE PARTS LIST

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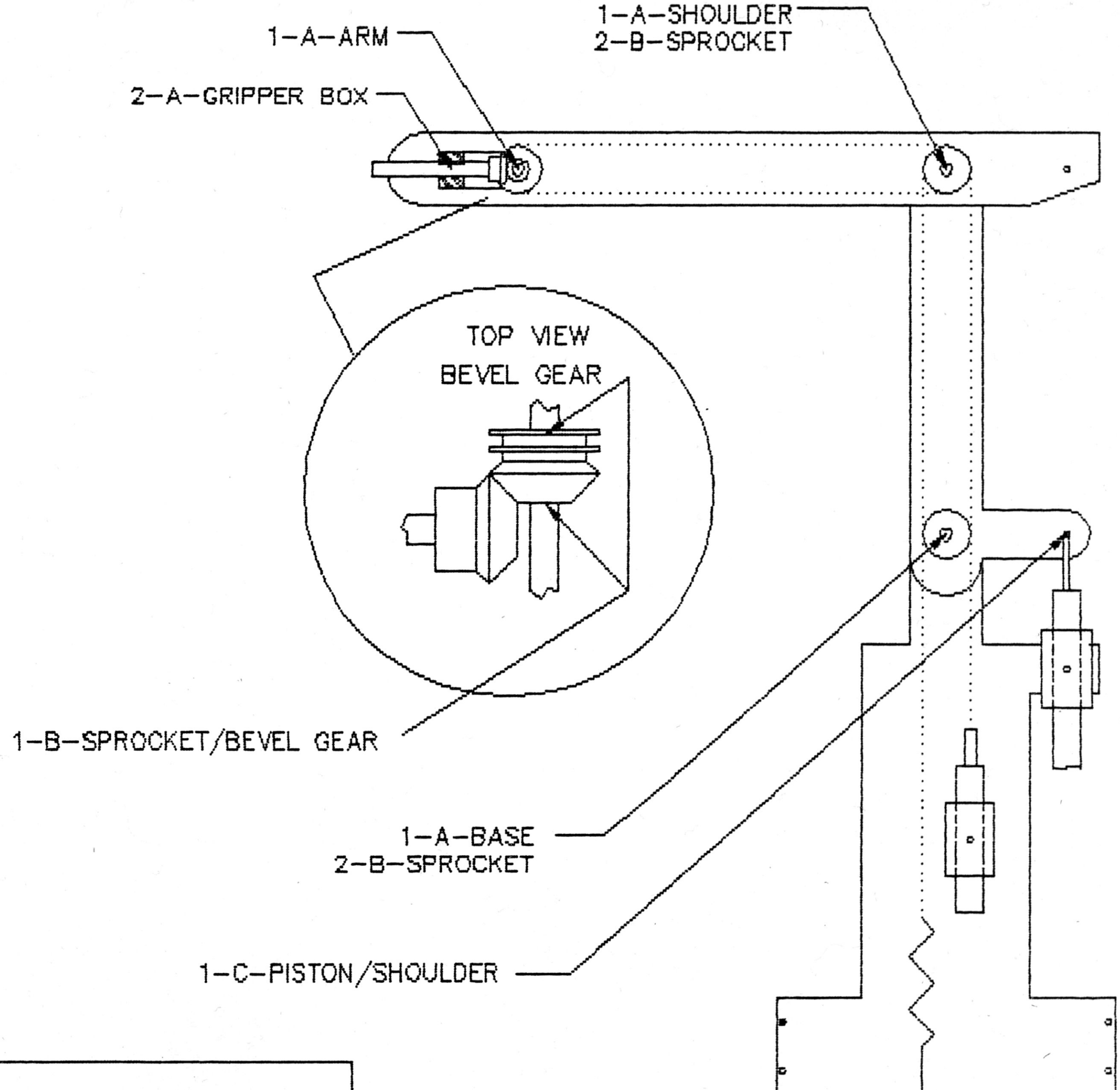
DATE 4/2/86	DRAWING # #8



KEY:

QUANTITY-TYPE-LOCATION

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B: B2-10S BEARING
C: BUSHINGS

NOTE: SEE PARTS LIST

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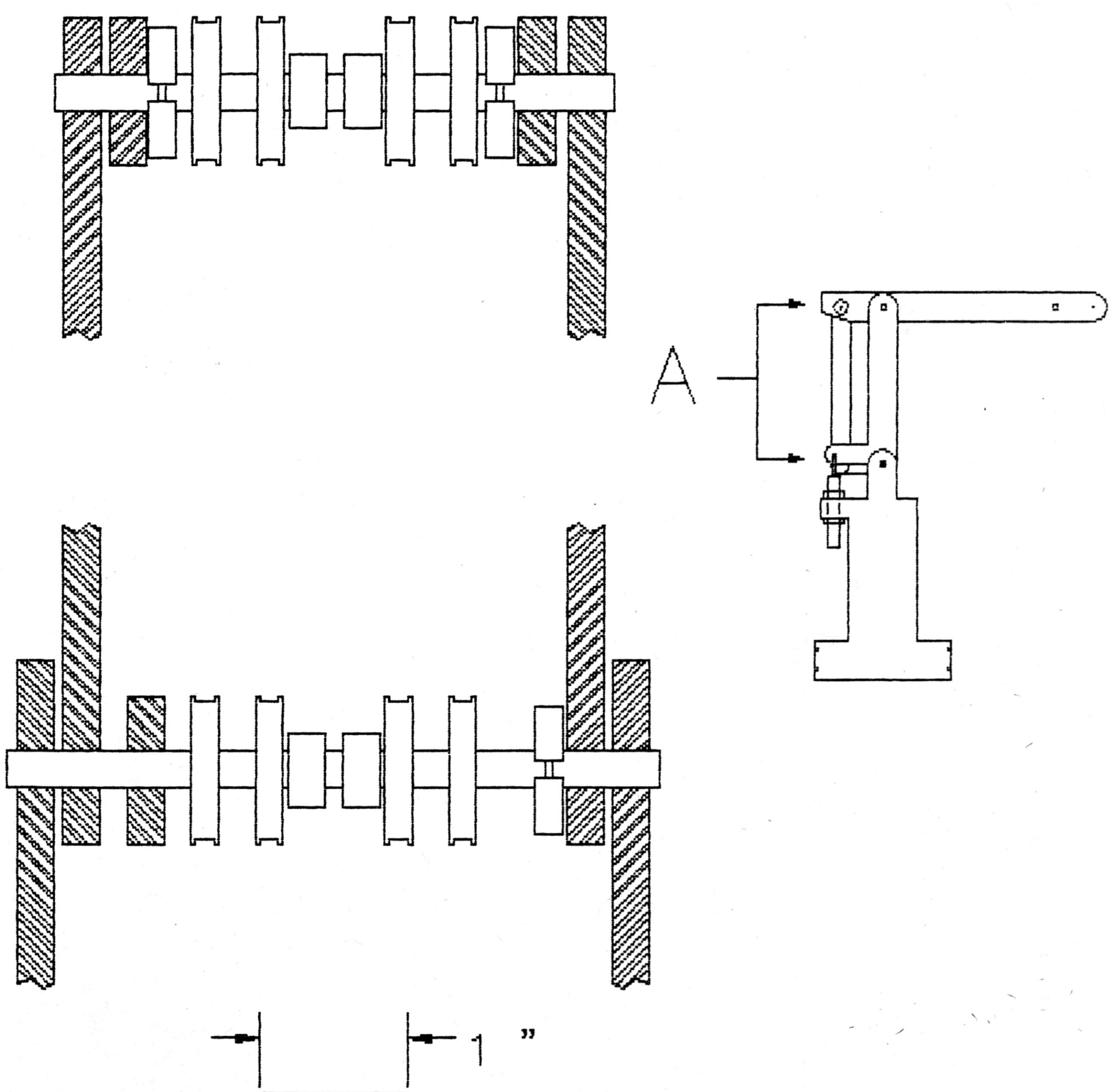
DRAWING #	# 9

SECTION A INSIDE VIEW



DRAWING TITLE
SPROCKET/CHAIN MECHANISMS

NAME
PAUL TILL

DATE
4/2/86

DRAWING # # 10

List of Parts

Part	Stock #	Quantity	Source
Bearings			
	B2-115	8	Winfred M. Berg
	B2-105	10	Winfred M. Berg
Sprockets			
	3MDP285-20	1	Winfred M. Berg
	3MDP55-20	9	Winfred M. Berg
Bevel Gear			
	M24P-1	1	Winfred M. Berg
Shoulder Screw			
	PZ24-3	1	Winfred M. Berg
	PZ20-3	1	Winfred M. Berg
Shafts			
	S4-85-0	2	Winfred M. Berg
	S4-50-0	1	Winfred M. Berg
Bushings			
	B6-9	5	Winfred M. Berg
Set Screw			
	CS-7	6	Winfred M. Berg
Gear Clamp			
	CG1-11	4	Winfred M. Berg
Pistons			
	SDR-08-1.5	2	Clippard Minimatic
	SDR-08-1	2	Clippard Minimatic
Valves			
	FV-4D	4	Clippard Minimatic
Solenoid			
	AVSC	8	Clippard Minimatic

Appendix B

ASEA Drawings

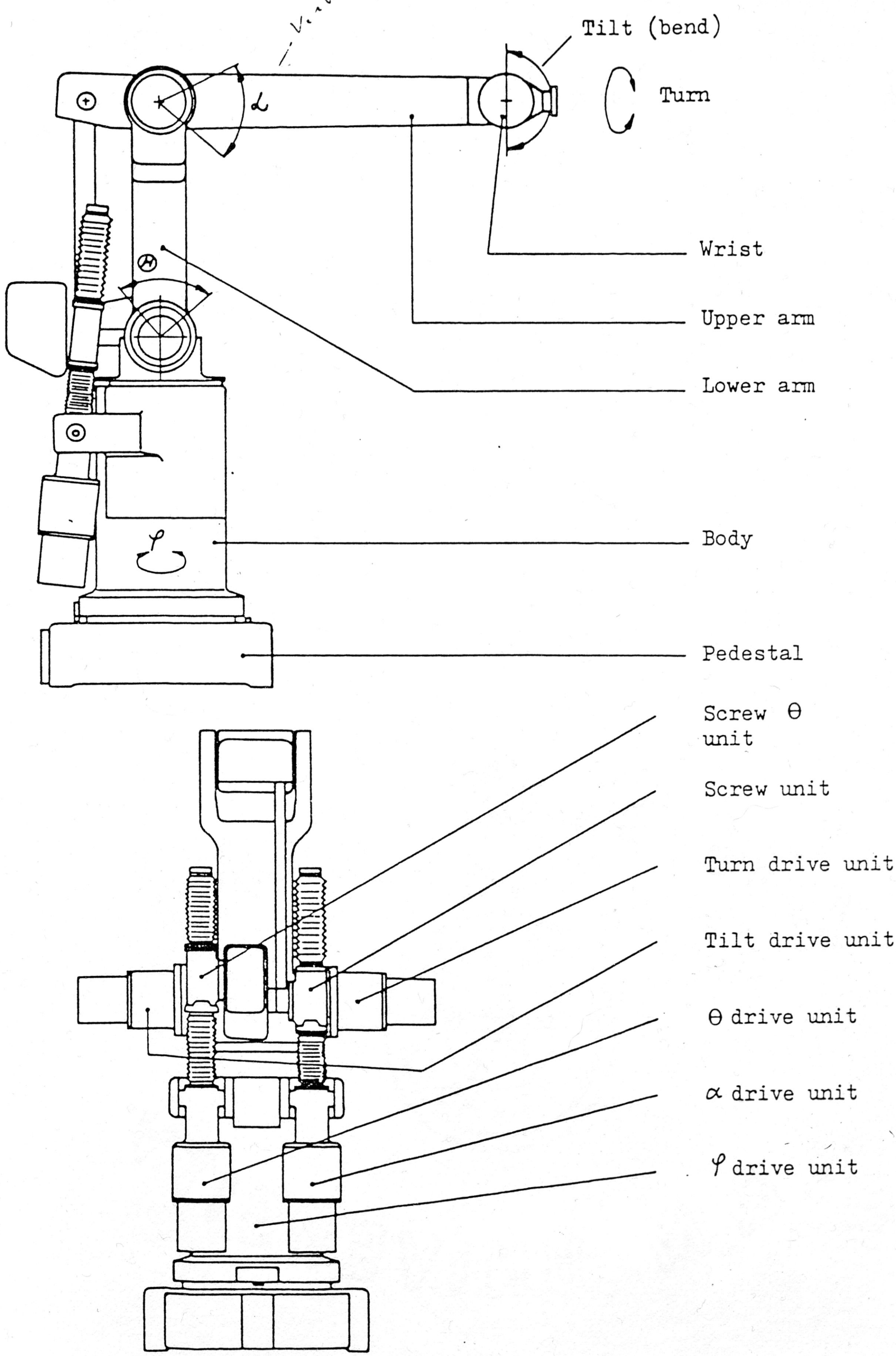


Fig. 3-3 Mechanical components of the industrial robot

Environment:

The robot and the controls mounted on it are designed to withstand ambient temperatures from +5 °C to +70 °C. The rating of the dc motors applies up to ambient temperatures of 50 °C. For ambient temperatures above 50 °C the permitted handling capacity must be determined in consultation with ASEA in each individual case.

Repeat accuracy: ± 0.20 mm at wrist
Working range: see Fig. 3-2

Speeds:	Arm motion,	rotation	95 °/s
	" "	radial	0.75 m/s
	" "	vertical	1.0 m/s
	Wrist motion:	bend	120 °/s
	" "	turn	200 °/s

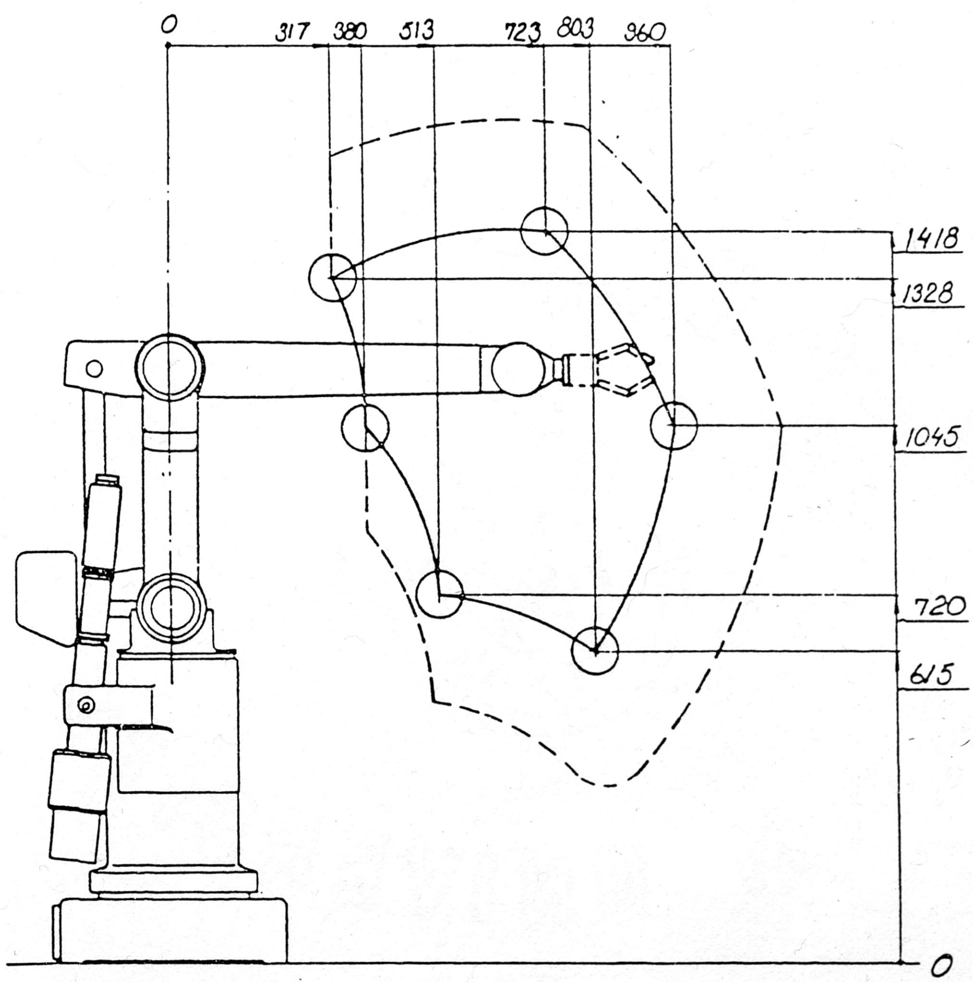


Fig. 3-2 Working range of industrial robot

Lower arm:

Mounted on the body is a bearing bracket to which the lower arm is fixed and in which it pivots. The motion of the lower arm (θ-motion) is obtained by means of a drive unit consisting of a motor unit and ballscrew transmission; these are rigidly mounted on the body. The motion of the ballscrew is transmitted to the lower arm via a lever pivotting at the ballscrew and attached to the lower arm. The drive units for the turn and tilt motion of the wrist are mounted on the lower arm around its lower turning centre.

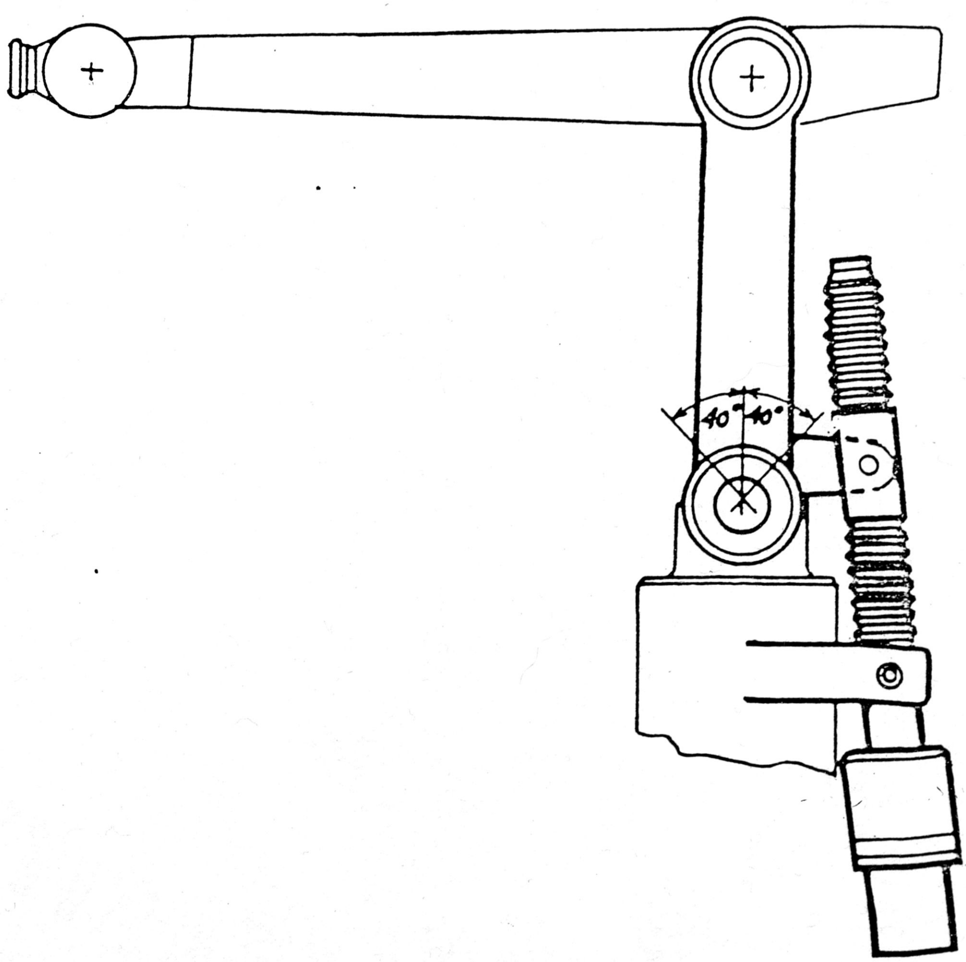


Fig. 3-5 Lower arm with drive unit

Upper arm:

The upper arm is fixed to, and pivots on, the upper end of the lower arm. Movement of the upper arm is achieved as follows.

The drive unit, consisting of the motor unit and the ballscrew transmission, transmits a motion to two link rods articulated on a shaft extending from the ballscrew nut assembly. One of the link rods is attached to a shaft fixed to the upper arm and the other end is attached at the centre of rotation of the lower arm. Together with the upper and lower arms, these two link rods form a parallelogram. As figure 3-6 shows, movement of the nut assembly and one corner of the parallelogram will move the wrist up and down.

Electrical and compressed-air lines to control the grippers run through the upper arm. At the rear of the arm there is a connection for the supply of compressed air. Outlets for the gripper, two individually controllable pneumatic outputs and an electrical contact with four wires are mounted on the underside at the front of the arm.

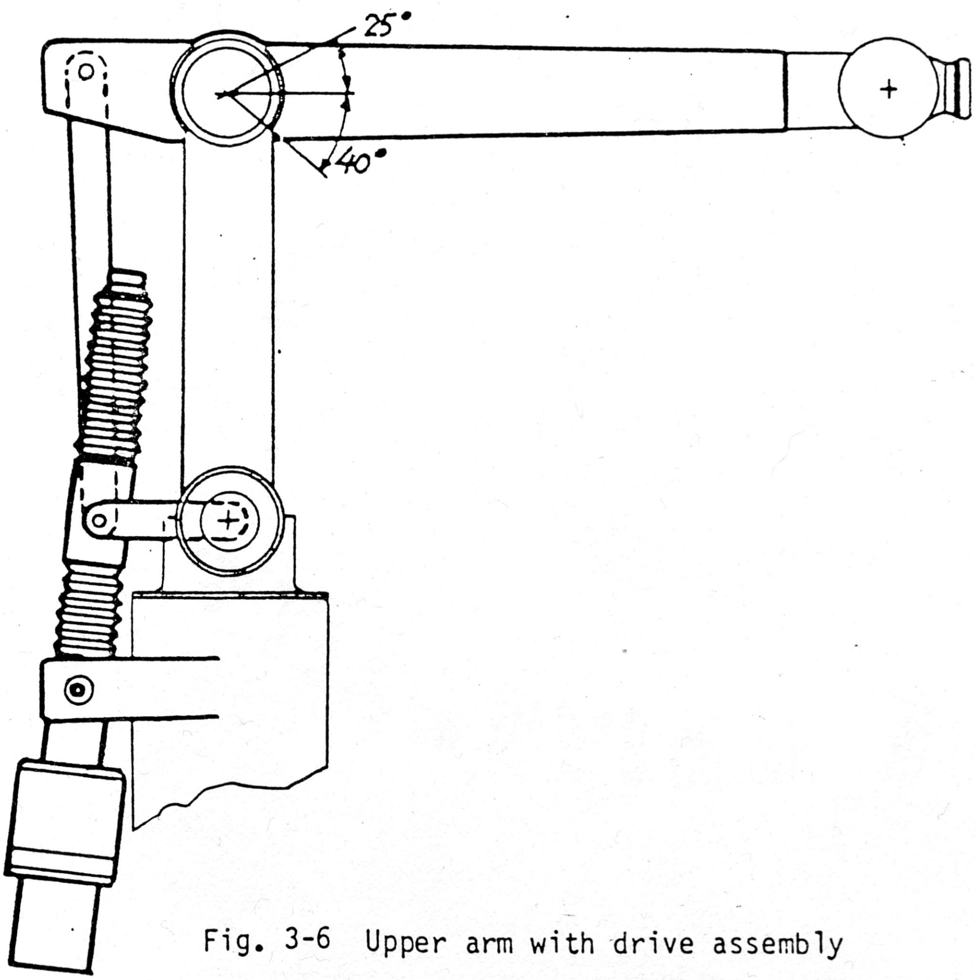


Fig. 3-6 Upper arm with drive assembly

Wrist:

The wrist is rigidly mounted on the upper arm. Two motions are available at the wrist, a turning motion and a tilting motion. These motions are achieved as follows. The drive unit for each motion can either be a dc motor equipped with a resolver and a transmission consisting of a gearbox, or a pneumatic rotary cylinder for turning at right angles or 180°. With pneumatic power, only one motion can be driven and the other must always be locked. The motion of the drive unit is transmitted to the wrist via a linkage system.

The linkage system operates as follows. A linkage disc is coupled to the drive unit, which is mounted on the lower joint of the lower arm. Mounted on this linkage disc are two link arms displaced π/2 rad (90°) on the linkage disc. The other end of the link arms is mounted on a linkage disc pivotting in the upper arm. From here the motion is transmitted to a linkage disc in the wrist via two more link rods. The turn and tilt motions have separate linkage systems on either side of the arm system. Wrist tilt is achieved because the linkage disc at the wrist is fixed to the moving part of the wrist. Wrist turn is achieved by means of an angled gear unit which transfers the motion from the linkage disc to a turning disc free to rotate in the wrist. The angled gear unit is adjustable so that subsequent adjustments can be made in cases requiring very little backlash.

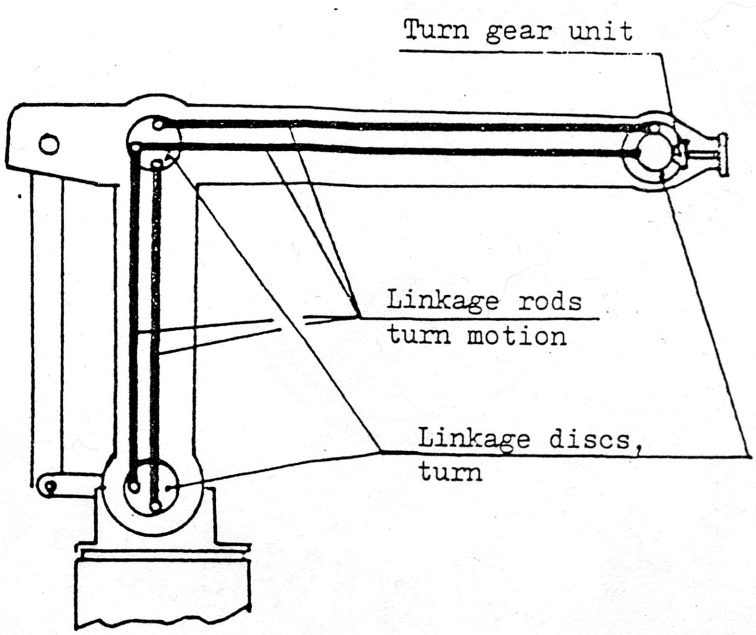


Fig. 3-7 Schematic diagram of wrist transmission

ASEA

Arbetsområde

Industrirobot 6 kg

6397 001-AU

Department	Year	Week
YBR	74	41

This document is based on licence drawing No. | Sheet 1 | Cont. –

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B.Nilsson		Ban	Hm

European projection | √ indicates R_a in μm

Sheet | Cont. | Year | Wk | Dept | Rev.

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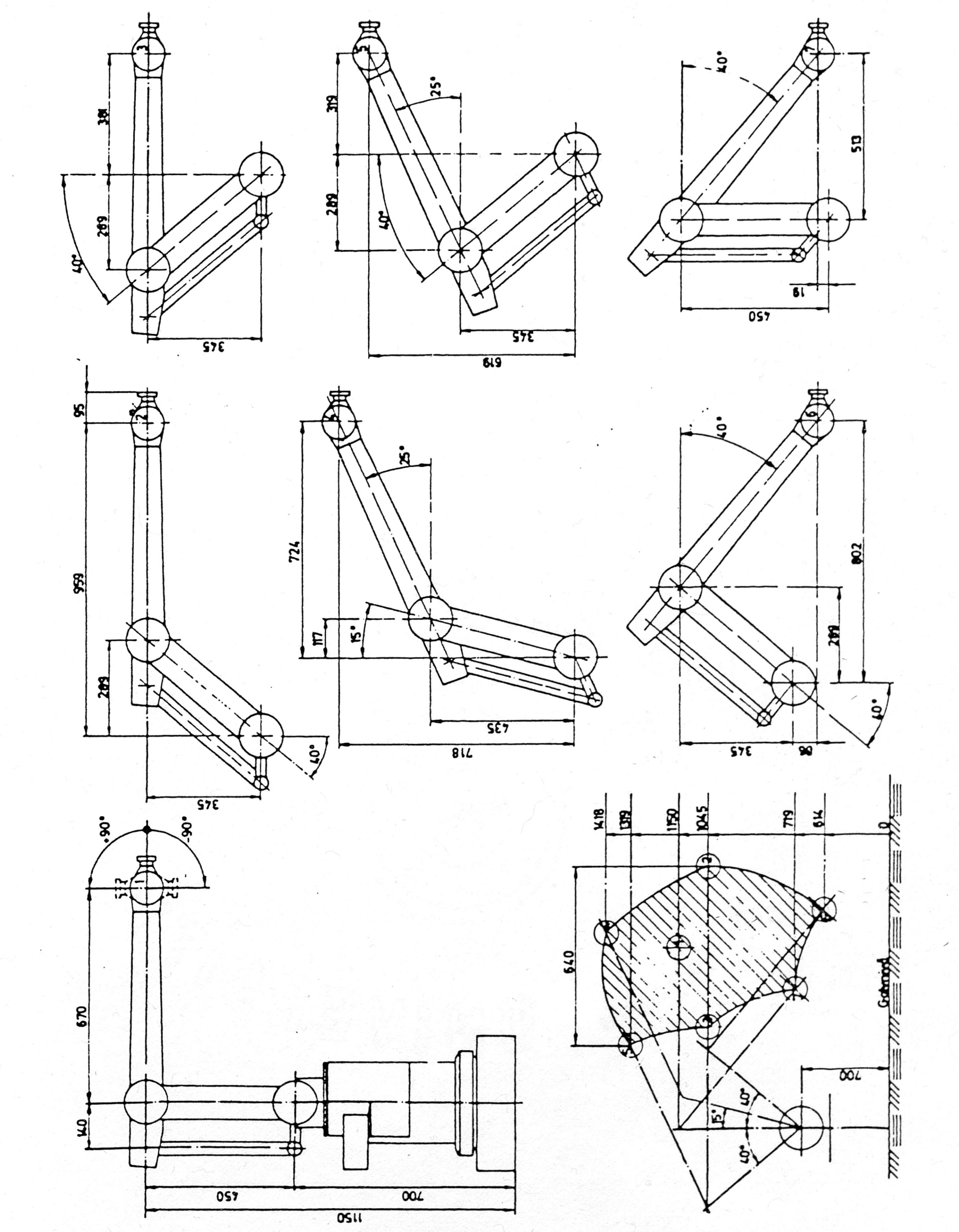

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ASEA

Industrirobot 6 kg
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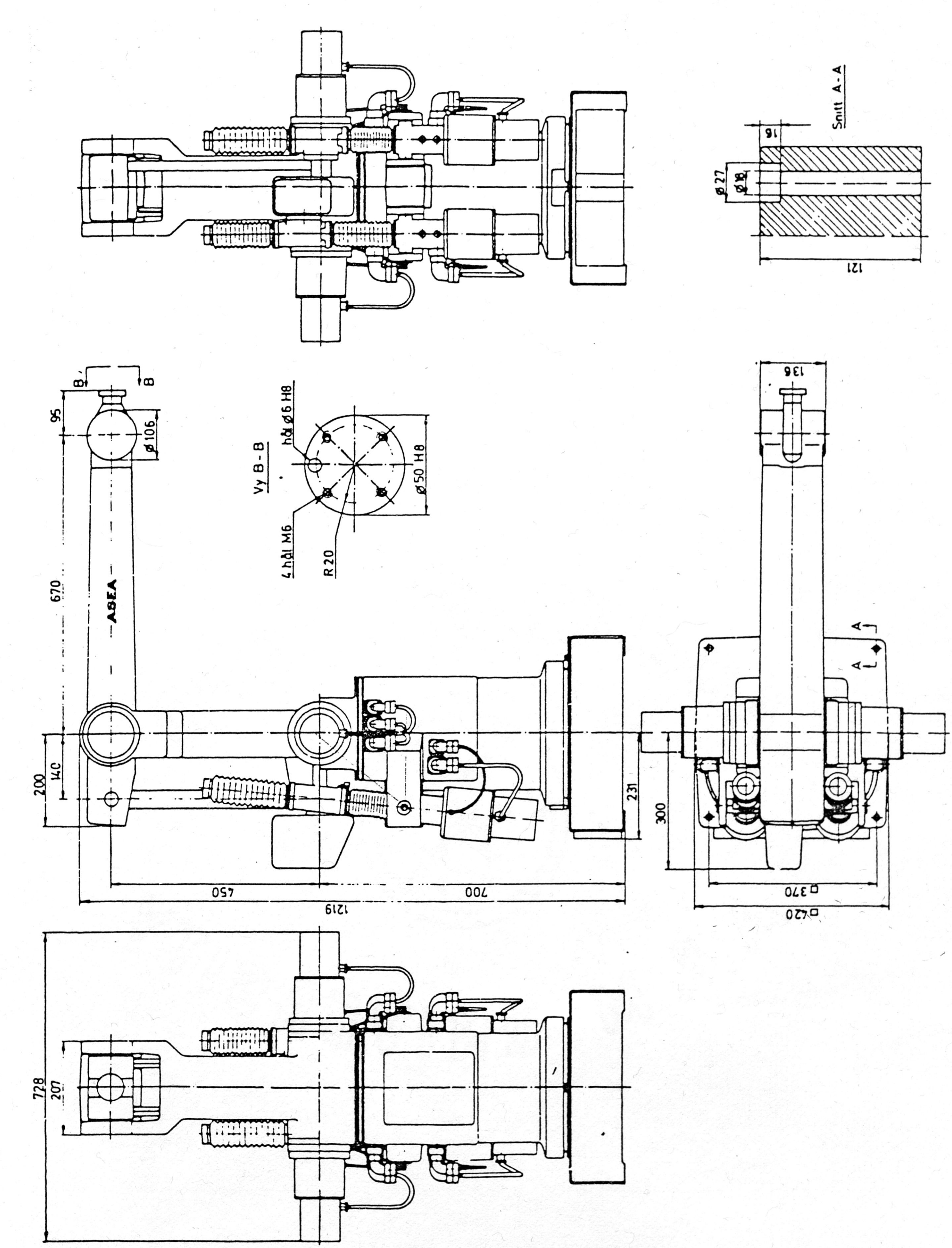

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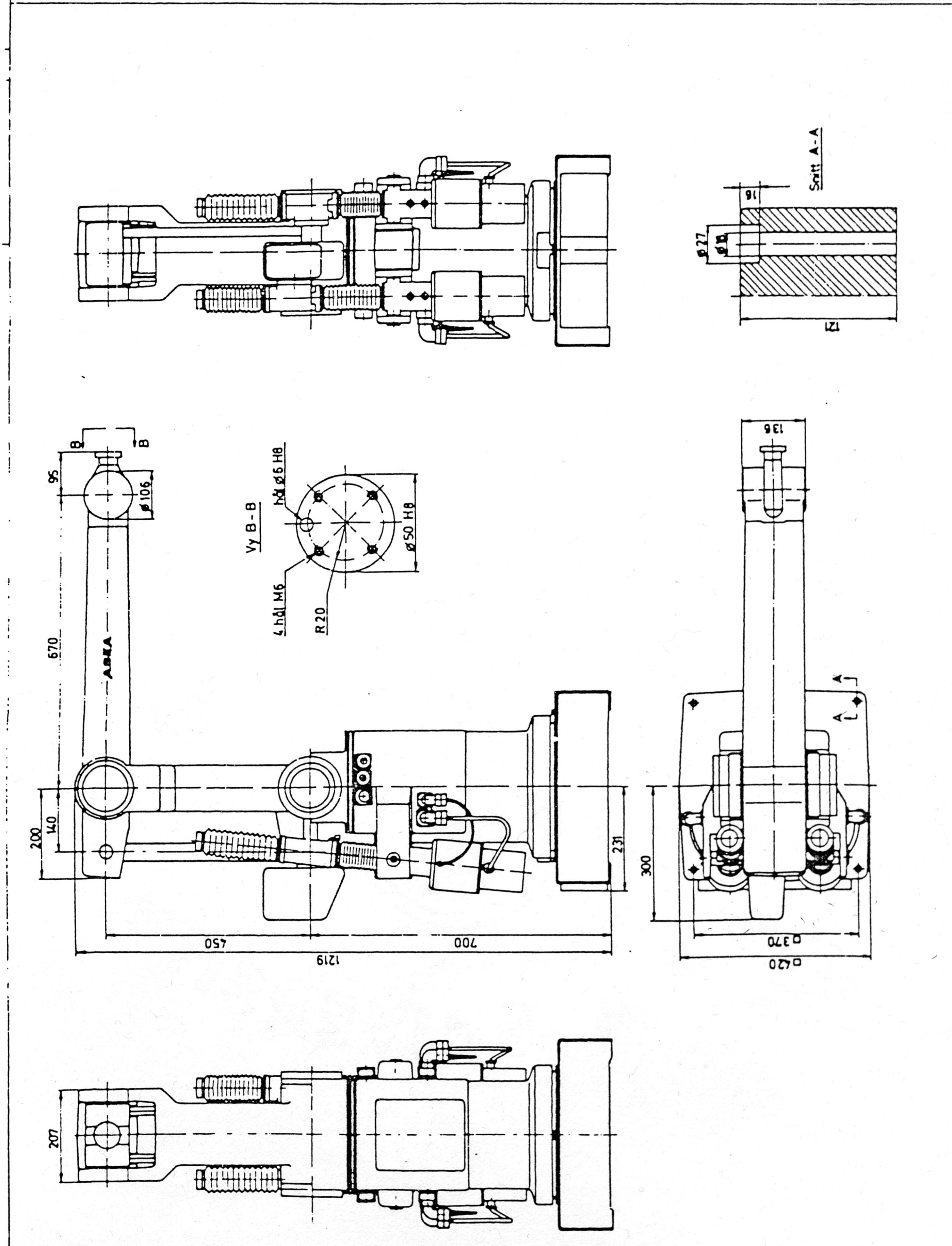

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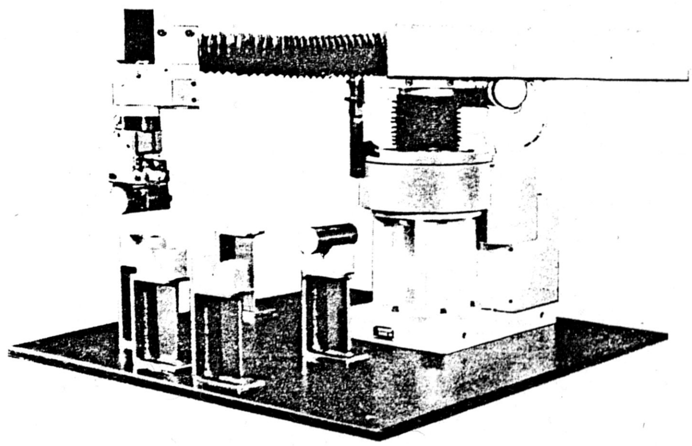
New FMS Servo Robot Specification Sheet

Preliminary

Following specifications are preliminary based upon the actual performance of pre-production models, and should be used for planning purposes only. Final specifications will be published with market introduction of robot scheduled for last quarter 1982.

Capability Descriptio

It is the intent of this robot to fill the applications requirement for a small parts, high precision, high speed, low cost, high technology robot. Payload will be from 5 kg (10 lbs) to grams. Seiko Instruments traditional precision will provide ±0.025mm (±.001 in.) or better. High speed is a requisite requirement and will be at least 1200mm/second. Low cost will be achieved through interchangeable axis of either DC servo or pneumatic, providing a strong correlation between cost and performance requirement. The full DC servo robot and controller will provide interface with any level of technology required by the application and plant facility. There is no other robot like it!



Contact your local distributor for a demonstration or possible beta station installation at your factory.

Performance Specification

Robot Category:	Precision, Point-to-Point, Simultaneous Servo AND/OR Non-Servo with 4-5 axis. NOTE each axis is modular so as to permit choice of either servo or non-servo movement.
Main Axis Motions:	VERTICAL: 120mm (4.7 in.) HORIZONTAL: 300mm (11.8 in.) PLANE ROTATION: 210° GRIP ROTATION: 290° (In Any Axis)
Speed:	1200mm/sec (47 inch/second)
Payload	5 kg (11 lbs)
Repeatability:	±0.25mm (±.001 in.)
Controller:	Z-80 based computer Interface: RS 232 Memory: 400 steps Spare I/O: 20 inputs and 16 outputs Display: 4 lines x 40 character LCD Alpha Numeric
Accessory/Options:	Each axis may be optional DC servo of Pneumatic non-servo Cassette tape drive 5th Axis Automatic tool/grip change

Appendix C

Common Robots Reviewed

AP 10

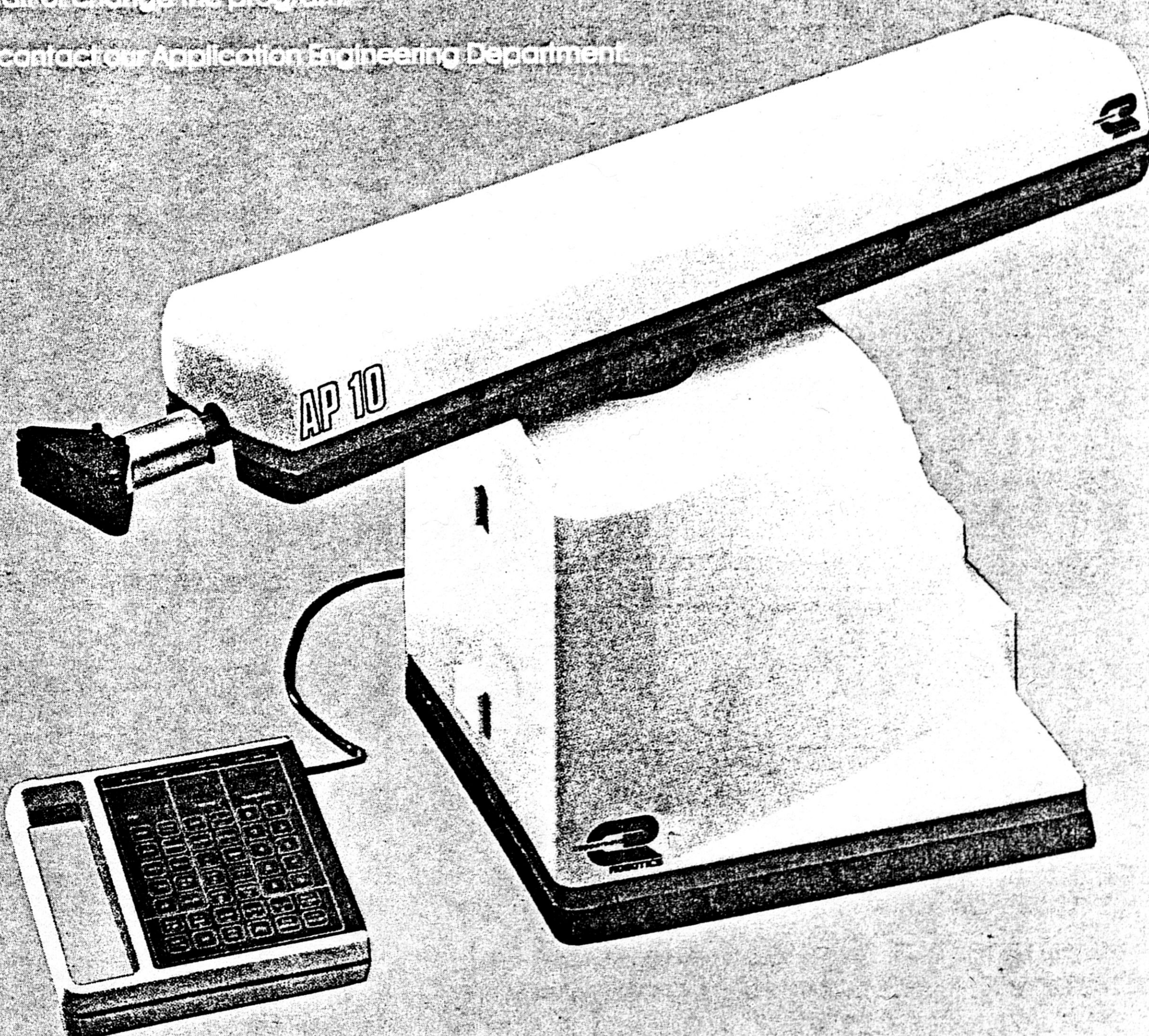
e AP-10 is a pneumatically powered, microprocessor controlled industrial robot.
e used for a variety of tasks requiring parts handling, parts feeding and parts
ting. It is easily programmed through a hand held master teach control.

cause of simplicity and rugged design, it is well suited for industrial application,
ere dependability, durability, and easy maintenance are required.

e AP-10 consists of the robot itself, an electronic controller, and a teach control
ogramming device. The robot is protected by a fiberglass enclosure. The
erators control, which is available in NEMA 12 or pedestal mount configuration is
nnected to the robot by means of a cable.

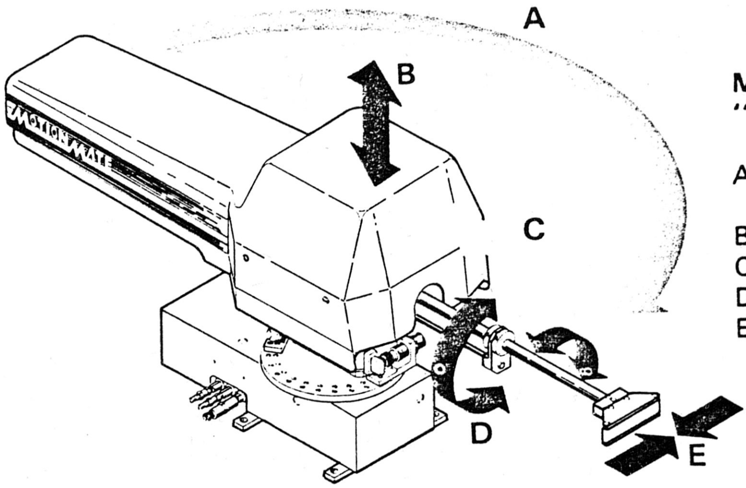
e teach control guides the operator through the sequence of operation; no
ecial skills are required to edit or change the program.

more information, please contact our Application Engineering Department.



copperweld
ROBOTICS

MotionMate's Five Axes of Movement



MotionMate offers five axes of movement, or "degrees of freedom." They are as follows:

A — Base Rotate with a motion range of 180° which is adjustable in increments of 15°
B — Lift of 3"
C — Extend to 12"
D — Wrist Rotate 90° or 180°
E — Grasp

Technical Specifications

AXIS OF MOTION					
AXIS	DESCRIPTION	FUNCTION	STROKE	MOTION/SPEED	AXIS DRIVE
A	Base rotate	Horizontal rotation	180°	180° per second	Rack and pinion via air control
B	Lift	Vertical linear	3"	12 to 24 i.p.s. depending upon load	Air cylinder
C	Extend	Horizontal linear	12"	12 to 24 i.p.s. depending upon load	Air cylinder
D	Wrist	Wrist rotation	90° 180°	1/4 second 1/2 second	Cam actuated
E	Grasp	Open/close	±18°	1/8 second	Air cylinder actuated draw bar

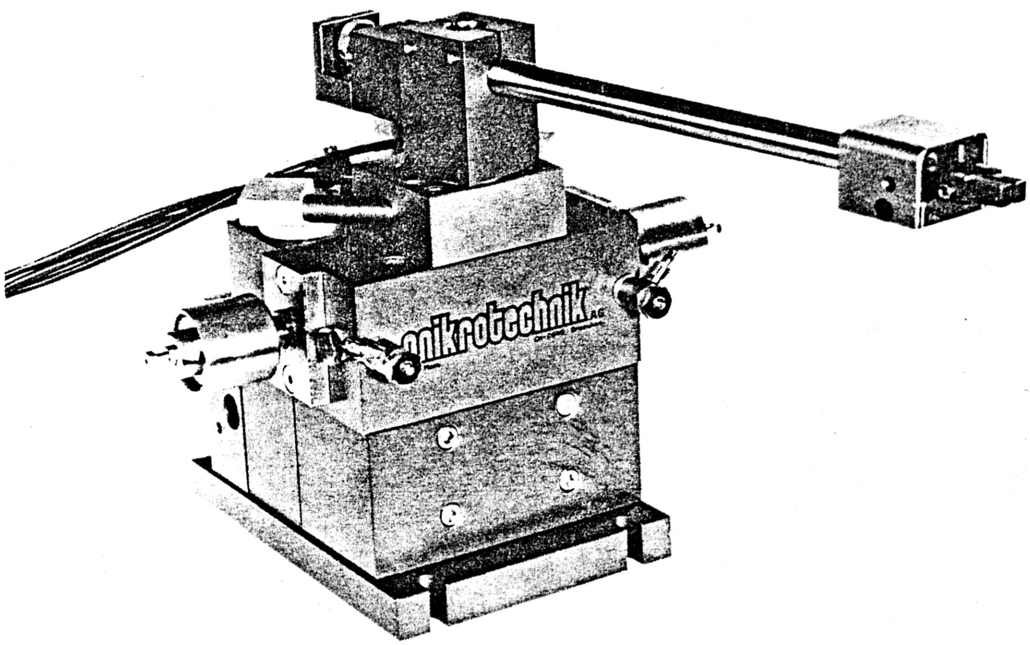
Weight of robot	160 pounds
Max. load capacity at wrist	5 pounds
Repeatability	± .005
Axis drive method	Pneumatic at 80 p.s.i.
Power source	115V/60Hz, 220V/50Hz optional
Axis motion detectors	Proximity switches on base rotate, lift and extend
Adjustable mechanical stops	On base rotate, lift and extend
Positioning	Adjustable mechanical stops
System speed	12" to 24" per second linear depending upon load 180° per second base rotate depending upon load
Operating temperature	+20°F to +140°F
CONTROL	Electronic, micro processor with remote portable teaching module
Memory capacity	Up to 300 steps
Program method	Push button via portable teach module
Maximum time interval between steps	10.79 minutes
Auxiliary equipment inputs/outputs	6 outputs and 8 inputs each rated at 115V/60Hz. Other voltages available.
OPTIONS	Linear gripper Pivot type gripper Vacuum gripper with pump Base Rotate — 115V/60Hz Base Rotate — 220V/50Hz Wrist Kit Extend lift kit 6" Extend lift kit 8" Extend reach kit 18" Counter adapter kit, manual reset, 4-digit, 115V/60Hz

mikrotechnik AG

Solothurnstrasse 186 CH-2540 Grenchen / Switzerland

Technical and Electronic Development Industries

Rotary Loader Type MD 32



- Angle of rotation infinitely variable from 0 - 185°.
- Vertical stroke with 2 independantly adjustable depth stops of 0 to 50 mm each.
- 3 swivel positions can be utilised. Maximum angle 90°. Intermediate position between 0 - 45°.
- Limit of angle of rotation and vertical stroke damped by means of adjustable damping units.
- The patented sensing units can be placed on all end positions.
- Combination possibilities with all Mikrotechnik automation elements.

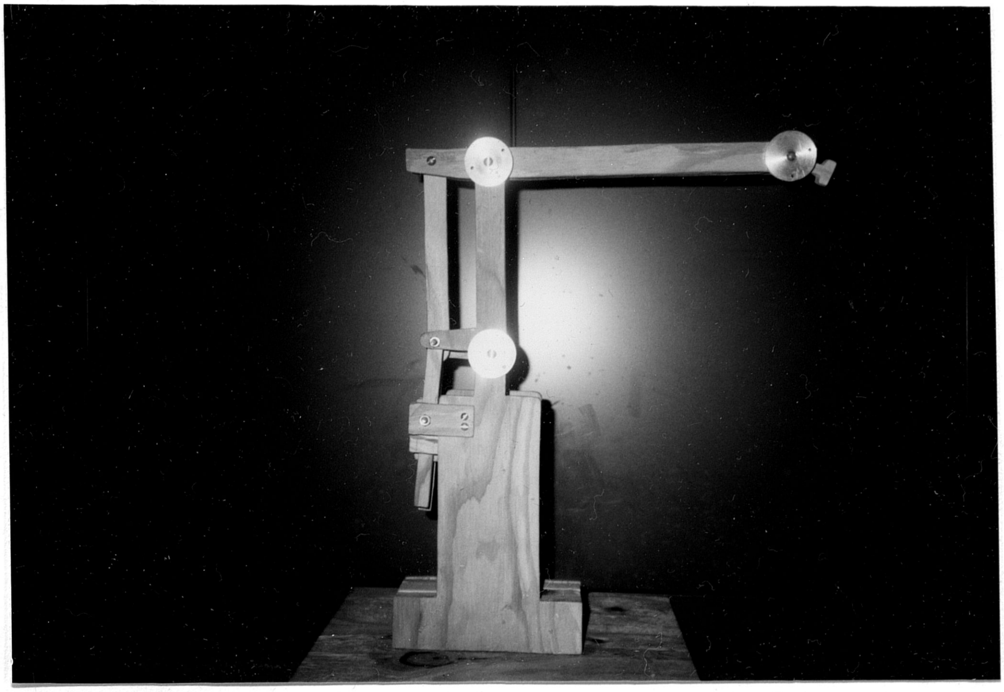
General Agents and Technical Service:

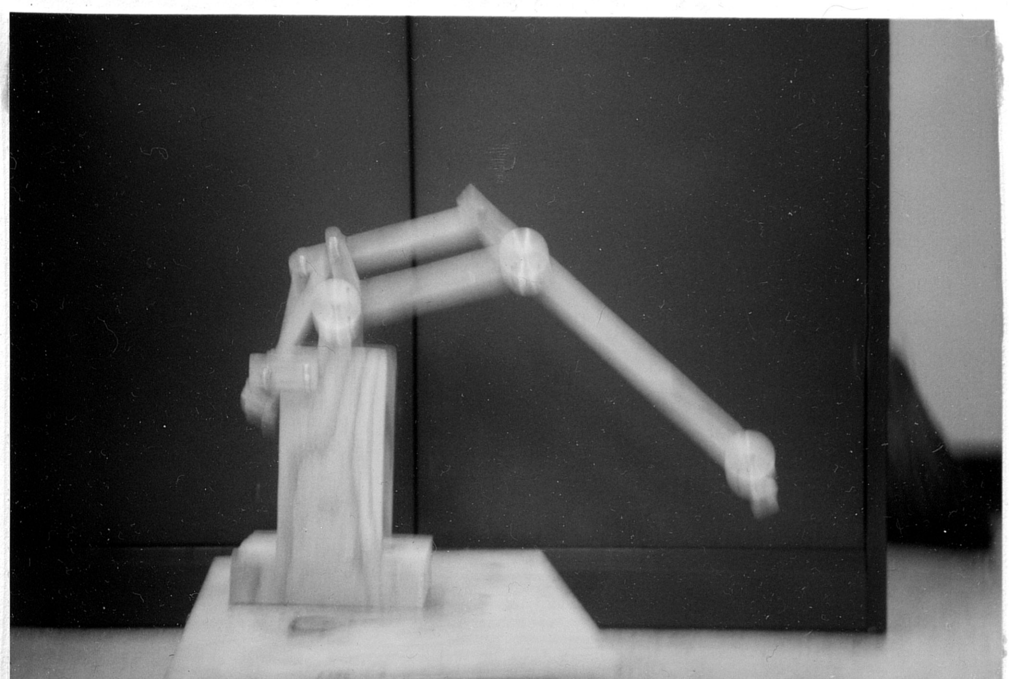
METO-FER LTD. AUTOMATIONS AND ELECTRONICS

Solothurnstrasse 186 CH-2540 Grenchen / Switzerland Telephone 065 8 84 22 Telex 3 43 32

Appendix D

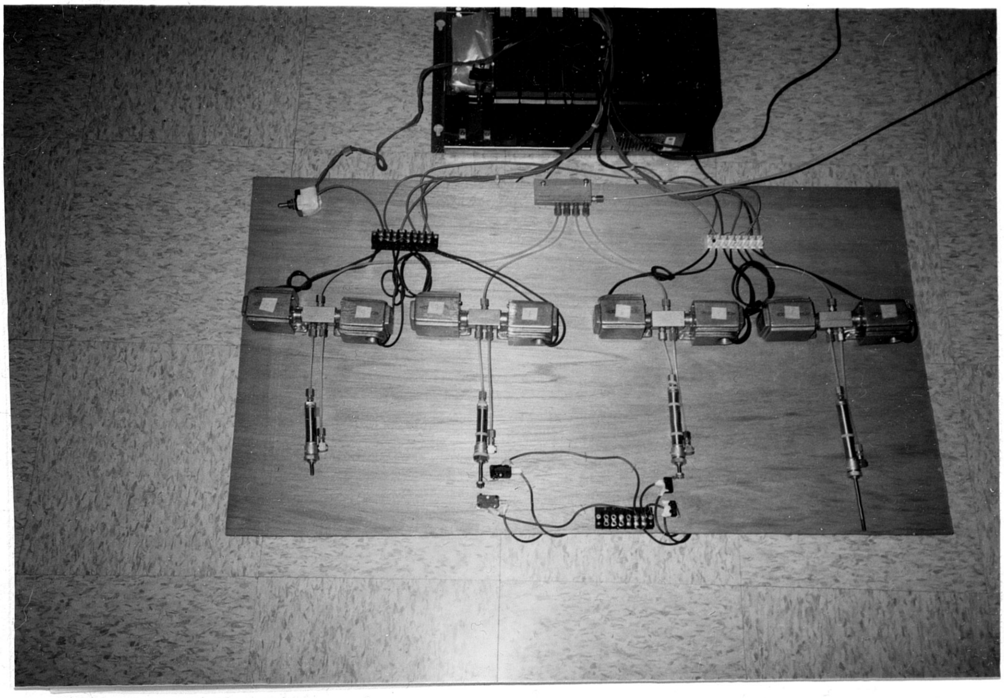
Photograph of Model

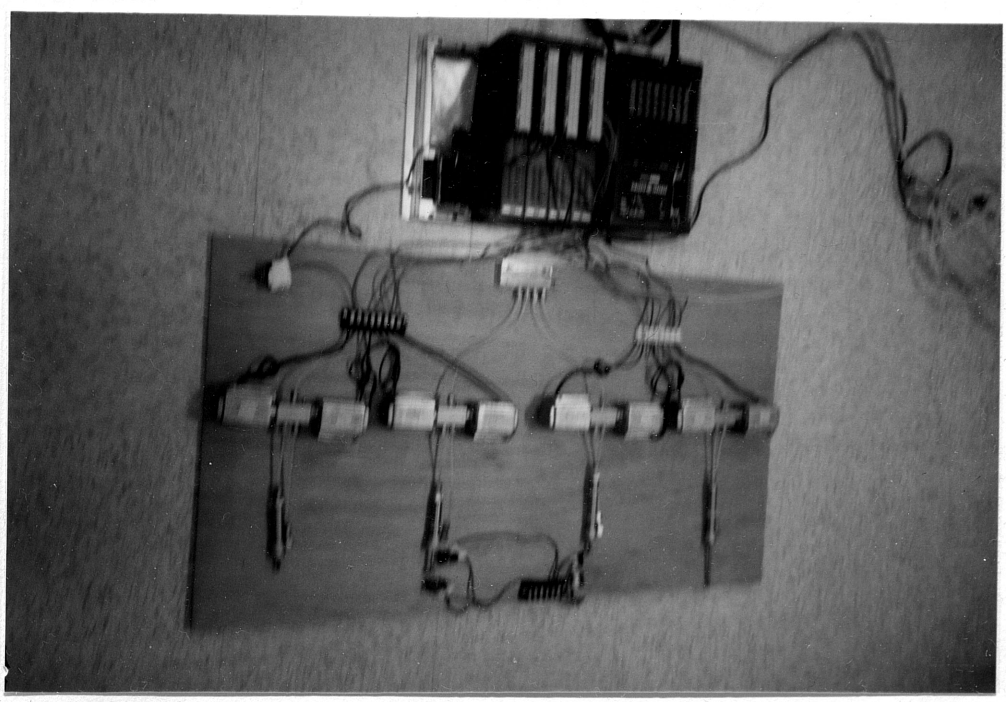




Appendix E

Photograph of Interface Board

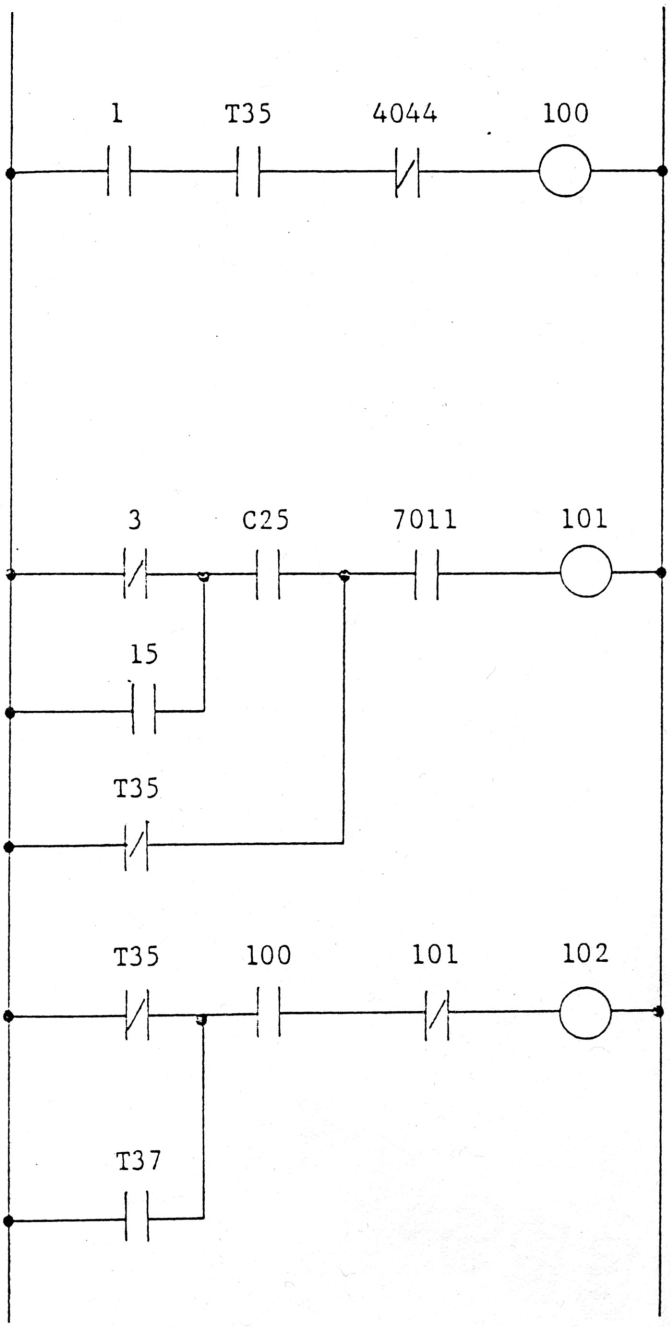




Appendix F

Example of Ladder Diagram Logic

The following example of a ladder diagram uses many of the instructions listed up to this point. The key sequence shows how to enter the rung.



STR 1 ENT

AND TMR 3 5 ENT

AND NOT 4 0 4 4 ENT

OUT 1 0 0 ENT

STR NOT 3 ENT

OR 1 5 ENT

AND CNT 2 5 ENT

OR NOT TMR 3 5 ENT

AND 7 0 1 1 ENT

OUT 1 0 1 ENT

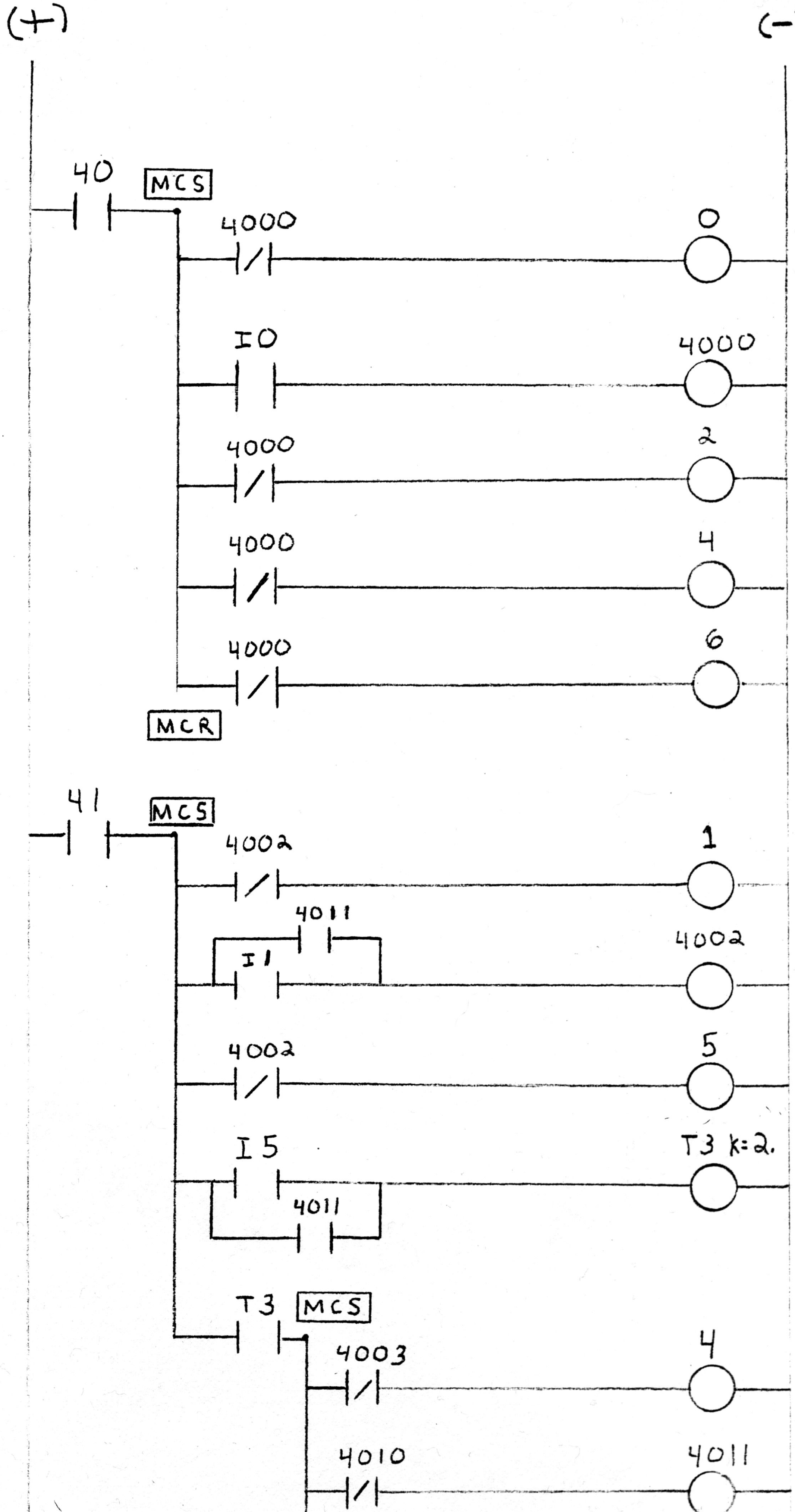
STR NOT TMR 3 5 ENT

OR TMR 3 7 ENT

AND 1 0 0 ENT

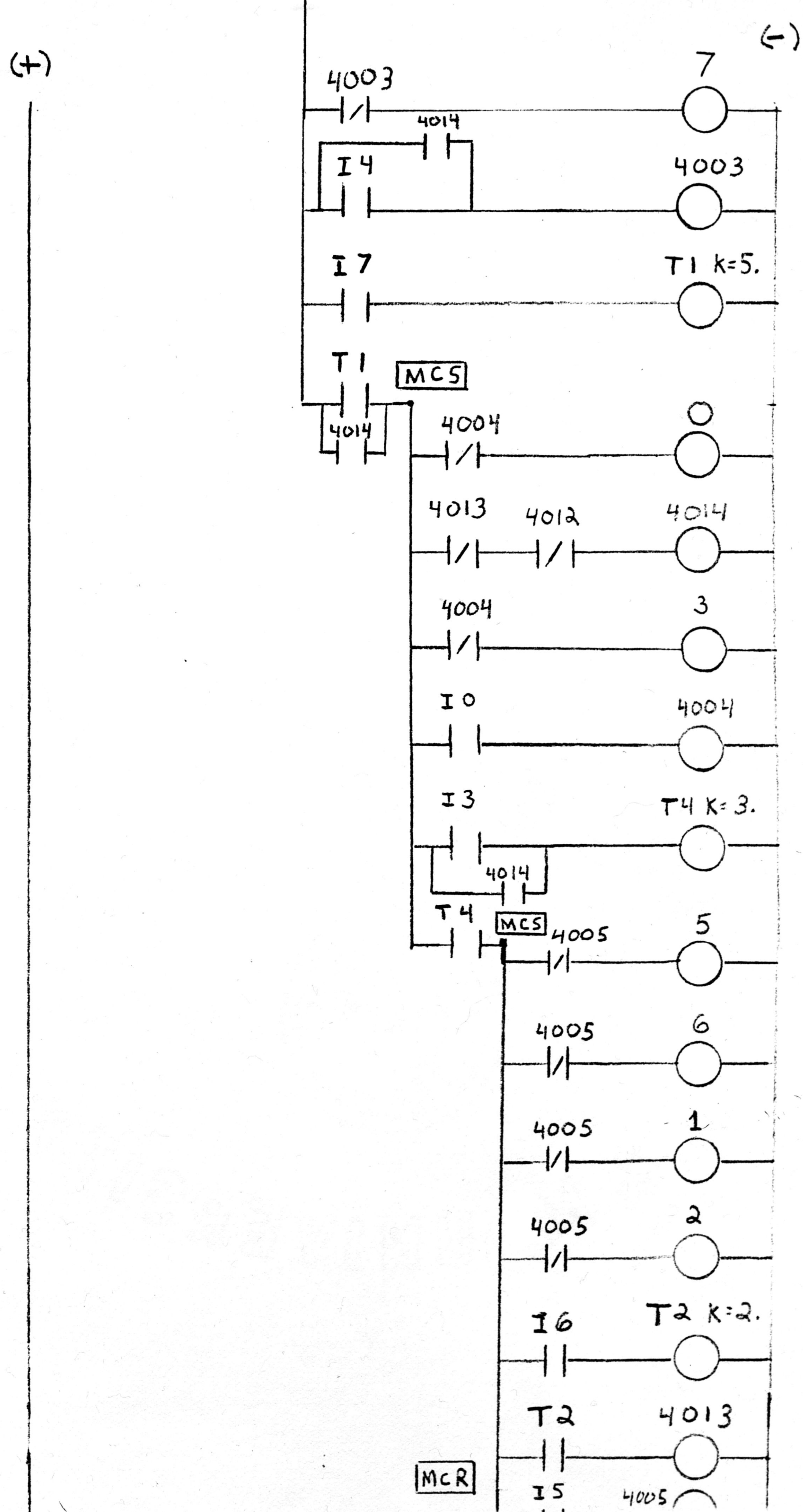
AND NOT 1 0 1 ENT

OUT 1 0 2 ENT


(+)
(−)
40
MCS
4000
0
IO
4000
4000
2
4000
4
4000
6
MCR
41
MCS
4002
1
4011
I1
4002
4002
5
I5
T3 k=2.
4011
T3
MCS
4003
4
4010
4011

Appendix G

Simulation Program


(+)
(−)
4003
7
4014
I4
4003
I7
T1 K=5.
T1
MCS
4014
4004
0
4013
4012
4014
4004
3
I0
4004
I3
T4 K=3.
4014
T4
MCS
4005
5
4005
6
4005
1
4005
2
I6
T2 K=2.
T2
4013
MCR
I5
4005