

/INSTRUMENTATION AND
MODIFICATION OF THE IRI/M50
ROBOT FOR AUTOMATIC CONTROL RESEARCH/

by

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CHAPTER I

INTRODUCTION OF RESEARCH

This Thesis deals with modification of the hardware of an industrial robot. These modifications were made to research the controllability of the robot arm. The specific robot modified was the International Robomation/Intelligence M50 Robot (IRI/M50). The IRI/M50 robot was acquired for research of Model Referenced Adaptive Control by Department of Mechanical Engineering, Kansas State University.

The IRI/M50 is an industrial robot with a typical shoulder-elbow link arrangement. Figure 1 is an illustration that shows the general arrangement of the manipulator. The IRI/M50 is of the general class of robots, termed pick-and-place. This class of robots can perform tasks that do not require smooth movement between specified points. An example of such a task may be the loading and unloading of pallets. The IRI/M50 robot is not capable of performing such tasks as welding or painting which require a smooth movement between set points.

The manipulator stands 52 inches tall and has a spherical work envelope of radius 80 inches. The manipulator moves in this spherical work envelope by the rotation of five joints which gives the robot five degrees of freedom. The arm of the IRI/M50 robot can be turned about the base, and then moved in

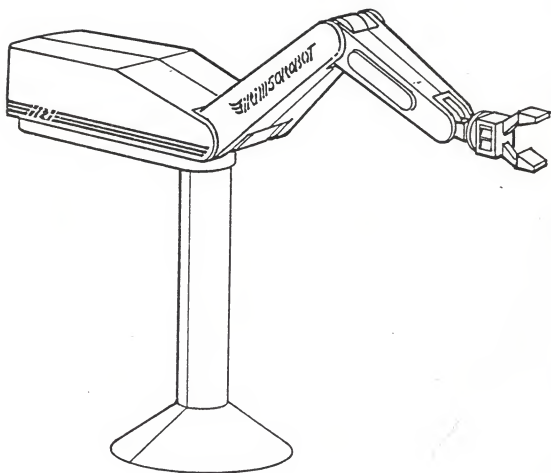


Figure 1 IRI/M50 Robot

the vertical plane of the arm by the shoulder and elbow joints. The end effector can then be rotated and oriented in the vertical plane of the arm by the wrist of the robot. These moves make the robot capable of locating the end effector in three dimensional space and then orienting the end effector with roll and pitch and lacking only in yaw. It is the lack of the yaw that gives the five degrees of freedom rather than the typical six.

The robot arm is driven with compressed air. The use of compressed air to drive the robot was made for several reasons. The primary reason for the use of air is cost, a comparable robot using an alternate power source would cost 25-30% more than the IRI/M50. Air is readily available in most industrial work places and the installation of the IRI/M50 robot would not require an additional power source. Compressed air is clean, safe and reliable. The final reason for the use of pneumatics is the reliability of pneumatic motors. The air is supplied from a central source at approximately 120 PSI and then distributed to individual pneumatic motors.

The distribution of the air to the individual axis is accomplished by five pressure control valves, one for each axis. The pressure control valves are two position valves, on and off. The valves are actuated by pilot air pressure which is controlled by a solenoid that is energized by the control computer. The pressure to the motors is maintained at a constant pressure of approximately 80 PSI by a technique called

dithering.

Dithering is a technique that varies the duty cycle of pulses that are sent to the solenoid. By varying the duty cycle of the solenoid the average output of the pressure control valve is varied proportionally. In an effort to smooth out the pulses in the air distributed to the motors, accumulators have been used. The accumulators act as energy storage elements which tend to smooth out the air flow to the drive motors. The pressure sent to the motor from the pressure control valve is controlled by the robot control computer and is modified for different movements.

The compressed air from the supply is directed to the individual motors by the pressure control valves and then the air is ported to the motor by an air motor valve. The air motor valve is very similar to the pressure control valve. Both the air motor valve and the pressure control valve dither the pilot air to control the position of the spool. The motor valve is a three position spool type valve that is controlled by pilot pressure that is turned on and off by two solenoids. The duty cycle of the pulses to the solenoids control the flow of air to the motor. These pulses control the rate and the direction of air flow. By controlling the pulses the motor can be actuated in the desired direction with a desired speed.

Each of the individual motors work through a chain reduction drive to actuate an axis of the robot. There are two sizes of pneumatic motors on the robot, one-half horsepower and one and

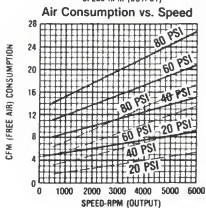
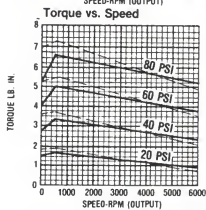
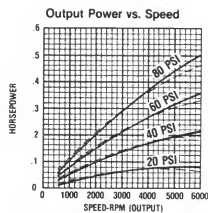
TABLE 1

AXIS PARAMETERS FOR THE IRI/M50 ROBOT

Axis #	Axis Name	Motor Size (HP)	Encoder Resolution (etch/rev)	Axis Scale (counts/10 deg)	Chain Reduction Ratio	Axis Range	Axis Rate (deg/sec)
1	Torso	0.5	100	9038	813.42	360 deg, +1.5 rev	60
2	Shoulder	1.5	100	6937.8	624.402	180 deg, +90 deg	30
3	Elbow	1.5	100	4964.4	446.796	230 deg, +90 deg -140 deg	45
4	Pitch	0.5	1500	3636.7	21.8202	240 deg, +120 deg	120
5	Roll	0.5	1500	3636.7	21.8202	360 deg, 2 rev	120

one-half horsepower. Table 1 has information about each of the axes including the size of motors driving the joints of the robot. From the table it is observed that the shoulder and elbow are driven by the large motors. These joints require the large motors because the links actuated by these motors have to work against gravity. The motors are of the standard vane type rotary motors. The speed-torque curves for the one half-horse motors are shown in Figure 2. From the curve it can be seen that the motors do not generate a large amount of torque. The maximum torque is six inch-pounds but the motors do operate at a relatively high speed. It is this low torque and high speed that requires the large chain reduction used in each of the axes of the IRI/M50 robot.

The position of the joints of the robot are detected by an optical encoder. Optical encoders are feedback devices that are used to detect the relative positions of the links of the robot. The encoders are relatively simple devices. Each of the devices consists of a shaft, etched glass disc, light emitting diode, light sensors and a few logic gates. The etched glass disc is constructed by etching the glass with evenly spaced radial segments. The glass disc is then mounted to the shaft of the encoder. On one side of the glass disc a light source is mounted. This light source is directed at the glass disc through an aperture that separates the light into two portions separated by one half the distance between the glass etchings. On the other side of the glass disc, the light sensors are



Reversible
Models

Single Rotation
Models

Figure 2 Output Curves for the One-Half Horsepower Motor

mounted opposite the light source. An illustration of the exploded view of the optical encoder is shown in Figure 3. As the glass disc rotates, the light source is alternately covered and uncovered by the etching with respect to the light sensors. If the outputs of the light sensors are monitored it can be observed that the outputs are two square waves that are ninety degrees out of phase. This output is referred to as a quadrature output. The output is monitored by the control computer and from the phase relationship of the quadrature output the computer can tell direction of rotation of the encoder. Knowing the direction of rotation the computer then counts up or down each state change in the encoder output. Each of the joints has an encoder connected to the shaft of the drive motors. Because the motor and encoder are directly connected, the position of the encoder counted by the control computer, is the position of the drive motor. The encoder is initially set by moving the robot links to known positions and setting the counters to zero.

There are two different kinds of encoders on the IRI/M50 robot. The two encoders differ in the number of etches on the glass discs. The encoders located on the torso, shoulder, and the elbow of the robot have 100 etches per revolution. The pitch and roll encoders have 1500 etches per revolution. This information is also shown in Table 1.

One of the major factors in the selection of the IRI/M50 robot for research was the powerful control computer. The robot

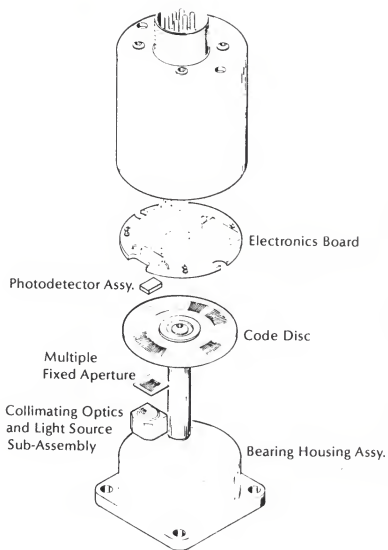


Figure 3 Encoder Illustration

is controlled by a very sophisticated computer. The control computer is comprised of one Motorola 68000 microprocessor which does the bulk of the general control work and five Motorola 6800 microprocessors that receive commands from the 68000 and carry out the menial tasks in the control algorithm. The 6800 gives the commands to the solenoids to actuate the valves, reads the encoders and periodically sends this information to the 68000 for processing which then returns updated commands.

In summary, the IRI/M50 Robot has many features which make it a good choice for Model Referenced Adaptive Control research. The basics of the robot were present but the robot lacked the capability to perform smooth continuous motion. The work reported in this thesis was to modify two aspects of the hardware design to improve the capability of the robot perform smooth continuous motion. Once the hardware modifications were made, the robot control algorithm could be modified to further improve the control of the robot.

In Chapter II the characteristics of the robot which limit its capability will be discussed. In Chapter III the modifications to remedy the limitations will be developed. Chapter IV describes the implementation of the modifications and presents the results of the performance. In Chapter V conclusions and recommendations for further research are presented. Computer interface circuits, software subroutines, and baseline data are in the Appendix.

CHAPTER II

PROBLEM DESCRIPTION

The IRI/M50 robot as described in Chapter I was found to have several hardware problems that affected the controllability of the robot. These hardware problems required attention if the Model Referenced Adaptive Control was expected to be implemented with any success. These items were, first the air motor valves and, second the feedback from the optical encoders.

The air motor valves control the speed and direction of the pneumatic drive motors, which in turn move the robot arm. The valves are standard spool type pneumatic valves. Illustrations of a air motor valve are shown in Figures 4 and 5 on the following pages. The valve consists of a valve body, a spool, and two pilot pressure actuating solenoids mounted in the end caps. The valve body has five ports. One of the ports in the motor valve is a supply pressure port, two are exhaust ports to the atmosphere. The remaining two ports are to the motor. The flow through the specific ports is controlled by the spool. The position of the spool in the valve body determines the flow route of the compressed air. It is the shape of the spool and the method of positioning the spool that affect the controllability of the arm. The spool is moved by pilot air pressure which is pulsed on and off by the dithering of the solenoids. This dithering contributes to the unsteady movement

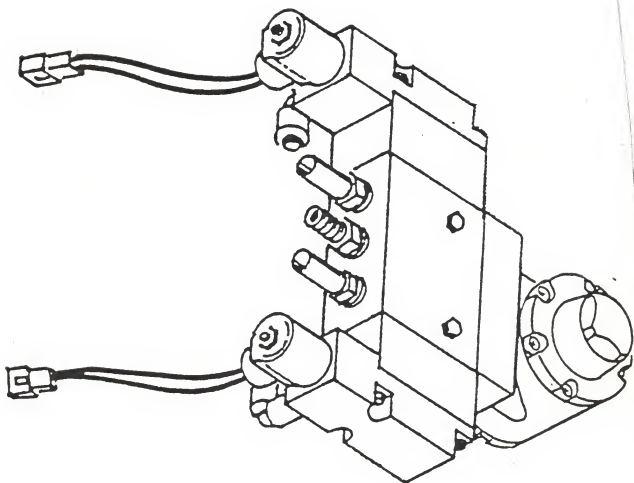


Figure 4 Illustration of Air Motor Valve

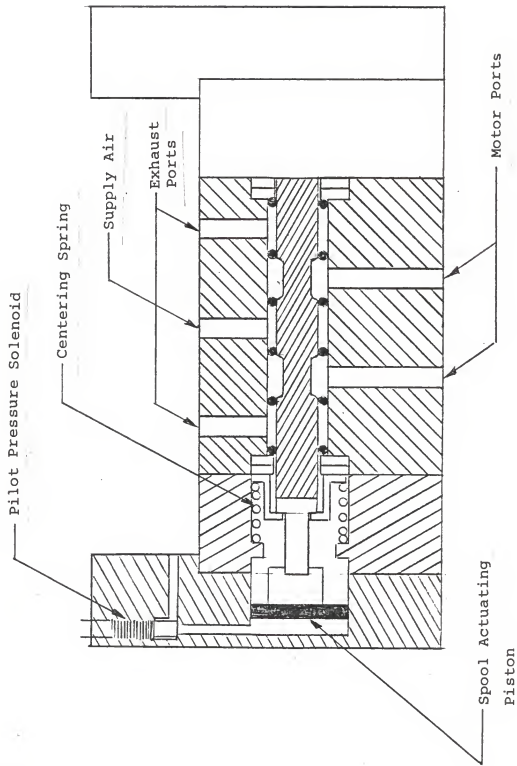


Figure 5 Original Air Motor Valve

of the robot arm. This unsteady movement of the arm makes the robot incapable of moving from point to point in a smooth fashion.

In addition to the unsteady movement of the arm contributed to by the dithering of the spool, the valve also has other inherent problems. Because of the way the spool is moved back and forth in the dithering process and the method of lubrication, the spool tends to become "gummed-up". As the spool becomes more and more sticky it requires a longer and longer duty cycle to output the same flow rate to the motor. To control the flow rate to the motor, the control computer must compensate for this nonlinear time dependent element in the system. These nonlinear time dependent elements are hard to deal with in the control process. The IRI/M50 requires that the operator periodically update the control parameters by performing a calibration routine for the spool valves. This calibration routine finds the minimum pulse width that causes the motor to be actuated. Which is then stored in the control parameters. This solution to the problem makes use of the powerful computational capability of the control computer. The nonlinearity of the system is compensated for by the control computer. The time dependent elements requires periodic updates by the operator to compensate for these changing properties.

The second identified problem was the positions of the optical encoders. The encoders, are the position feedback mechanisms for the links of the robot arm. These encoders as

mentioned previously, are mounted directly to the shafts of the drive motors for each of the axes. The encoders mounted in these positions are a feedback of the positions of the motors. As stated in Chapter I, the motors drive the links through a large chain reduction. This is where the problem arises. If the chain reduction systems were perfect and the output of the motors were directly proportional to the output of the links the position of the encoders would be acceptable. The chain reduction systems are not perfect and the outputs are not proportional to the output of the motors. The chain drive has flexibility, backlash and some damping qualities. These factors make the positions of the motors unacceptable for the feedback elements of the robot control algorithm.

These two hardware problems were identified in the investigation of the IRI/M50 for Model Referenced Adaptive Control implementation. Before further work could be accomplished these problems needed to be corrected. In Chapter III the solution to these problems will be discussed.

CHAPTER III

SOLUTION PROPOSAL

In Chapter II several of the hardware problems associated with the IRI/M50 robot were discussed. In this chapter, solutions to these hardware problems are proposed. These proposed solutions will include modifications of the air motor valve and the mounting of the optical encoder. With the implementation of these modifications, Model Referenced Adaptive Control and the elasticity of the joints can be researched.

It was not necessary to modify all five of the axes. For the purpose of research, modification of one axis would be sufficient. If one axis could be modified and adequate controllability accomplished then the remaining axes could be modified in a similar manner. The axis that was modified was the torso, the joint that rotates the arm about the base. There were several reasons for the choice of modifying the torso, one reason being the access to the hardware. The torso air motor valve is located in a position that it can be removed and replaced relatively easily. The second reason for the choice of the torso axis was the fact that the torso is the axis that is most effected by the changing inertia due to the movement of the joints of the arm. This large change in inertia was an ideal situation to test the implementation of the Model Referenced Adaptive Control. This adaptive control scheme modifies the

gains of the control system depending on the time varying parameters of the system. For the torso the inertia is one of the time varying parameters that affect the performance of the system and the large changes in the inertia require large changes of the gains in the control system. These large changes of the gains make the system easier to monitor and verify that the control system is controlling as anticipated. In addition to the easy access of the air control valve and the advantages of the large changes in inertia of the torso axis there was one more advantage to the use of the torso. This advantage was that the movement of torso was not subject to gravitational force. This simplified the problem without detracting from the significance of the research.

The first problem to be considered was the air motor valve. The problem, as stated in Chapter II, was that the spool of the valve assemble is dithered. This dithering creates a nonlinear time dependent element contributing to the unsteady movement of the arm. The task at hand was to modify the system to eliminate this unsteady movement.

The modified valve needed to be easily controlled from a computer and it was desired that the output of the valve be continous and proportional to the input. The output would be varied from full on in one direction to full on in the other direction with the change in flow being proportional to the command. In addition to being proportional the output of the valve should also be continuous, as opposed to pulsing as in the

current valve.

In the investigation of the current air motor valve, the valve and motor assembly were tested on a dynamometer. The assembly was mounted on the dynamometer and connected to the supply air. The spool of the air motor valve was then manually moved a known amount from the centered position. At regular intervals torque-speed curves were generated. These curves are shown on Figure 6. The dynamometer test revealed some interesting information. The first piece of information observed was the dead zone of the spool valve. This dead zone is a region near the centered position of the spool. In this region the spool can be moved 0.05 inches from center and there is no flow through the valve. The second piece of information to be acquired was in the region just past the dead zone. In this region it was observed that there was bypass air flow through the valve. The air flow did not drive the motor, instead the flow bypassed the motor and flowed directly from the supply to the exhaust. This region was also 0.05 inches in width. Past the bypass region it was found that there was a small region of 0.05 inch of proportional flow. In this region the torque-speed characteristics of the motor were proportional to the position of the spool. In the proportional region, the further the spool was moved from the center the greater the flow to the motor. Past the proportional region the valve saturates. In saturation, the flow was a maximum and the position of the spool did not affect the flow rate. The torque-speed curves for

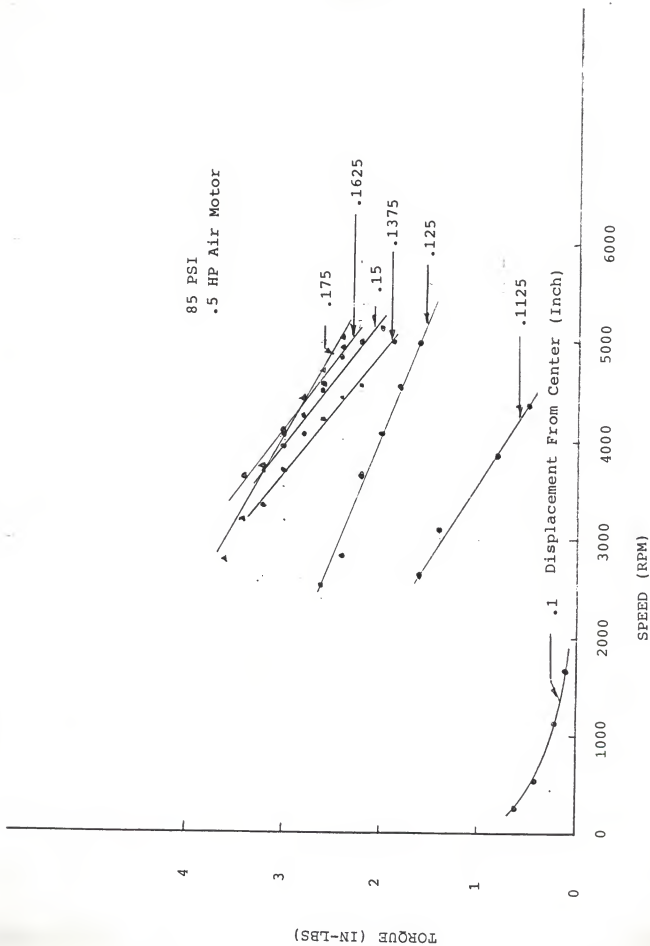


Figure 6 Original Air Motor Valve Torque-Speed Curves

the dynamometer test are shown in Figure 6. In summary as the spool was displaced from the centered position the flow went from a no flow condition, to bypass flow, to a small proportional region, and lastly to saturation.

Considering the information from the dynamometer test and the performance desired from the air motor valve several solutions were proposed. Of these proposals one was selected as a likely solution to the problem. The solution was to modify the existing valve to obtain the desired performance. This modification required a new spool, constructed such that the dead zone and the bypass region were eliminated and the proportional region was greater in width. In addition to the modification of the shape of the spool, the spool must be positioned by a smooth continuous motion rather than by the dithering process used in the original design. These changes should provide better control of the flow to the motor.

The performance found in the air motor valve was undesirable and a new spool was designed to decrease the dead zone, eliminate the bypass flow, increase the proportional region, and allow accurate positioning of the spool. The new valve had lands and cuts, this eliminated the bypass flow, and with more gradual, increased the region of proportional flow. The design of the lands determine the relationship between the position of the spool and the flow conditions of the valve. The lands of the new spool were designed such that the flow always drives the motor. With the modified design, the bypass flow was

eliminated. The old valve has the cuts nearly perpendicular to the spool axis. It was this perpendicular cut that causes the valve to have a small proportional range of air flow. As shown in Figure 8, the new valve has a gradual slope on the cut for the flow control segment of the spool. This gradual slope gives the spool a proportional relationship. Figure 9 shows the torque-speed relationships, from the dynamometer test, for the modified air motor valve. It should be noted that curves for the modified valve were generated at greater intervals than the unmodified valve. It can be observed that the proportional range for the valve has more than doubled and that the maximum output of the valve was not decreased by the new spool. It was observed that the bypass region of the valve was eliminated on the modified valve. The 0.05 inch dead zone was not eliminated from the valve due to the method of sealing the spool. The spool is sealed with O-rings. These O-rings have flexibility and a certain amount of stiction that make the design of a spool without dead zone nearly impossible. The dead zone will need to be compensated for in the control algorithm. These changes to the spool give the valve a greater proportional region and eliminate the bypass region. The remaining task in the valve design was the design of an accurate positioning device.

In Figures 7 and 8, illustrations of the modified valve are shown. As can be seen from the illustrations, the solenoids, pilot pressure hardware, and spool were removed from the valve body. The proposed method of actuation of the spool is by a

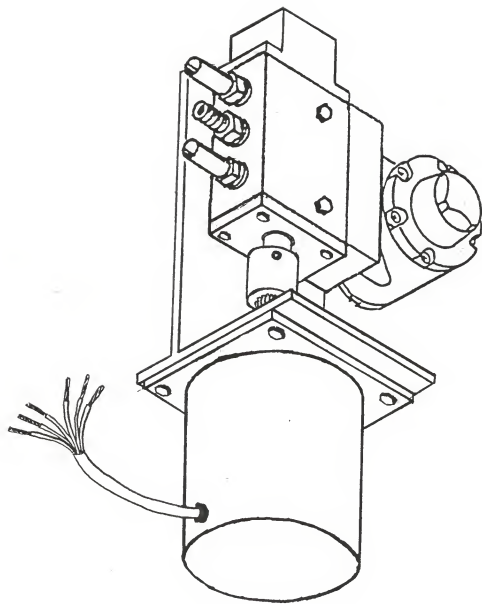


Figure 7 Illustration of Modified Air motor Valve

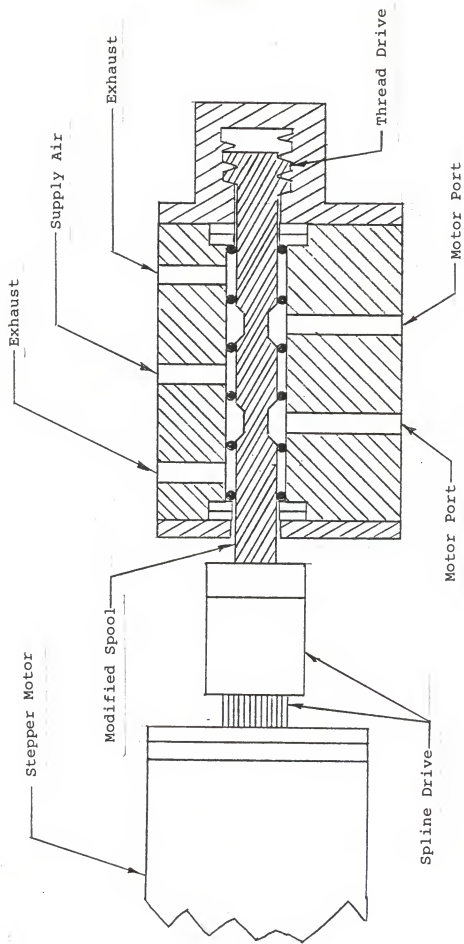


Figure 8 Modified Air Motor Valve

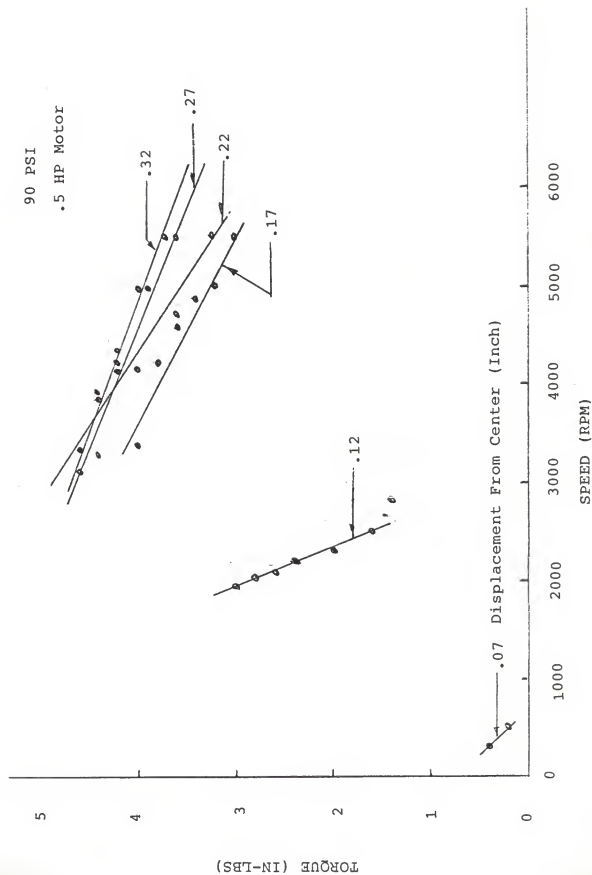


Figure 9 Modified Air Motor Valve Torque-Speed Curves

screw drive. The new spool extends from the valve body on both ends. On one end of the spool, a splined drive couples the spool and a stepper motor. This coupler allows the stepper motor to transmit torque to the spool yet the spool can translate. On the other end, the spool is threaded with a coarse thread (5 thread/inch). This threaded end is mated with a matched threaded piece, mounted to the valve body. With this arrangement, when the stepper motor is rotated, the spool is rotated, pushing or pulling the spool toward or away from the stepper motor depending on the direction of rotation. This allows the spool to be accurately positioned by the rotation of the stepper motor. With this positioning scheme the valve can be driven from full on in one direction to full on in the other direction a spool displacement of 0.5 inch is obtained by driving the stepper motor through 2.5 revolutions. The stepper motor can be driven at 200 Hz with 200 steps/rev in the full step mode. The valve can be turned from full on in one direction to full on in the opposite direction in a time of 2.5 sec. The system has a linear precision of .001 inch in full step mode and .0005 inch in the half step mode.

The second task is that of getting an accurate feedback of the arms position. As discussed in Chapter II, the optical encoder was coupled directly to the drive motor of the axis. Due to the chain drive system having elastic properties, the position of the arm was not proportional to the position of the motor. The position of the arm can be read by attaching an

additional encoder directly to the arm. The additional encoder would be attached to the arm through a traction drive reduction which has only one function, to drive the encoder. Since the traction reduction drives only the encoder it can be very accurate, eliminating the elastic properties that are found in the chain drive. By driving the encoder through a reduction ratio, rather than direct, the precision in the position feedback is retained. It was found the the torso of the IRI/M50 robot was well suited for this modification. The base of the robot extends through the body and at the intersection a large disc was mounted to the base. Then the encoder was mounted to the arm with the shaft of the encoder being driven by the disc. The disc functioned as a large drive and the shaft of the encoder as a small drive. These two working together form the reduction for driving the encoder. This traction reduction was not of sufficient magnitude to retain the necessary precision of the arm position using the same encoder. An encoder with 1500 etches/revolution was used for the arm feedback. By using this encoder rather than the original torso encoder of 100 etches/revolution the gearing ratio was effectively increasing by 15. With the more precise encoder and the traction reduction from the disc and shaft, the additional encoder has adequate precision for research of the elasticity of the joint. The additional encoder has a precision of 5194 counts/10 degrees as compared to the original encoder of 9038 counts/10 degrees.

During the modification of the IRI/M50 robot, bythe addition

of the encoder and the modified air motor valve, it became evident that the current control computer would not be adequate for the control requirements. The control computer, although being very powerful, was found to be difficult to work with. The control computer did not have a conventional operating system and support of a high level program language. Since the current system lacked an operating system and a high level language support any programming would have to be done in 68000 machine code or in an external development system. In addition, IRI was not willing to provide any information about the software currently being used by the robot. Since there was no information available about the software and the task of decoding the machine code was insurmountable, the only option for adding new control functions to the robot would be to take out the current software system and reprogram a control software. This was not a desirable option. A more attractive option was to control the torso of the the robot using a separate computer. Two computers were considered for this task, a 68000 educational board and the VME10. Each of these computers has advantages and disadvantages. The 68000 educational board is a simple computer easily expanded and interfaced but must be programmed in assembly language or in a development system. The VME10 is a powerful machine capable of supporting high level languages and interfacing through serial or parallel ports. The VME10 is more complex and requires greater knowledge of the VME10 operating system. The VME10 was

chosen for the project for several reasons.

The first reason was that the VME10 is a 68000 microprocessor based machine. Being a 68000 based machine the VME10 retains some compatability with the IRI/M50 control computer. The intent was that at some future date the VME10 and the IRI/M50 would communicate and support each other. The second advantage to the VME10, as mentioned before, is that the VME10 has FORTRAN 77 as a resident high level language. This allows the control algorithms to be written in a high level language, compiled and run in machine code. By using a machine that supports a high level compiler, the control algorithms are more easily written yet they run fast because the high level language is converted to machine code. Another advantage to the use of the VME10 is the support equipment available. The VME10 is supported by a printer, floppy disk, and hard disk. This support equipment is very desirable in program development. These features, the 68000 based machine, the high language compiler and the support equipment make the VME10 a good choice for a control computer for the IRI/M50.

The VME10 has a Dual Parallel Port (DPP) that was used as the interface to the robot. The DPP is a memory mapped device which is controlled, programmed, written to and read from at specific memory locations. The actual device used in the DPP is a Motorola 6821 Parallel Port. The DPP has 16 data lines available for use in the interface. Of the 16 data lines, 8 were designated as a data bus and the remaining 8 were

designated as control and address lines. With this arrangement the encoders and the stepper can be controlled from the VME10.

In this chapter solutions have been proposed to overcome the limitations of the robot described in Chapter I. The solutions involve the modification of the air control valve and the addition of an additional encoder. In the next chapter the implementations of the proposed solutions are described.

CHAPTER IV

RESEARCH IMPLEMENTATION AND EVALUATION

Discussed in this chapter are the methods of implementation of the proposed solutions from Chapter III.

The first modification to the robot was the installation of the additional optical encoder to feedback the position of the robot arm. The encoder was installed as proposed in Chapter III. An optical encoder with 1500 etches/revolutions was mounted in a fixture to the robot such that the shaft of the encoder was rotated by traction between the encoder shaft and a disc that was mounted to the base of the robot. The added encoder has a precision of 5194 counts/10 degrees as compared to 9038 counts/10 degrees for the motor encoder. This difference means less precision for the added encoder. Even with the lower precision the added encoder showed movement of the arm that was not shown by the motor encoder. To correctly control the robot arm it was required to know the relation between the the position given by the motor encoder and the position given by the added arm encoder. Both of these encoders were interfaced to the VME10 using the interface circuits shown in the Appendix.

These encoder interface circuits decode and count the quadrature outputs of the optical encoders. The output of the encoders are connected to the board through optical isolators. The quadrature signals from the encoders are processed by the

logic of the interface circuits to produce pulses which control an up/down counter. The logic circuit acts as a finite state machine which produces a pulse for each change of the state of the encoder. The up/down counter acts on the pulses from the finite state machine, which produces an up count pulse or a down count pulse depending on the phase and state change of the quadrature signal. There are 20 bits in the cascaded up/down counters. These 20 bits allow count values from -524288 to 524287. These values are larger than the number of expected counts from either of the torso encoders. These 20 bits are accessed as 3 bytes through addressable buffers that are latched when the interface is read by the computer. The interface boards are accessed by the control lines from the DDP designated as address lines and the data was transferred by the DDP lines designated as the data bus. The FORTRAN subroutine READEN reads the current count of the encoders and returns the values to the control algorithm. This subroutine READEN is found in the Appendix of this thesis. The modification was tested and performed as expected. When the subroutine READEN was called, it returned the current count of the arm encoder and the motor encoder.

In preparation for the valve modifications to the robot, several tasks had to be performed. The first of these tasks was establishing a base line for the performance of the robot. This base line documented how the robot performed prior to the valve modifications. The base line was established for each of four

conditions. These conditions were for various motor inertia loads due to the arm position and the load carried by the end effector. The four different positions are shown in the illustrations of Figure 10. The inertia varied from low to high. Position One, the low inertia position, was with the arm was folded up over the axis of rotation. Position Four, the high inertia position was with the arm was fully extended and a load in the end effector. The arm was moved back and forth through a 90 degree arc for each of the inertia positions. As the arm was moving the encoders were read 100 times per second for 20 seconds and the values stored in memory. These values were then plotted using the PLOT program available on the VAX computer and hardcopies were created with the use of the Tectronix 4114 terminal. These plots, the status of the robot at the time of the test, and the program that made the moves are in the Appendix of this thesis.

After the establishment of the base line for the current system the new valve was installed and interfaced to the control computer. The interface to drive the new valve is basically a stepper motor driver. The primary component of the interface is an integrated circuit Stepper Motor Controller (SAA 1042). The interface circuit is shown in the Appendix of this thesis. This interface circuit drives the stepper motor that controls the position of the spool of the motor control valve. The circuit has three control lines from the computer; step, CCW/CW, and full/half step. The stepper motor is controlled by the signal

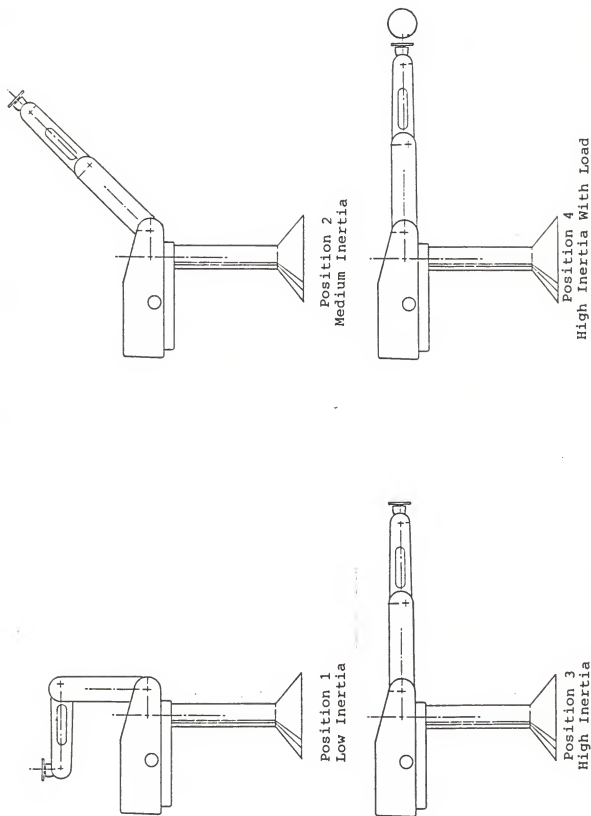


Figure 10 Robot Positions For Baseline Data

on the control lines. When the signal on the CCW/CW line is high the stepper motor will step counter clockwise, and when the signal is low the stepper motor will step clockwise. When the signal is high the stepper motor takes a full steps, and when the signal is low the stepper motor takes half steps. The last control line controls the motor steps. Every time this line is pulsed the stepper motor will step one step in accordance with the other control lines. The output signals from the Stepper Motor Controller are four signals with the proper sequencing to drive the four phases of a stepper motor. For the size of stepper motor used in this project, transistors are required to pass the operating current. These are driven directly by the Stepping Motor Controller. The control signals to drive the transistors could have been produced directly by the computer. The advantage to using the SAA1042 is that with the controller stepping the motor the processor is freed to perform other more important tasks such as the control algorithm. FORTRAN subroutines to drive the valve by the stepper motor were written and can be found in the Appendix of this thesis.

Several alterations were made to the system to allow the modified control valve to operate. The first of these modification was the plugging of the pilot pressures lines. Several of the pilot pressure lines associated with the torso axis had to be plugged. Two of the lines plugged were the brake lines. These pressure lines activate the brakes for the torso. The brakes are controlled by the robot control computer which

releases the brakes to allow movement of the axis. The robot control computer was replaced by the VME10 which the robot control computer has no knowledge of. If the brakes are not disconnected, when the VME10 commands the axis to move, the brakes remain activated. The easiest solution to this problem was to disconnect the pressure lines which activate the lines and plug the lines. Also the pilot pressure line that was used to dither the spool was removed from the system and the line plugged. One additional modification to the system was the opening of the pressure control valve. The robot control computer operates the pressure control valve and adjusts the pressure to the air motor valve dependent on the required movement. With the removal of control of the torso from the control computer, the control computer is ignorant of the desired move. The simple solution is to open the pressure control valve to allow a constant supply pressure to the air motor valve. The opening of the valve was accomplished by blocking the valve from returning to the centered position.

With these modifications made, the torso motor control valve could be operated from the VME10. Before the modified valve was operated, it was necessary to add an additional safety valve to the air supply line to the robot. The spool in the original air motor valve is centered by two springs. When the dither signal is present in the solenoids, the spool returns to the neutral position. In the neutral position the valve does not allow air flow and the arm remains stationary. In the event of a power

failure or when the emergency shut down switch is depressed the 24 volt power to the solenoid is removed and the system stops. Since the spool of the modified valve is activated by the stepping motor it does not return to center with the loss of power or an emergency shutdown. If the spool was in a position that allowed air flow to the motor the robot would continue to turn until the air supply line was twisted from the fixture. This action prompted the installation of a solenoid actuated normally closed valve in the air supply line. The power to the solenoid was taken from the robot. With this arrangement, the solenoid would close in the event of a robot power failure and there would be no air supply to the robot and, the robot would stop without damage.

After the installation of the safety valve, the modified air motor valve was tested. The valve was actuated, driving the robot arm. The valve was controlled from the VME10 computer. It was observed that movement could be controlled from the computer and that the movements were smooth and the speed increased gradually through the proportional range of the valve. The valve operation was only operated in an open loop system. A sample time timer would need to be installed in the VME10 computer to perform closed loop control tests. That is one of the recommendations for further work.

At this point the modifications were in place and functioning as anticipated. The encoders could be read and the valve could be operated by calling FORTRAN subroutines. With

only slight additional modifications the robot arm will be capable of supporting extensive control research. These suggested modifications will be discussed in the following chapter.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

In the preparation of the IRI/M50 robot for research use two hardware problems were identified, as stated in Chapter II. These two problems were the control of the air motor valves and inaccuracy in the feedback signal due to the elasticity of the chain drive. The hardware problems limit the controllability of the robot by adding nonlinear time dependent parameters to the system. In Chapter III solutions to these problems were proposed. The solution proposed to improve the control of the air motor valve was, the modification of the spool and the method of actuation of the spool. These modifications of the valve eliminated the undesirable bypass air flow and increased the proportional range of the valve. The proportional actuation of the spool was accomplished by rotating the spool in a screw drive with a stepper motor. The problem of the inaccuracy of the feedback signal was resolved by installing an additional encoder directly to the robot arm. The additional encoder provides a more accurate feedback of the position of the robot arm. The original encoder provides a feedback of the position of the motor. The difference in the signals from the encoders is due to the elasticity of the drive system. Both of the encoders and the stepper motor that drives the valve were interfaced to a control computer. The control computer chosen

for the research was the Motorola VME10, 68000 based, computer. The encoders and the stepper motor were interfaced to the computer by interface circuits which allow the computer to read the encoder counts and to control the stepping motor. FORTRAN subroutines to read the encoder counts and control the stepper motor were written and tested on the VME10.

There is one additional requirement to the system before it can operate as a feedback control system. This is the addition of a sample time timer to the VME10. In the digital control of a system it is required that each update or loop in the control algorithm occur at a specific intervals of time. The VME10 does not have an adequate clock for timing this process. This timer is necessary and therefore must be provided externally. This clock can be implemented without major modifications to the system.

The control line for the DDP of the VME10 could be tied to the output of a timer that gives a pulse periodically, at the sample time of the system. Internally the control line could be tied to the processor interrupt line. The system would be interrupted periodically by the external clock. The control algorithm would be written to recognize this interrupt as the sample time of the controller.

In addition to adding an external timer, more sophisticated circuitry to drive the stepper motor may be desirable. With the present system the control algorithm can only step the stepper motor one step at a time. If the speed of the control algorithm

is faster than the time it takes for the stepper motor to take one step, the present system will function without any problem. If the control algorithm takes a longer time than the time for the stepper motor to step one step, the speed of response of the air control valve will be reduced. This reduction in the response time will degrade the performance of the system. A controller consisting of two counters and a small amount of logic circuit would provide the needed additional capability. One counter would count the number of steps to be accomplished in the sample time and the other counter would provide the pulse rate required to complete the steps within the sample time. The logic circuitry would gate the pulses to the stepper motor controller and the step number counter until the required number of steps were accomplished. Both counters would be reset and loaded from the control computer.

With the addition of the sample time timer and the more sophisticated circuitry on the stepper motor interface the robot will be prepared for the Model Referenced Adaptive Control research for which it was acquired. That work is the subject of another researcher.

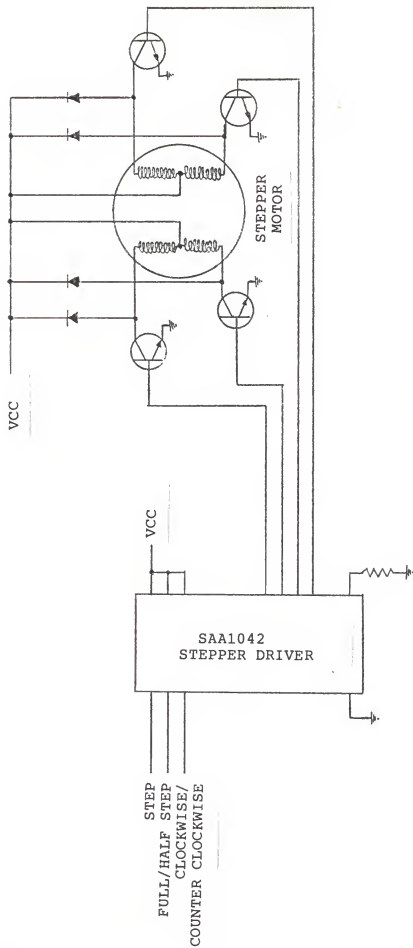
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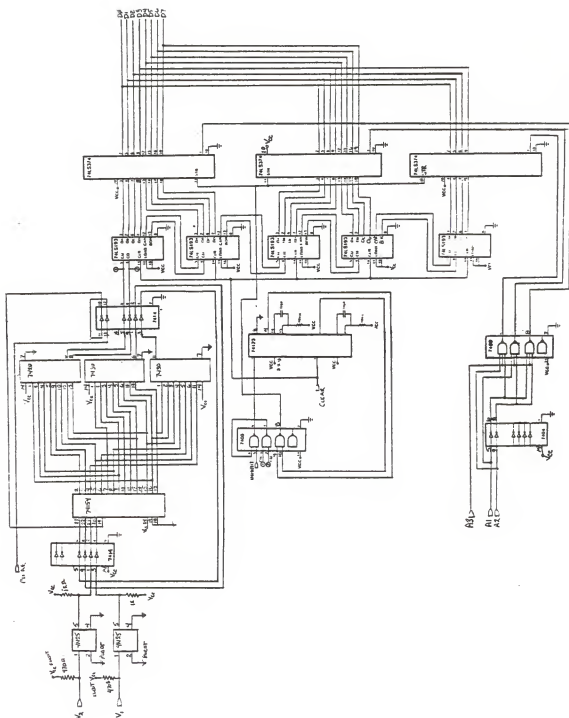
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APPENDIX



Stepper Motor Driver Schematic



Motor Encoder Interface Schematic

I/O PORT INITIALIZER SUBROUTINE

THIS PROGRAM IS CALLED FROM FORTRAN AND ALLOCATES THE I/O PORT
AREA FOR USE.

THE CALLING SEQUENCE IS:

CALL PINIT

* INTSUB	IDNT	1,1	I/O PORT ALLOCATOR
* PINIT	EQU	1702247264	PINIT IN RAD50
*	DC.L	PINIT	PROCEDURE NAME
	DC.L	0	NO DYNAMIC MEMORY
	DC.W	0	NO COMMON BLOCKS
	DC.W	0	NO VIRTUAL ARRAYS
	DC.W	0	NO ARGUMENTS
*	LEA.L	PAAPB(PC).A0	ALLOCATE I/O PORT ACCESS AREA
	MOVE.L	#1,D0	
	TRAP	#1	
*	RTS		
* PAAPB	DC.L	0	TASK
	DC.L	0	SESSION
	DC.W	%0010000100000000	OPTIONS
	DC.W	%0800	ATTRIBUTES
	DC.L	'PAA '	NAME
	DC.L	\$(F1C1E0	ADDRESS
	DC.L	%10	LENGTH

END

```

C*****
C
C   THIS PROGRAM SETS UP THE DATA DIRECTION REGISTERS ON THE PIA
C-----
C
C   SUBROUTINE SETUP
C
C   INTEGER CRA,DDRA,PDRA,CRB,DDRB,DDRB
C
C   CRA=15843818
C   DDRA=15843816
C   PDRA=DDRA
C   CRB=15843822
C   DDRB=15843820
C   PDRB=DDRB
C
C   CALL POKE(CRA,0)
C   CALL POKE(DDRA,65535)
C   CALL POKE(CRA,65535)
C
C   CALL POKE(CRB,0)
C   CALL POKE(DDRB,0)
C   CALL POKE(CRB,65535)
C
C   CALL POKE (PDRA,1)
C   CALL POKE (PDRA,0)
C
C   RETURN
C   END
C*****

```

```
C*****
C
C
C   THIS SUBROUTINE STEPS THE STEPPER MOTOR CLOCKWISE ONE STEP
C-----
C
C   SUBROUTINE STEP CW
C
C   INTEGER PDRA,PDRB
C   PDRA=15843816
C   PDRB=15843820
C
C   CALL POKE (PDRA,96)
C   CALL POKE (PDRB,0)
C
C   RETURN
C   END
C*****
```

```
C .....
C
C
C THIS SUBROUTINE STEPS THE STEPPER MOTOR COUNTER CLOCKWISE ONE STEP
C -----
C
C SUBROUTINE STEPCC
C
C   INTEGER PDRA,PDRB
C   PDRA=15843816
C   PDRB=15843820
C
C
C   CALL POKE (PDRA,64)
C   CALL POKE (PDRA,0)
C
C   RETURN
C   END
C .....
```

```

C .....
C
C
C THIS SUBROUTINE READ THE VALUES OF THE OPTICAL ENCODERS
C AND RETURNS THE VALUE TO THE MAIN PROGRAM
C
C THE PROGRAM IS CALLED BY
C CALL READEN (ARMEN,MOTOREN)
C
C WHERE ARMEN IS THE VALUE OF THE ENCODER ATTACHED TO THE
C ROBOT ARM. THE VALUE IS IN ENCODER UNITS
C
C AND MOTOREN IS THE VALUE OF THE ENCODER ATTACHED TO THE
C DRIVE MOTOR ON THE ROBOT ARM. THE VALUE IS IN ENCODER UNITS
C .....
C
C SUBROUTINE READEN (ARG1,ARG2)
C
C SET PIA REGISTER VALUES
C
C INTEGER PDRA,PDRB,ARG1,ARG2,LB,MB,HB
C
C PDRA=15843816
C PDRB=15843820
C
C READ LOW BYTE ARM ENCODER
C
C CALL POKE (PDRA,2)
C CALL PEEK (PDRB,LB)
C
C READ MED BYTE ARM ENCODER
C
C CALL POKE(PDRA,6)
C CALL PEEK(PDRB,MB)
C
C READ HIGH BYTE ARM ENCODER
C
C CALL POKE (PDRA,10)
C CALL PEEK (PDRB,HB)
C HB=HB-240
C
C SET RETURN VALUE
C
C ARG1=HB*65536+MB*256+LB
C IF (HB.GT.7) THEN
C ARG1=ARG1-1048576
C ENDIF
C
C READ LOW BYTE MOTOR ENCODER
C
C CALL POKE (PDRA,18)
C CALL PEEK(PDRB,LB)
C
C READ MED BYTE MOTOR ENCODER
C
C CALL POKE(PDRA,22)
C CALL PEEK(PDRB,MB)
C

```

```
C   READ HIGH BYTE MOTOR ENCODER
C
    CALL POKE(PDRA,26)
    CALL PEEK(PDRB,HB)
    HB=HB-240
C
C   ASSIGN RETURNED VALUE
C
    ARG2=HB*65536+MB*256+LB
    IF (HB.GT.7) THEN
    ARG2=ARG2-1048576
    ENDIF
C
    CALL POKE(PDRA,0)
C
    RETURN
    END
```

 *
 * FORTRAN POKE SUBROUTINE
 *

* THIS PROGRAM PROVIDES A POKING CAPABILITY FOR FORTRAN. THIS
 * ALLOWS FORTRAN TO MODIFY SPECIFIC MEMORY LOCATIONS. THE CALLING
 * SEQUENCE IS:

* CALL POKE (ADRS,VALUE)

* WHERE

* ADRS IS AN INTEGER*4 VARIABLE WHICH CONTAINS THE ADDRESS TO
 * BE MODIFIED.

* VALUE IS AN INTEGER*4 VARIABLE AND HOLDS THE VALUE TO BE
 * STORED AT ADRS.

* THIS SUBROUTINE WORKS WITH WHOLE WORDS ONLY !!

* THE MEMORY TO BE MODIFIED MUST HAVE BEEN PREVIOUSLY ALLOCATED
 * BY SOME OTHER ROUTINE.

POKESUB	IDNT	1,1	POKE SUBROUTINE FOR FORTRAN
POKE	EQU	1717772096	POKE IN RAD50
DC.L	POKE		PROCEDURE NAME
DC.L	0		NO DYNAMIC MEMORY REQUIRED
DC.W	0		NO COMMON BLOCKS NEEDED
DC.W	0		NO VIRTUAL ARRAYS
DC.W	2*4		TWO ARGUMENTS PASSED
MOVE.L	14(A7),A0		ADDRESS OF ADRS IN A0
MOVE.L	(A0),A1		ADRS IN A1
MOVE.L	10(A7),A0		ADDRESS OF VALUE IN A0
MOVE.W	2(A0),(A1)		DATA TO VALUE
RTS			
***** END			

 *
 * FORTRAN PEEK SUBROUTINE
 *

* THIS PROGRAM PROVIDES A PEEKING CAPABILITY FOR FORTRAN. THIS
 * ALLOWS FORTRAN TO READ SPECIFIC MEMORY LOCATIONS. THE CALLING
 * SEQUENCE IS:

* CALL PEEK (ADRS,VALUE)

* WHERE

* ADRS IS AN INTEGER*4 VARIABLE WHICH CONTAINS THE ADDRESS TO
 * BE READ.

* VALUE IS AN INTEGER*4 VARIABLE RETURNED FROM THE CALL.

* THIS SUBROUTINE WORKS WITH WHOLE WORDS ONLY !!

* THE MEMORY TO BE READ MUST HAVE BEEN PREVIOUSLY ALLOCATED
 * BY SOME OTHER ROUTINE.

PEEKSUB	IDNT	1,1	PEEK SUBROUTINE FOR FORTRAN
PEEK	EQU	1691174080	PEEK IN RAD50
	DC.L	PEEK	PROCEDURE NAME
	DC.L	0	NO DYNAMIC MEMORY REQUIRED
	DC.W	0	NO COMMON BLOCKS NEEDED
	DC.W	0	NO VIRTUAL ARRAYS
	DC.W	2*4	TWO ARGUMENTS PASSED
	MOVE.L	14(A7),A0	ADDRESS OF ADRS IN A0
	MOVE.L	(A0),A0	ADRS IN A0
	MOVE.L	10(A7),A6	ADDRESS OF VARIABLE IN A6
	CLR.L	(A6)	
	MOVE.L	(A0),D1	
	SWAP	D1	
	MOVE.B	D1,3(A6)	
	RTS		
	END		

SECTION 13-4.16 DATE 11 11 84 TIME 14 8 16

```

80 C VALVE TESTING ROUTINE
81 C FOR THIS ROUTINE TO RUN THE LIMITS HAVE TO BE EDITED
82 C THE SHOULDER LIMIT SHOULD BE CHANGED FROM 10000 TO 6938
83 C AND FROM 11500 TO 115000
84 SMOVER 26
85 C PT 1 MINIMUM INERTIA PLACEMENT OF ROBOT FOR TORSO MOVEMENT
86 LCNTR 1 2
87 35 MOVER 27
88 MOVER 26
89 DCNTR 1 35
90 MOVER 32
91 MOVER 28
92 C PT 2 MEDIUM INERTIA PLACEMENT OF ROBOT FOR TORSO MOVEMENT
93 LCNTR 2 2
94 36 MOVER 29
95 MOVER 28
96 DCNTR 2 36
97 MOVER 30
98 C &M63 MAXIMUM INERTIA PLACEMENT OF ROBOT FOR TORSO MOVEMENT
99 LCNTR 3 2
00 37 MOVER 31
01 MOVER 30
02 DCNTR 3 37
03 MOVER 1
04 C IF LESS CYCLES ARE NEEDED AT ANY POINT LOAD COUNTERS 1,2,3
05 C WITH 1 TO GET 2 CYCLES OR WITH 3 TO GET 6 CYCLES.
06 C EACH PT 1,2,3 HAS ITS OWN COUNTER 1,2,3 RESPECTIVELY.
07 STOP

```

SECTION 13-4.16 DATE 11 11 84 TIME 15 12 31

```

PEAKPOINT: 199
NOT IN ONE-STEP MODE
CURRENT LINE: 0
DEBUG OFF
MOVES ENABLED
SPEED MODIFIER: 100
RIPPERS: B OPEN A CLOSED
EIGHT: 40

```

XES:	TORSO	SHOULDER	ELBOW	PITCH	ROLL
ALIBRATED:	1	1	1	1	1
NABLED:	1	1	1	1	1
URRENT POSITION:	802	16596	10081	34345	27565
LEAFANCE:	0	0	0	0	0
PEED:	100	100	100	100	100
RESSURE:	68	69	82	59	71

LOCATION = 13-4.16 DATE 11 11 84 TIME 14 15 47

BREAKPOINT: 198
 NOT IN ONE-STEP MODE
 CURRENT LINE: 208
 DEBUG OFF
 MOVES ENABLED
 SPEED MODIFIER: 100
 GRIPPERS: B OPEN A CLOSED
 WEIGHT: 10

AXES:	TORSO	SHOULDER	ELBOW	PITCH	ROLL
CALIBRATED:	1	1	1	1	1
ENABLED:	1	1	1	1	1
CURRENT POSITION:	839	47545	10694	34365	27576
TOLERANCE:	0	0	0	0	0
SPEED:	100	100	100	100	100
PRESSURE:	68	78	70	70	79

COMMANDS: (G)O, (SPACE), (CONT)INUE, (E)DIT, (D)ATA, (S)TATUS OR (H)ELP
 E

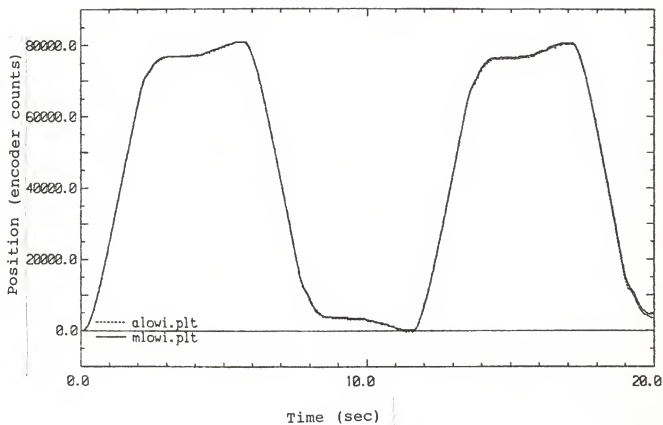
EDIT APPLICATION: (R)CL, (P)OINTS, (L)IMITS OR (CLEAR)? P

POINTS: (L)IST, (A)DD, (M)ODIFY, (D)ELETE, (R)EAD, (C)OPY, (Z)ERO OR (H)ELP? L 25 99
 SW VERSION 4.13-4.16 DATE 11 11 84 TIME 14 8 16

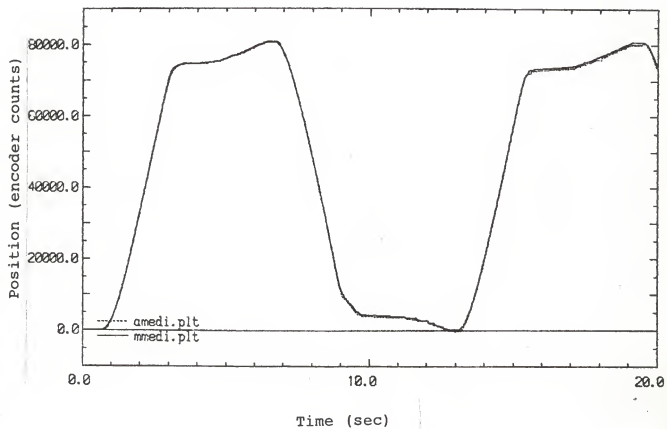
POINT TABLE LIST

	TORSO	SHOULDER	ELBOW	PITCH	ROLL
POINT #25	-151600	42419	15849	47523	7096
POINT #26	80311	6938	4964	65226	-1474
POINT #27	162674	6938	4964	65226	-1474
POINT #28	80216	31873	44241	33659	24711
POINT #29	162674	31873	44241	33659	24711
POINT #30	80311	60239	44667	33618	-1474
POINT #31	162674	60239	44667	33618	-1474
POINT #32	84716	40958	5554	64522	-719
POINT #50	0	16000	10200	33527	28387
POINT #51	0	46717	10848	33527	28387
POINT #52	0	62440	57091	0	0

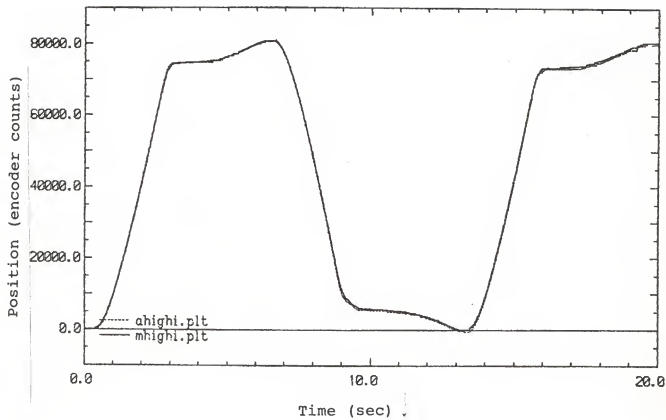
Base Line Data - Position 1



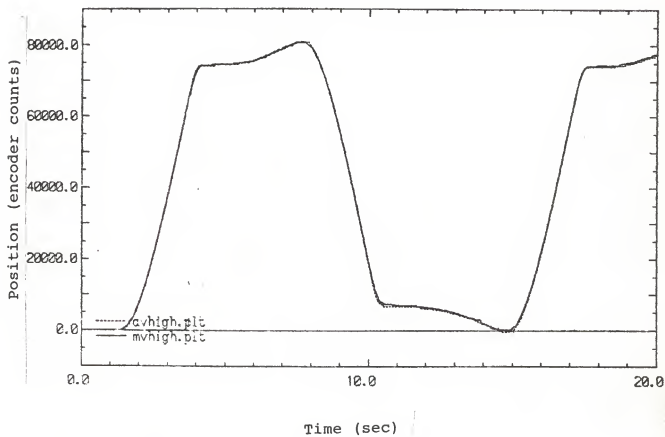
Base Line Data - Position 2



Base Line Data - Position 3



Base Line Data - Position 4



INSTRUMENTATION AND
MODIFICATION OF THE IRI/M50
ROBOT FOR AUTOMATIC CONTROL RESEARCH

by

GREGORY L. SPAULDING
B.S., Kansas State University, 1980

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

MASTER OF SCIENCE

Department of Mechanical Engineering

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1985

ABSTRACT

In the preparation of the IRI/M50 robot for research use two hardware problems were identified. These two problems were the control of the air motor valves and inaccuracy in the feedback signal due to the elasticity of the chain drive. The hardware problems limit the controllability of the robot by adding nonlinear time dependent parameters to the system. Solutions to these problems were proposed. The solutions proposed to improve the control of the air motor valve was the modification of the spool and the method of actuation of the spool. These modifications of the valve eliminated the undesirable bypass air flow and increased the proportional range of the valve. The proportional actuation of the spool was accomplished by rotating the spool in a screw drive with a stepper motor. The problem of the inaccuracy of the feedback signal was resolved by installing an additional encoder directly to the robot arm. The additional encoder provides a more accurate feedback of the position of the robot arm. The original encoder provides a feedback of the position of the motor. The difference in the signal from the encoders is due to the elasticity of the drive system. Both of the encoders and the stepper motor that drives the valve were interfaces to a control computer. The control computer chosen for the research was the Motorola VME10, 68000 based, computer. The encoders and the stepper motor were interfaced to the computer by interface circuits which allow the computer to read