1991

Design of a High-Speed Automation System for Welding Posts and Findings

Todd Archer
University of Rhode Island

DESIGN OF A HIGH-SPEED AUTOMATION SYSTEM

FOR WELDING POSTS ON FINDINGS

BY

TODD ARCHER

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENT FOR THE DEGREE OF

MASTER OF SCIENCE

IN

MECHANICAL ENGINEERING

AND APPLIED MECHANICS

UNIVERSITY OF RHODE ISLAND

1991

MASTER OF SCIENCE THESIS

OF

TODD ARCHER

APPROVED:

Thesis Committee

Major Professor ______________________

____

____

____

DEAN OF THE GRADUATE SCHOOL

UNIVERSITY OF RHODE ISLAND

1991

ABSTRACT

Foreign competition has created a demand within the United States to produce goods in a cost effective manner. This project addresses the problem by automating the process of earring manufacture. A working prototype is developed and tested.

Fixed automation has been selected over flexible automation since it is better suited to the given task. A parts feeding system has been designed and developed by another graduate student. This system is integrated with a welding machine that has been modified for high-speed use. Tests are conducted to determine important parameters in the welding process.

In order to coordinate system operations and monitor events, mechanical components and electrical circuitry are created. These elements are connected to a personal computer, where the events are monitored and controlled. A software program has been written to allow the machine operator to control the system automatically or manually.

ACKNOWLEDGEMENT

I would like to thank Prof. Philip Datseris for the guidance and support that he has given to me over the course of my studies and thesis preparation. His extensive knowledge of mechanism design has never failed to impress me. It has been a pleasure to work with him for these past two years.

I would also like to acknowledge Mr. James Byrnes for the technical expertise he has provided during the course of this project. His assistance has been greatly appreciated by all the members of the Robotics Research Center.

Special thanks go out to Mr. Robert Ansay, Mr. Steven Dawley, and Mr. James Peckham from the Engineering Instrument Shop at URI. Their dedication and expertise were only exceeded by their generosity. They were indispensable to this project.

And finally, I would like to thank Dr. Biwu Yang, Mr. Narayan Srinivasa, Mr. Anantha "Manny" Subrimani, and Mr. Hemant Kurande. Their friendship made my experience here at URI a most enjoyable experience.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

This project began in response to one company's search to become more competitive in the global marketplace. The company, Dama Incorporated, is a jewelry manufacturer located in Johnston, Rhode Island. Dama is presently involved in the production of earrings by producing earring blanks for other businesses. These companies would then create the finished earring by having their workers manually weld earring posts onto the earring blanks. This step in the production of earrings is a time consuming manual process. For a small production shop, such as Dama, with limited space and resources, this step in the process is not economically feasible as it is currently being performed.

Automation of this process will make earring production viable for Dama and competetive in a world market. Dama Inc., and Prof. Datseris with funding from the Rhode Island Partnership for Science and Technology, began investigating automated earring manufacture in 1986.

1.2 PROBLEM DESCRIPTION

The problem addressed in the project requires that earring posts will be automatically welded to earring blanks. The earring blank designs will be formed on a metal strip. This strip will be fed into a welding station that will weld a stainless steel post onto an earring blank on the strip. After the welding process, the final product will be stamped out of the strip. The earring post is shown in Figure 1.

The proposal submitted to the partnership indicated that a rate of 3600 welds per minute would be achieved by the system. The system would consist of nine separate welding stations, each capable of 400 welds per minute. Later, an agreement between the partnership and Dama reduced the number of welding stations to three, decreasing the total system output to 1200 welds per minute.

1.3 PREVIOUS WORK

Automation within the jewelry industry has usually been limited to the large volume production of simple pieces, such as earring blanks. However with all the advantages that automation has to offer such as increased productivity, uniform quality, and competitive pricing of products [1,2], automation is slowly migrating to assembly procedures. One example of an automatic assembly system currently in use in the jewelry industry was developed at the University of Rhode Island [3]. This flexible automation system consists of robotic manipulators which not only cut a

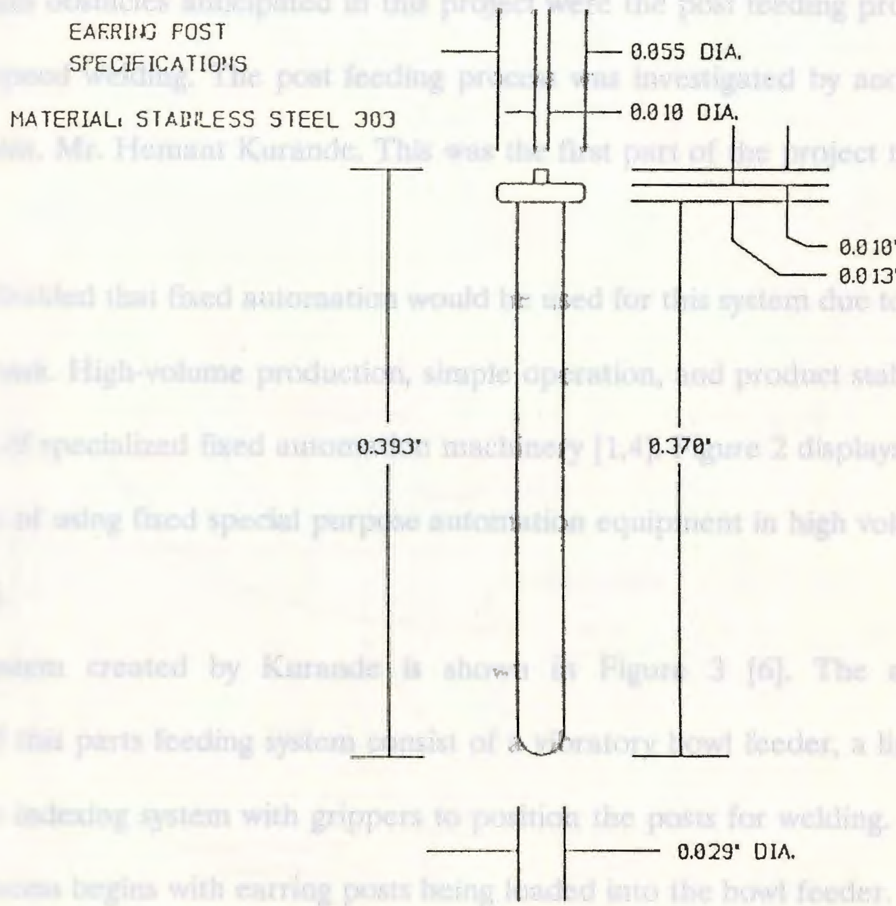


Figure 1 Earring Post Shape and Dimensions

chain to a specified length, but also attach the clasps to each end of the chain and complete the task by joining the clasps to close the chain loop.

The main obstacles anticipated in this project were the post feeding process and the high-speed welding. The post feeding process was investigated by another graduate student, Mr. Hemant Kurande. This was the first part of the project to be undertaken.

It was decided that fixed automation would be used for this system due to the nature of the task. High-volume production, simple operation, and product stability justify the use of specialized fixed automation machinery [1,4]. Figure 2 displays the cost advantage of using fixed special purpose automation equipment in high volume production [5].

The system created by Kurande is shown in Figure 3 [6]. The main components of this parts feeding system consist of a vibratory bowl feeder, a linear feeder, and an indexing system with grippers to position the posts for welding.

The process begins with earring posts being loaded into the bowl feeder. The bowl feeder transfers the posts to the linear feeder. The linear feeder then conveys the posts to a wheel that has cammed slots that accept the posts. The posts travel with the wheel's rotation until they are picked up by two opposing fingers which tightly grasp the post and lift it from the wheel. The post is pressed up against the bottom of the metal strip travelling above the wheel. At this point the post is welded to the metal strip.

The motions of the two fingers are controlled by two separate cams. One of

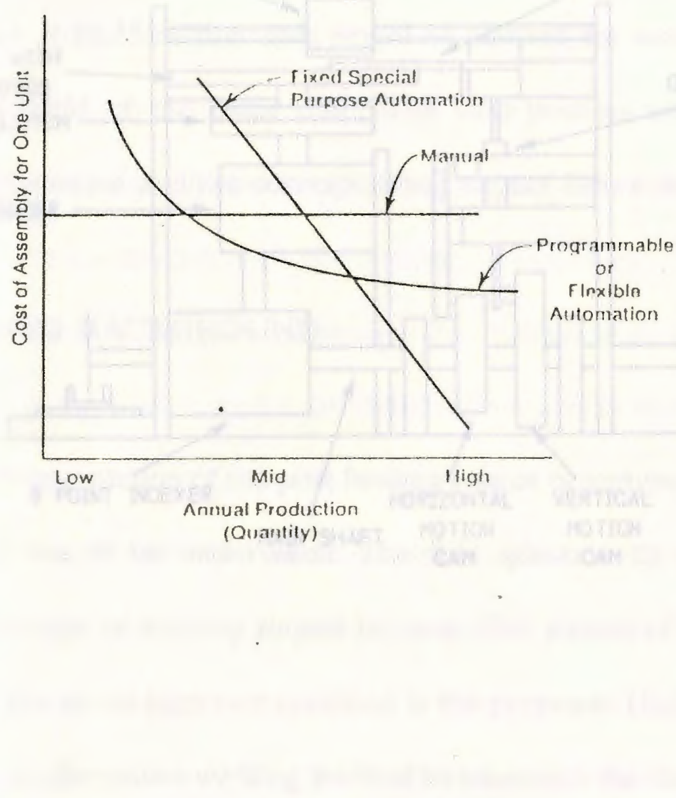


Figure 2 Assembly Cost Chart

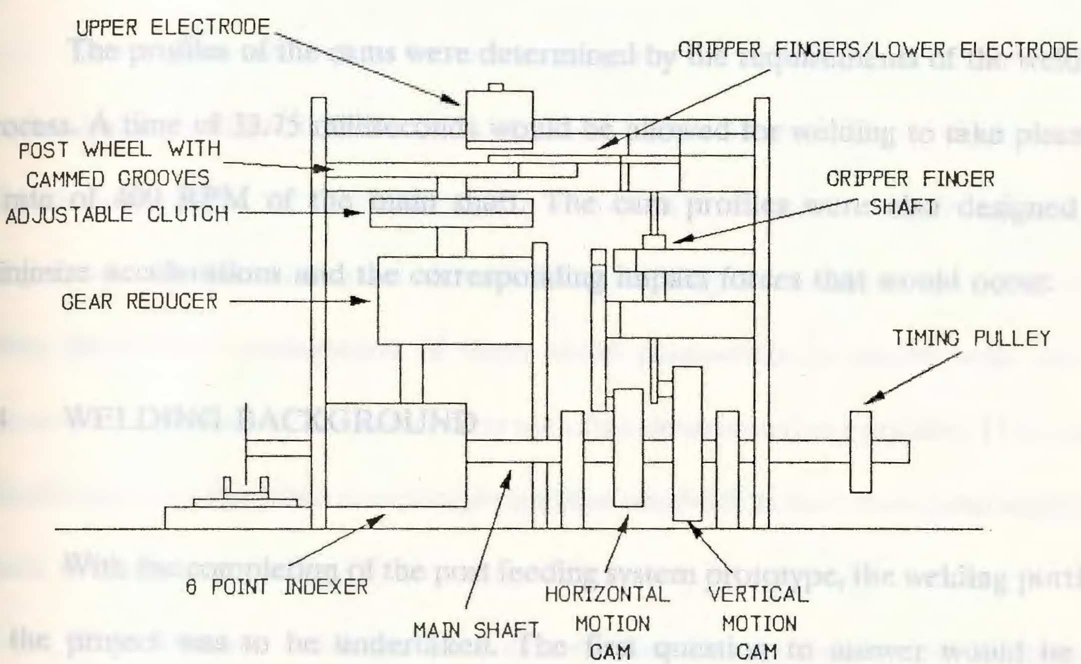


Figure 3 Machine Design by Kurande

the cams controls the vertical motion of the grippers and the other controls the opening and closing of the fingers. These cams ride on the same shaft that also controls the motion of the wheel. This shaft is coupled to a six-point indexer unit, which provides the necessary intermittent motion. The indexer in turn is connected to a 16:1 ratio gear reducer. This combination will produce 3.75 degree intermittent rotation for the wheel.

The profiles of the cams were determined by the requirements of the welding process. A time of 33.75 milliseconds would be allowed for welding to take place at a rate of 400 RPM of the main shaft. The cam profiles were also designed to minimize accelerations and the corresponding impact forces that would occur.

1.4 WELDING BACKGROUND

With the completion of the post feeding system prototype, the welding portion of the project was to be undertaken. The first question to answer would be to determine what type of welding should be used. The nature of this project requires rapid welding due to the high rate specified in the proposal. High-volume production requires a low maintenance welding method to minimize the duration of equipment down time. Also the quality of the welds would have to be consistent.

Several types of welding techniques were investigated, but only resistance welding met all the requirements. Resistance welding offers the advantages of being low cost, uses no consumables (solder or flux), requires little energy, is capable of high-speed operation, and produces consistent quality welds [7]. Tweedale [7] cites that resistance welding is ideal for incorporation in high-volume automation production.

1.5 RESISTANCE WELDING

Resistance welding is defined as a group of welding processes in which coalescence is produced by the heat obtained from resistance of the workpieces to electric current in a circuit of which the workpieces are a part and by the application of pressure [8]. The parameters in resistance welding are heat, pressure, and time. With the correct combination of these three parameters, a quality weld can be achieved. The values of the parameters are often determined empirically. The reason for this is due to the often complex geometries involved, power losses, and relatively quick and low cost testing [9].

The resistance welding process occurs when two workpieces, each connected to an electrode, are forced into contact. Although it may appear that the workpiece surfaces are in complete contact, at the molecular level they are not. The workpiece surfaces are actually quite rough at this level. The opposing workpiece surface peaks make initial contact with each other. The current that flows through the workpieces must travel from relatively wide channels to narrow ones. The current flowing through these narrow channels will cause these channel bridges to melt according to the following equation [10]:

$$M = \frac{I^2 Rt}{S.H. \cdot \Delta T}$$

where

M => the mass of the material

I => the electrical current

R => the resistance of the material

t => the time that current is applied to the material

S.H. => the specific heat of the material

DT => the temperature change

This process continues until current flow is no longer sufficient to create the required heat to melt the material. The welded joint now formed will rapidly cool and strengthen. Electrode force is maintained during this period to ensure a strong bond between the workpieces.

The greatest amount of heat will be generated at the location of the largest amount of resistance in the circuit loop. This is important to consider since there are several parts in the loop where this can occur. These points are:

1) wire to upper electrode
2) upper electrode to workpiece

3) workpiece to workpiece

4) workpiece to lower electrode

5) lower electrode to wire

The largest resistance must occur between the workpieces. If the other resistance points in the loop are only slightly less than the workpiece to workpiece resistance, most of the power will be lost, which will require more energy input and thereby decrease the energy efficiency of the system. Figure 4 displays the locations of possible heat generation for this application.

It is important that the surfaces of the workpieces be relatively free of any film or debris which would inhibit the flow of current. This occurs often in industrial applications, and workpieces may be coated to prevent rust or scaling.

1.6 TYPES OF RESISTANCE WELDING

Resistance welding can be divided into seven methods: flash welding, high-frequency resistance welding, percussion welding, projection welding, resistance seam welding, resistance spot welding, and upset welding.

Resistance spot welding is the method of joining two workpieces by a combination of heat, produced by the resistance to electric current by the workpiece material, pressure, applied by the electrodes during the heating process, and time. The size and shape of the weld will be determined by the geometry of the electrodes.

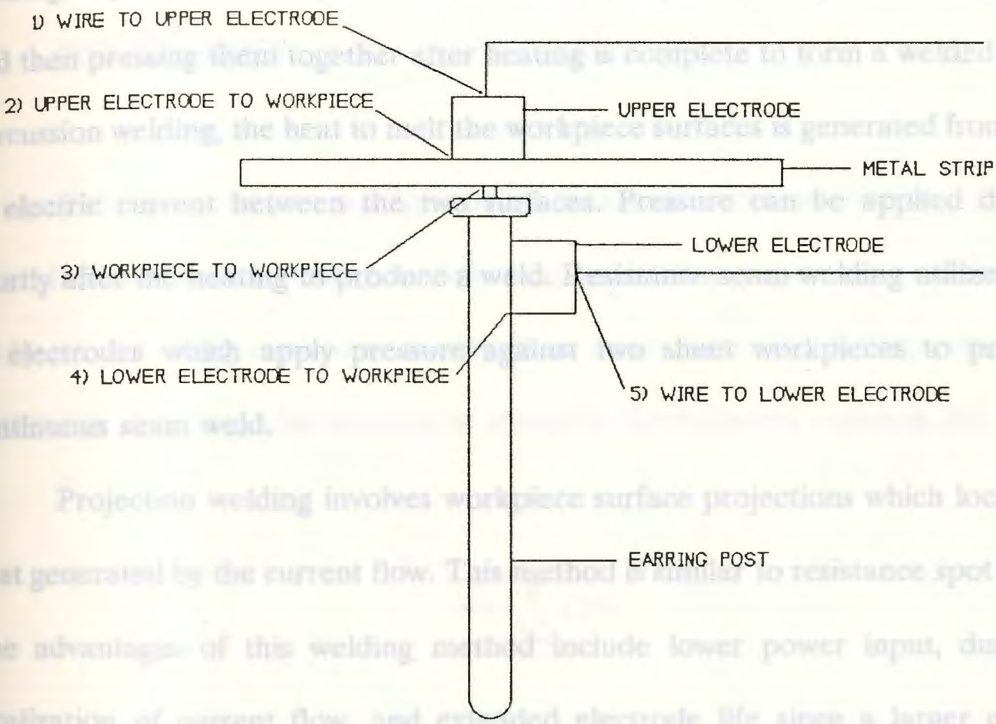


Figure 4 Assembly of Earring Post, Metal Strip, and Welding Attachments

Flash welding is the process in which two workpieces are heated by electric current. After heating is completed, the workpieces are then forced together to produce a bond. Upset welding is similar to the flash welding process, except that pressure is applied before and during the duration of current flow. High-frequency resistance welding requires the workpieces to be heated by high-frequency alternating current, and then pressing them together after heating is complete to form a welded joint. In percussion welding, the heat to melt the workpiece surfaces is generated from the arc of electric current between the two surfaces. Pressure can be applied during or shortly after the heating to produce a weld. Resistance seam welding utilizes wheels as electrodes which apply pressure against two sheet workpieces to produce a continuous seam weld.

Projection welding involves workpiece surface projections which localize the heat generated by the current flow. This method is similar to resistance spot welding. The advantages of this welding method include lower power input, due to the localization of current flow, and extended electrode life since a larger electrode contact surface is often used. This method of welding is used in this project. The nib on the head of the earring post will focus the current flow through this projection.

The types of bonds that can be obtained by resistance welding are the braze/soldered weld, the forge weld, the diffusion weld, and the fusion weld. The braze/soldered weld utilizes an intermediate material which bonds to both workpieces. The forge weld is obtained by using a very short weld pulse, which forges the workpieces together. In the diffusion weld, the workpiece surface is heated to the plastic range causing the workpiece materials to mix together. In the fusion weld, melting of material does occur and a weld nugget is formed by subsequent cooling. This bond is ideal for joining similar materials [11]. Fusion bonding is used in this project.

1.7 WELDABILITY

The ability to join workpieces by means of resistance welding is directly related to the material being used for the workpieces. Some materials are more easily welded using resistance heating than other materials. A calculation of the weldability of a particular material is shown in the following equation [8]:

$$W=\frac{R}{FKt}x100$$

where:

W	=>	the weldability factor
R	=>	the material resistivity
F	=>	the melting point of the material
Kt	=>	the relative thermal conductivity (copper = 1.00)

Cary [8] cites the following weldability factor categories:

$W <= 0.25 \;=>$ POOR

$0.25 < W <= 0.75 \;=>$ FAIR

$0.75 < W <= 2.00 \;=>$ GOOD

$W > 2.00 \;=>$ EXCELLENT

Stainless steel, which has a weldability factor of 1.33, will make a good workpiece for resistance welding, while brass, which has a weldability factor of 0.026, will make a poor workpiece.

CHAPTER 2

IMPLEMENTATION OF RESISTANCE WELDING

2.1 ELECTRODE DESIGN

The electrode design is an important consideration for the production of quality resistance welds. The material and design selection of the electrodes is critical in achieving a good weld with the least amount of power input.

The design of the electrodes has been determined to a great extent by the requirements of the system. Two opposing fingers are used to position the post, as shown in Figure 5. It was deemed logical that one of the fingers should become an electrode for the earring post. From early discussions, it was decided that the moving finger would be set as the electrode. It was also decided that the fixed finger would be electrically insulated from the post. The reason for this decision was to use steel as the material for the fixed finger to provide strong support and durability. Steel is not an efficient conductor of electricity, so the consensus was to isolate it from the current flow. A small piece of non-conductive material would be fastened at the portion of the finger gripping the post. During testing, it became evident that the

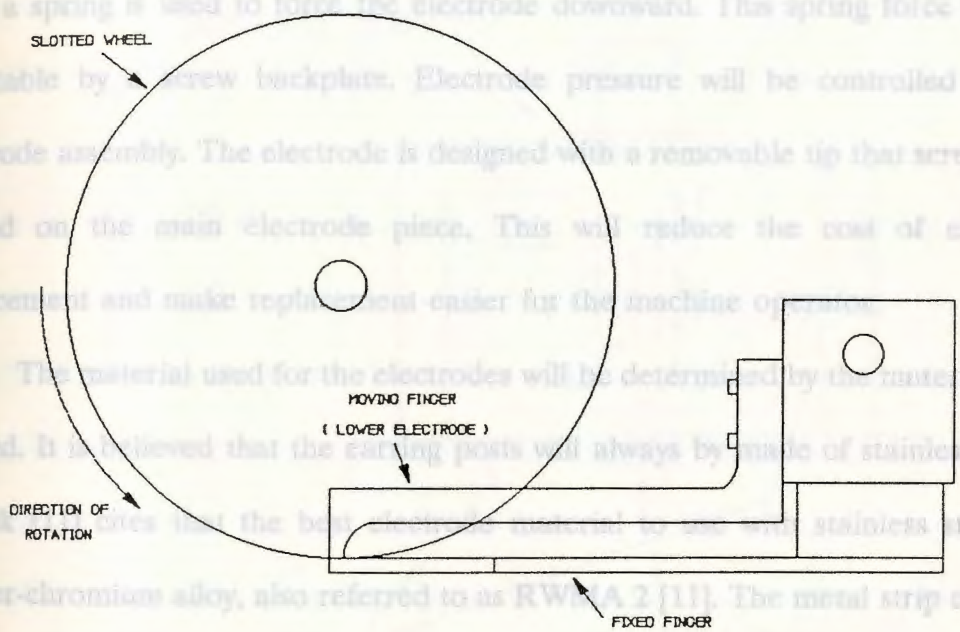


Figure 5 Lower Electrode Assembly

non-conductive materials used would not last long in operation. The insulation idea was abandoned and the steel finger would contact the post for durability considerations.

The design of the electrode contacting the metal strip was a straightforward solution. The electrode was housed in the support bracket for the strip guide rails, as shown in Figure 6. To make certain that the electrode maintains contact with the strip, a spring is used to force the electrode downward. This spring force is made adjustable by a screw backplate. Electrode pressure will be controlled by this electrode assembly. The electrode is designed with a removable tip that screws onto a stud on the main electrode piece. This will reduce the cost of electrode replacement and make replacement easier for the machine operator.

The material used for the electrodes will be determined by the material to be welded. It is believed that the earring posts will always by made of stainless steel. Unitek [11] cites that the best electrode material to use with stainless steel is a copper-chromium alloy, also referred to as RWMA 2 [11]. The metal strip currently being used is also made out of stainless steel, so the upper electrode will also use the same material.

Another consideration in the design of the electrodes is the pole placement. The direction of the flow of current will have an effect on the quality of the weld. Sosoka [12] found that polarity has a profound effect on the weld strength of dissimilar materials, varying by as much as a ratio of 2 to 1. A good rule of thumb is to place the negative electrode against the thinner or more resistive material [11].

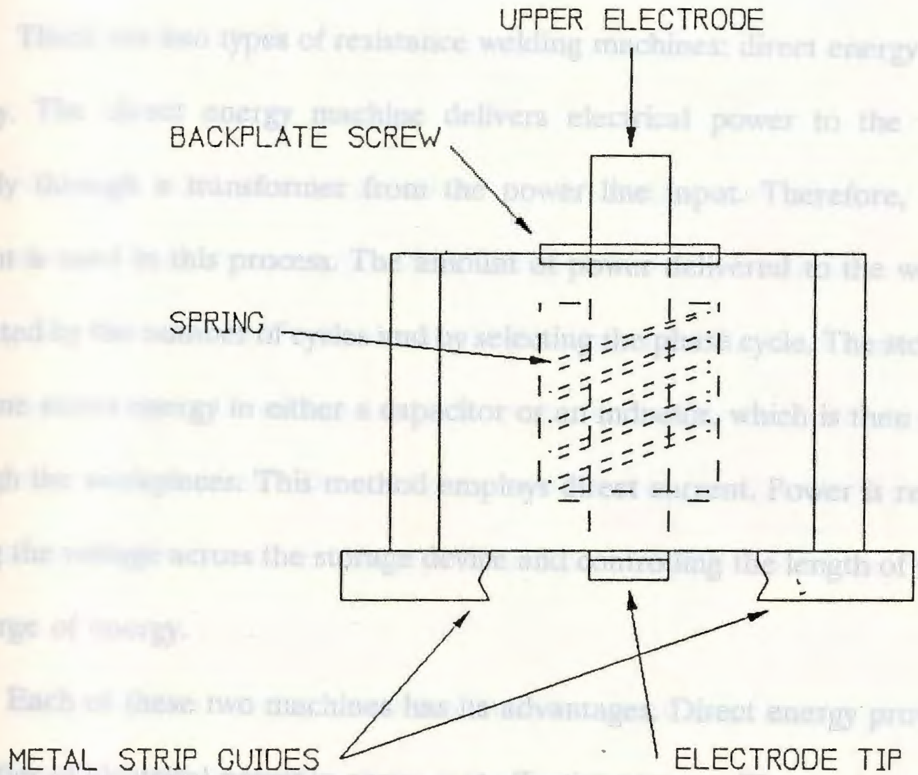


Figure 6 Upper Electrode Assembly

The upper electrode in this design was designated as the negative electrode, since the metal strip is thinner than the projection and head of the post.

2.2 TYPES OF RESISTANCE WELDING MACHINES

There are two types of resistance welding machines: direct energy and stored energy. The direct energy machine delivers electrical power to the workpieces directly through a transformer from the power line input. Therefore, alternating current is used in this process. The amount of power delivered to the workpiece is regulated by the number of cycles and by selecting the phase cycle. The stored energy machine stores energy in either a capacitor or an inductor, which is then discharged through the workpieces. This method employs direct current. Power is regulated by setting the voltage across the storage device and controlling the length of time of the discharge of energy.

Each of these two machines has its advantages. Direct energy provides large quantities of electrical power in a very cost effective manner. The method also allows practical rates of about five welds per second [11]. Stored energy devices are independent of power line fluctuations, capable of fast welding times, and produce welds of consistent quality [10]. Stored energy draws less power since energy is stored between welds. The short discharge times will also help prevent oxidation, deformation, and discoloration. Welding rates of greater than five welds per second are achievable with the stored energy machine [11].

Both machines also have disadvantages. The direct energy method requires the power line input to be well-regulated in order to provide consistent weld quality. The stored energy method usually requires a more complicated circuit design and is typically more expensive.

2.3 WELDING TESTS

Welding tests were undertaken to determine the values of the weld parameters pertinent to our application. These tests were performed on a resistance welding machine supplied by Aelectronic Bonding, Inc. The tests were performed manually, varying both voltage and electrode force. The weld duration was not adjustable on this machine. The weld pulse was set at approximately 35 milliseconds. The storage device used in this machine was a 15,000 microfarad electrolytic capacitor.

Stainless steel earring posts and stainless steel strip having a thickness of approximately 20 thousandths of an inch were used in these experiments. These workpieces would be representative of the materials used in actual production.

The voltage was varied within a range of 25 to 60 volts, incrementing at five volt intervals. At each voltage, the pressure exerted by the electrode was varied between 20 to 80 PSI, also incrementing at 5 PSI intervals. Several welds were made at each setting to average the results. Figure 7 displays the results of these tests.

The quality of the welded joints was determined by the strength of the joint

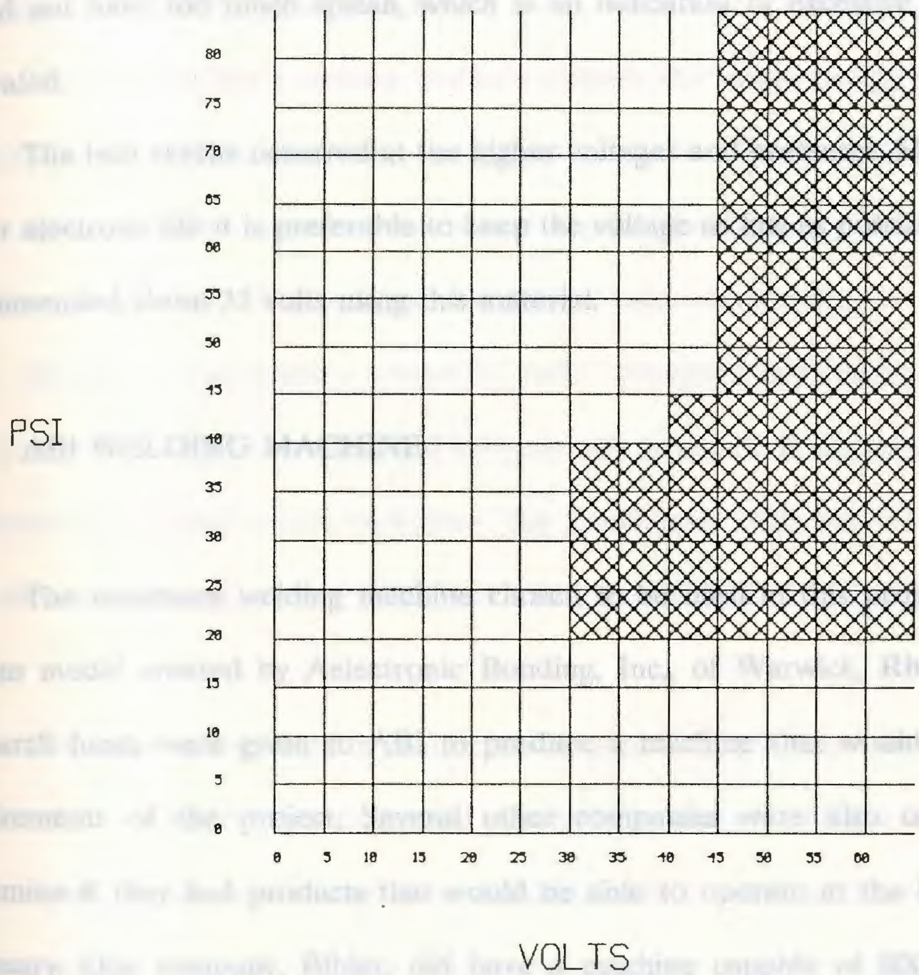


Figure 7 Welding Test Results

Shaded Area Indicates Acceptable Welding and its appearance. For strength, the post was required to maintain a strong bond with the metal strip after having been bent from one side to another. For appearance, the welded joint area should not be excessively discolored or burned and should not have too much splash, which is an indication of excessive heat being generated.

The best results occurred at the higher voltages and pressures. However, for longer electrode life it is preferable to keep the voltage as low as possible. ABI has recommended about 35 volts using this material.

2.4 ABI WELDING MACHINE

The resistance welding machine chosen to be used in this project was the custom model created by Aelectronic Bonding, Inc., of Warwick, Rhode Island. Research funds were given to ABI to produce a machine that would satisfy the requirements of the project. Several other companies were also contacted to determine if they had products that would be able to operate at the high speeds necessary. One company, Bihler, did have a machine capable of 800 welds per minute, which is twice the rate needed in this project. However, the quoted price of the machine was roughly 75,000 dollars. This amount of money was judged to be excessive. Another company, Unitek, did have a machine that could run at 550 welds per minute. The cost of this machine was only about 4 thousand dollars. However, the company was located in California. Modifications that would have to be made to the machine could have proven difficult due to this factor. Therefore, it was decided to go ahead with the machine from ABI. The custom designed model was claimed to be able to operate at four to six welds per second and the cost of the machine was only two thousand dollars.

The ABI resistance welding machine employs the stored energy method and uses an electrolytic capacitor as the energy storage device. The circuit can be broken down into several sub-systems: the power supply, the trigger pulse circuit, the resistor-capacitor control circuit, and the resistor-capacitor circuit.

The power supply unit is a basic AC to DC converter that consists of a heavy-duty transformer, bridge rectifier, and high-capacity capacitor. A six amp fuse is used to protect against excessive current draw. The transformer splits the AC line voltage into three sets of voltages: 162 VAC, 145 VAC, and 30 VAC. Figure 8 displays this circuit.

The trigger pulse circuit is located on the printed circuit board in the machine. The function of this circuit is to provide a noise-free pulse of specified duration that will be used by the resistor-capacitor control circuit to control the weld. A hand switch is connected to the circuit to allow an operator to manually trigger the pulse. This circuit is shown in Figure 9.

The resistor-capacitor control circuit is located on the same printed circuit board as the pulse timing circuit. The function of this circuit is to trigger the silicon-controller rectifier (SCR) to allow the electrolytic capacitor to discharge across the workpieces. The circuit also controls the re-charging of the capacitor. In addition, the

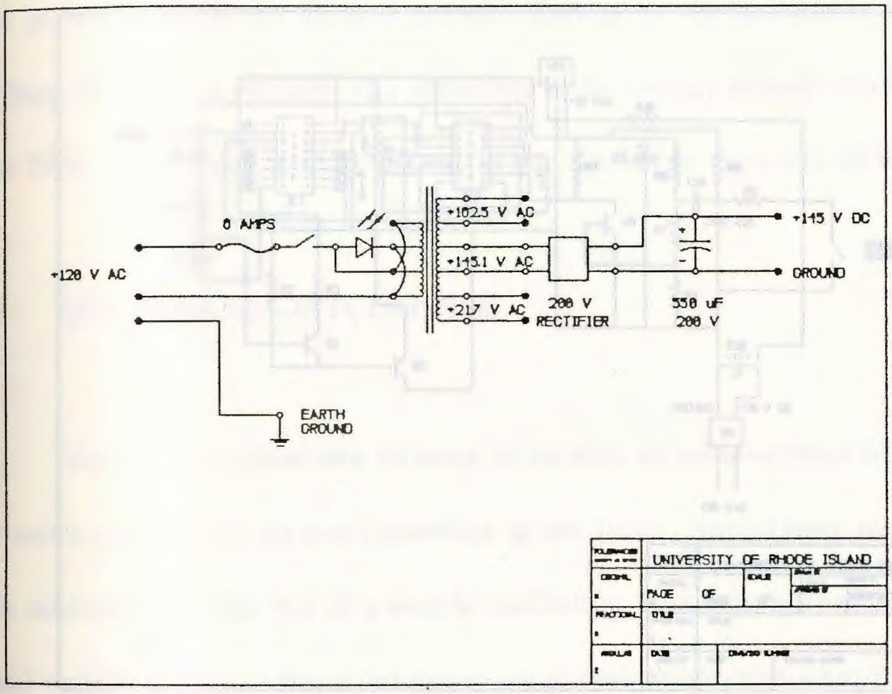


Figure 8 Power Supply Circuit

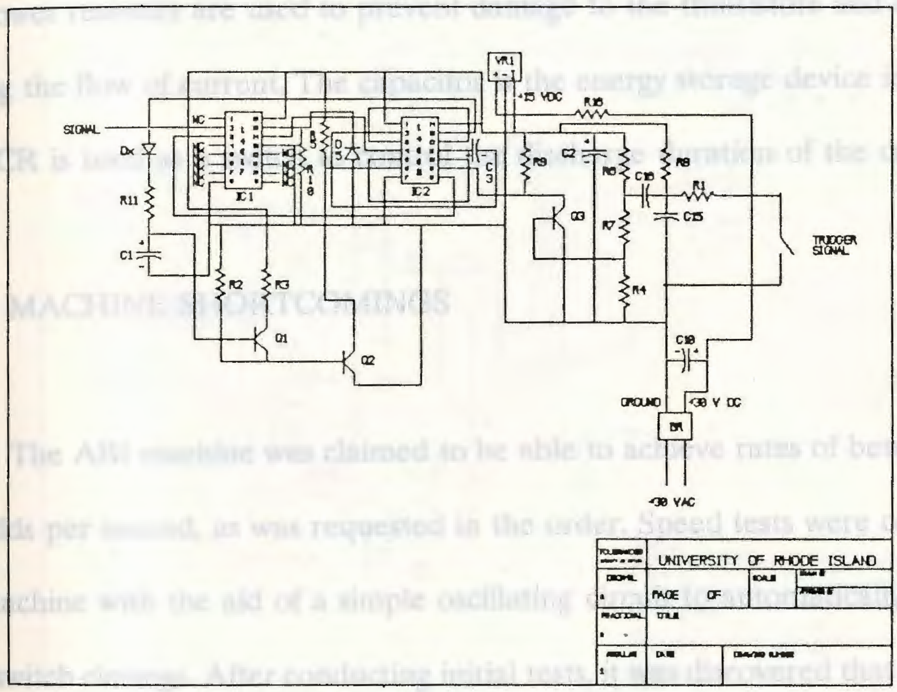


Figure 9 Trigger Pulse Circuit

circuit has a weld fire lockout feature which prevents the capacitor from discharging unless the capacitor has sufficiently recharged. Voltage across the capacitor is controlled by a potentiometer connected to the circuit. Figure 10 displays this circuit.

The resistor-capacitor circuit, shown in Figure 11, consists of dual power transistors, dual power resistors, a high-capacity capacitor, and a heavy-duty SCR. The power transistors are controlled to recharge the capacitor after it has discharged. The power resistors are used to prevent damage to the transistors and capacitor by limiting the flow of current. The capacitor is the energy storage device in the circuit. The SCR is used as a switch to control the discharge duration of the capacitor.

2.5 MACHINE SHORTCOMINGS

The ABI machine was claimed to be able to achieve rates of between four to six welds per second, as was requested in the order. Speed tests were conducted on this machine with the aid of a simple oscillating circuit to automatically control the hand switch closings. After conducting initial tests, it was discovered that the machine only had a maximum welding rate of about 3.5 welds per second. Reducing the weld duration had little effect in increasing the welding rate. Decreasing the capacitance also was ineffective. After conducting further speed tests, it was learned that the machine could only run at the maximum rate for only fifteen to twenty minutes before capacitor discharge terminated.

This problem was investigated and was discovered to be caused by the

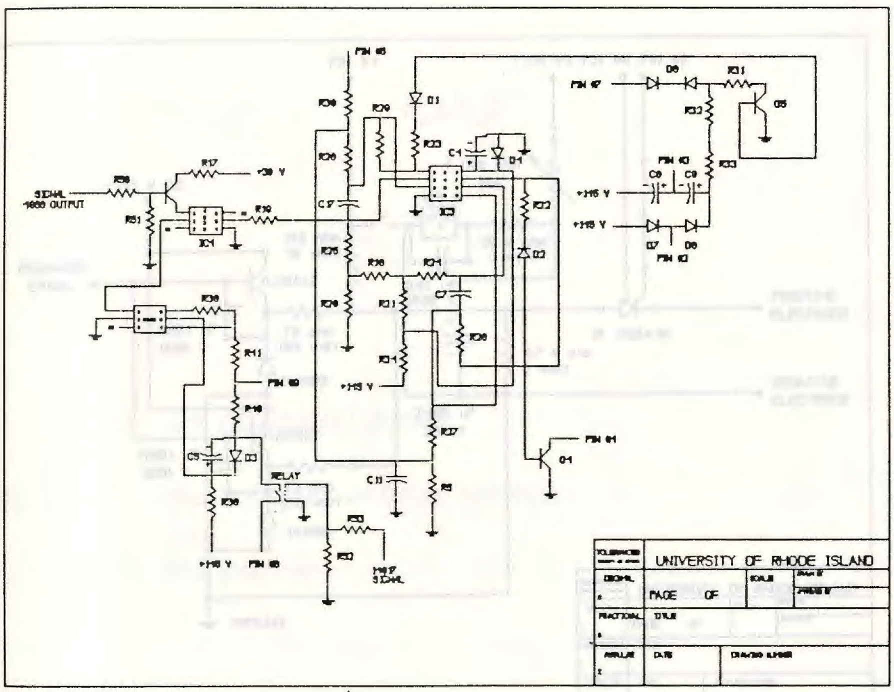


Figure 10 Resistor-Capacitor Control Circuit

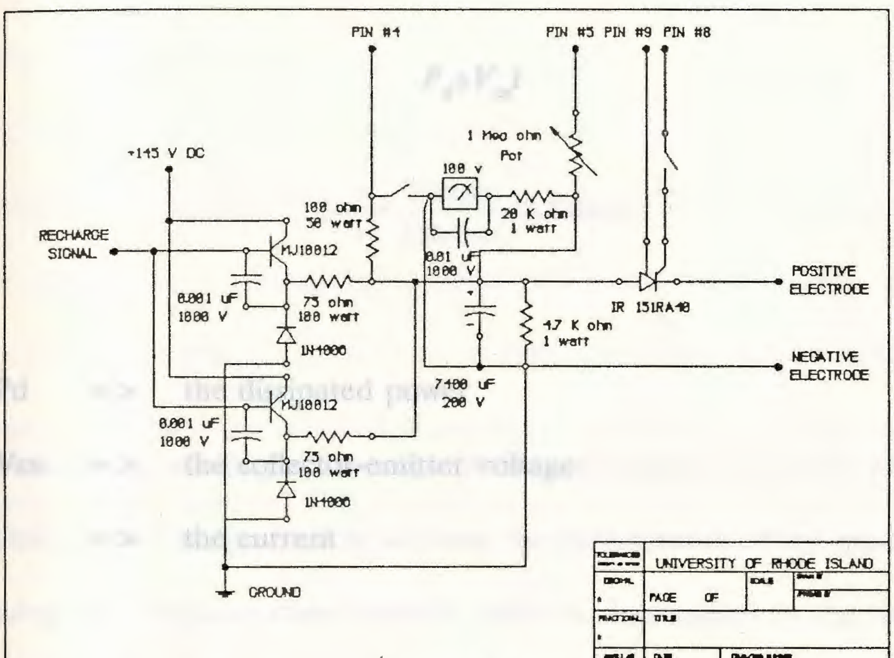


Figure 11 Resistor-Capacitor Circuit

overheating of the power transistors. Too much current was being forced through them during capacitor charging. The MJ10012 power transistor has a maximum power dissipation rate of 175 watts, a maximum collector-emitter voltage of 400 volts, and a maximum current rating of ten amps. The maximum collector-emitter voltage in this circuit is 145 VDC. The power equation used to determine the limits for the transistor is shown below [13]:

$$P_d \geq V_{ce} i$$

where:

Pd => the dissipated power

Vce => the collector-emitter voltage

i => the current

Therefore, the maximum current allowable for this transistor in the circuit is:

$$i \leq \frac{175 watts}{145 volts}$$

$$i \leq 1.207 amps$$

The current travelling through the power transistors is determined by the voltage set across the capacitor and the size of the power resistors. The voltage was adjusted to 30 volts for the tests. The power resistors were 25 ohms. According to the equation below:

$$i=\frac{v}{r}=\frac{30volts}{25ohms}=1.2amps$$

The transistor was working at the edge of its performance envelope. The engineer responsible for this design tried to increase the performance of the machine simply by reducing the charge-up time constant, which is determined by the values of the power resistors and capacitor. The values were decreased in the hope of attaining higher welding rates, without considering the added stress placed upon the other components in the circuit.

CHAPTER 3

MODIFIED MACHINE DESIGN

3.1 DESIGN STRATEGY

Modifications would have to be made to the circuit if the machine was to meet the project requirements. The welding rate had to be increased substantially. This rate is determined by the discharge and recharge times. The maximum discharge time is very small, approximately 30 milliseconds. The bottleneck in the system is the re-charging of the capacitor. The re-charging time is determined primarily by:

1) Capacitor voltage
2) Capacitor size
3) Power resistor value
4) Power transistor current transfer ratio

The resistor-capacitor (RC) time constant could be reduced by decreasing the values of the power resistors and the capacitor. Decreasing the resistance would put even more stress on the power transistors. Decreasing the capacitance would mean greater welding voltages in order to deliver equivalent power, which would decrease the time between maintenance. Also, simply decreasing the resistor values would not decrease the charging time because capacitors can only charge so fast due to the physical properties of its structure [14]. Power transistors were searched to find alternatives with better power handling capabilities. However, none were found with similar characteristics. The addition of more power transistor-power resistor loops was also looked into to decrease recharging time, but it was not given too much consideration since the capacitor was already possibly at the limit of its charging capability.

There was one modification which appeared promising. The modification involved increasing the number of resistor-capacitor circuits in the system. One capacitor would re-charge while another capacitor would be discharging. There were numerous advantages to this approach:

1) Allows for expansion
2) Allows for modular design
3) Expands on proven design
4) Puts less stress on components by distributing the workload

The disadvantages of this approach were that the size of the machine would be increased and the cost would rise. In addition, by distributing the work between subsystems, there is the chance of uneven quality. However, the size of the machine was not considered to be critical and it was judged that the rise in cost would not be large. In addition, the fact that electrical components usually have relatively close tolerance specifications diminishes the uneven quality argument.

3.2 MODIFICATIONS

The first step in the modification process was to correct the overheating problem occurring with the power transistors. Since it was determined that no other transistor could match the combination of low cost, good power handling capabilities and high current transfer ratio of the MJ10012, it was decided that the resistance value of the power resistors would have to be increased in order to reduce the power handling requirements. Higher values of resistances were tested, and it was discovered that the maximum welding rates increased only slightly. A resistance value of 75 ohms was selected over the original 25 ohm resistor. This would allow the welding machine to operate with voltages as high as 80 volts, which was considered to be the maximum the machine would operate.

Next, the circuit that provided the trigger pulse to the control circuit would have to be modified to provide a trigger pulse to each bank of control circuits in sequence. An additional circuit, shown in Figure 12, is added on to provide this function. The trigger pulse is fed into a decade counter that has been set to count up to four, thus providing four separate output signals. The counter resets the count at

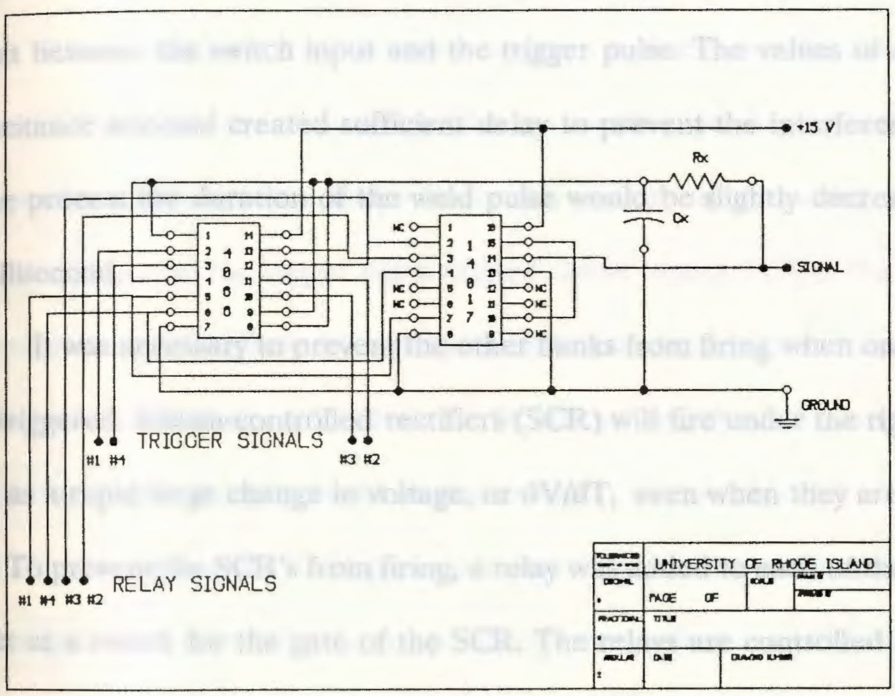


Figure 12 Channel Divider Circuit

four to restart the cycle. The four outputs of the decade counter are directed into a bilateral quad switch IC. These outputs control the opening and closing of each of the four switches. All four switches has as its input the original trigger pulse. Initially, the trigger pulse was input directly into the switches, but interference caused by the switch activations made neighboring banks fire simultaneously. A delay was needed to eliminate the interference problem. This was accomplished by adding a simple RC circuit between the switch input and the trigger pulse. The values of resistance and capacitance selected created sufficient delay to prevent the interference. However, in the process the duration of the weld pulse would be slightly decreased, less than 1 millisecond.

It was necessary to prevent the other banks from firing when one of the banks was triggered. Silicon-controlled rectifiers (SCR) will fire under the right conditions, such as a rapid large change in voltage, or dV/dT, even when they are not triggered [15]. To prevent the SCR's from firing, a relay was added to each of the bank circuits to act as a switch for the gate of the SCR. The relays are controlled by the decade counter output signals. Semiconductor switches were employed before mechanical relays, but they would not work in this situation. The high dV/dT would cause the semiconductor switch to close. Semiconductor switches possess characteristics such as reliability, durability, no contact bounce problems, and are relatively low cost that make them superior to mechanical relays for most applications. However, they were not suitable in this application.

3.3 PACKAGING

It was decided that the system be modular in design because of the high-volume production. Down times that are prolonged due to malfunctioning equipment can be costly. Therefore, it was judged that the welding machine have a modular design that would facilitate replacing defective units and parts.

The machine was divided into two sets of cabinets: one for the power supply, shown in Figure 13, and the other set for the welding circuitry, shown in Figure 14. The power supply cabinet would house the power supply circuit, the motorized potentiometer, and the trigger pulse printed circuit board (PCB). The front panel of this cabinet would contain the voltage meters and the power switch and fuse. The welding circuit cabinet would house the RC circuit and the RC control circuit PCB. The power supply cabinet would be connected to each of the four welding cabinets via a 15 wire cable with DB 25 pin connectors. The welding cabinets have two cable connections for electrode hook-up. Computer control of the system will be maintained through a cable connected to the power supply cabinet. The power supply cabinet will accept a 120 VAC power input.

This design allows for the easy replacement of defective units. Also, the cost of each unit, approximately 500 dollars, is relatively low, therefore maintaining an inventory of several spare units will not be financially draining. After replacement, the defective units could be repaired at a later time for convenience. The cabinets have been designed to allow for easy access to and replacement of bad components.

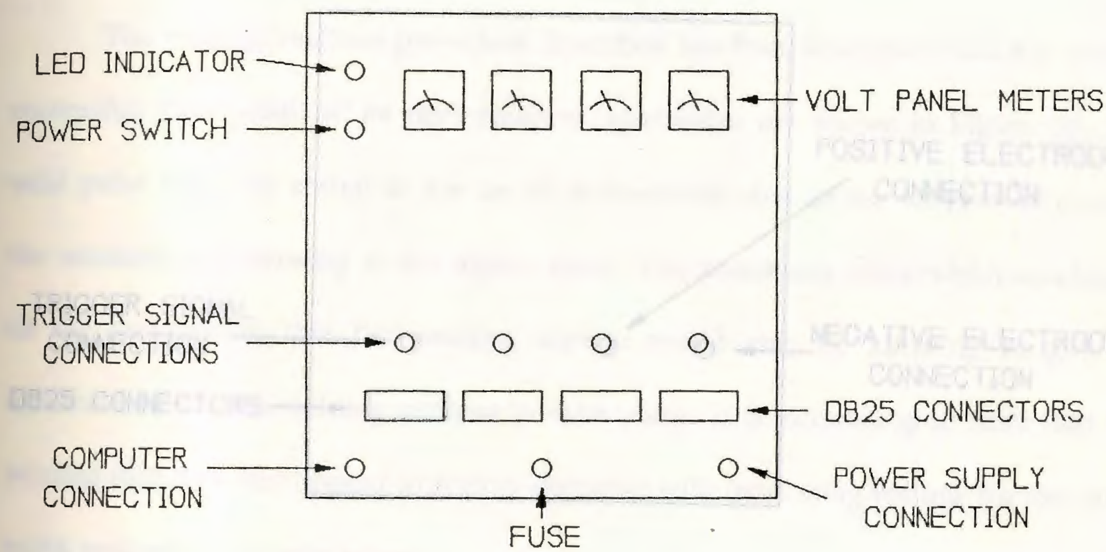


Figure 13 Power Supply Cabinet

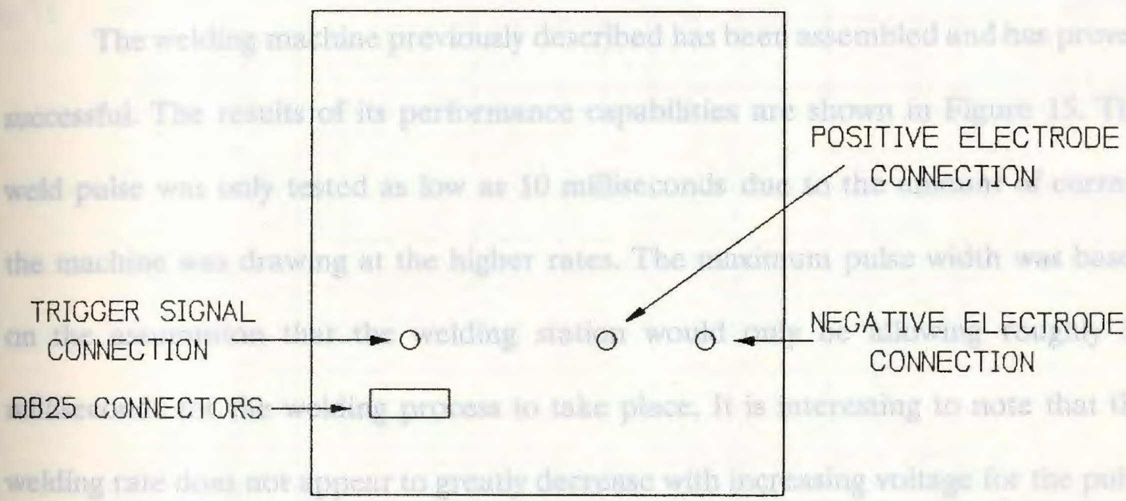


Figure 14 Welding Circuit Cabinet

It was decided not to place cooling devices, such as muffin fans, in each of the cabinets to dissipate the heat generated by the current flow through the power resistors. The fans would only place an unnecessary burden on the system power supply, not to mention adding extra clutter in the cabinets. External fans would handle the task of cooling the system components.

3.4 RESULTS

The welding machine previously described has been assembled and has proven successful. The results of its performance capabilities are shown in Figure 15. The weld pulse was only tested as low as 10 milliseconds due to the amount of current the machine was drawing at the higher rates. The maximum pulse width was based on the assumption that the welding station would only be allowing roughly 35 milliseconds for the welding process to take place. It is interesting to note that the welding rate does not appear to greatly decrease with increasing voltage for the pulse width and voltage range tested.

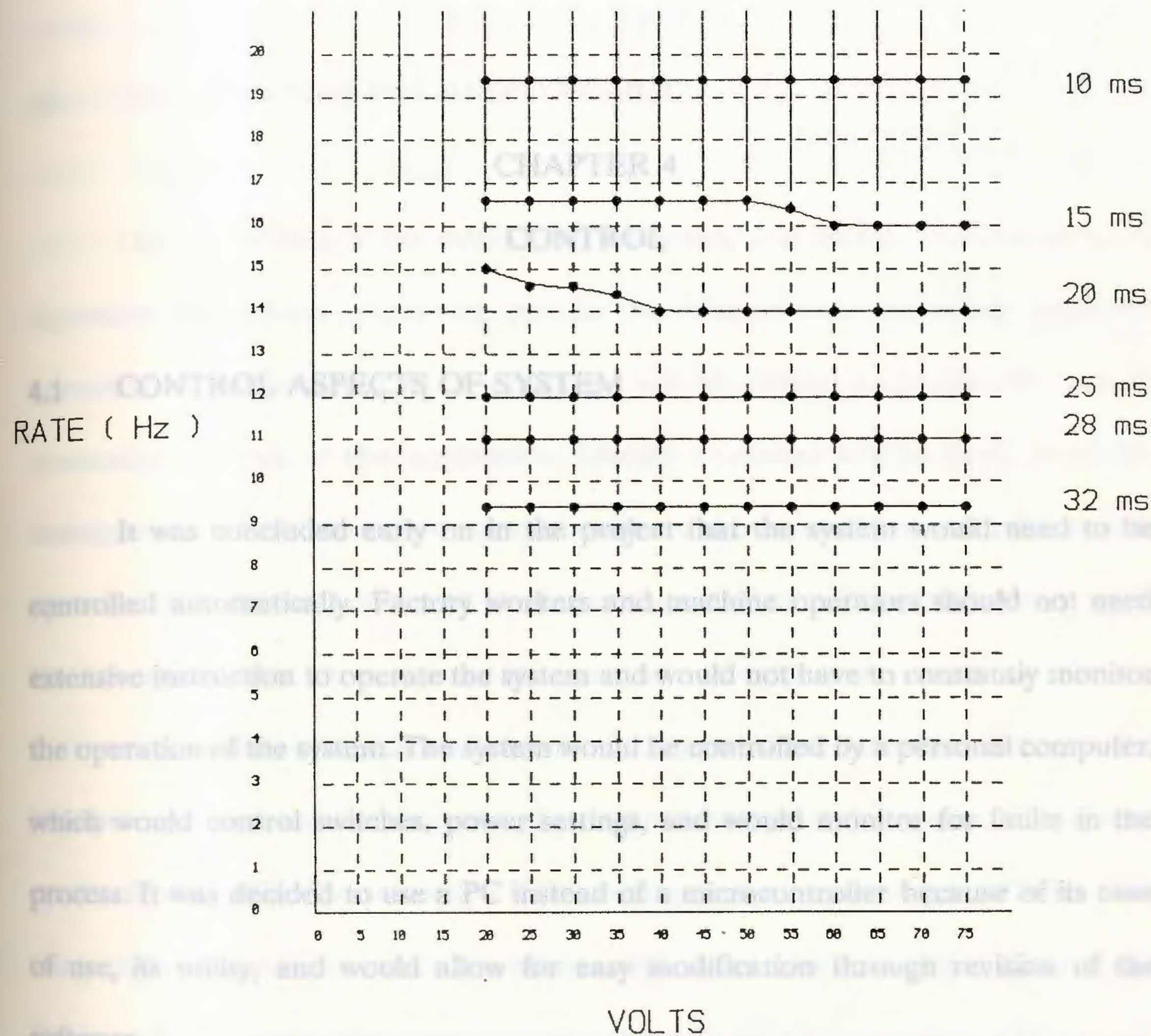


Figure 15 Welding Machine Performance Results

CHAPTER 4

CONTROL

4.1 CONTROL ASPECTS OF SYSTEM

It was concluded early on in the project that the system would need to be controlled automatically. Factory workers and machine operators should not need extensive instruction to operate the system and would not have to constantly monitor the operation of the system. The system would be controlled by a personal computer, which would control switches, power settings, and would monitor for faults in the process. It was decided to use a PC instead of a microcontroller because of its ease of use, its utility, and would allow for easy modification through revision of the software.

There were several aspects of the system that would need to be controlled or monitored. The flow of posts would have to be controlled to provide the proper flowrate. The system would have to be monitored to check for post jamming or weld failures. The weld triggering would have to be controlled to provide proper firing of the welding pulse. In addition the voltage setting of the welding machines would have to be controlled. It was also necessary to control the loop of metal strip between the press and the welding station.

4.2 DATA PROCESSING AND CONTROL

Data processing is the monitoring, recording, computing, and evaluating of important information concerning process variables in order to obtain improved operation of the process [16]. A computer will be utilized to handle the task of processing the data in this application. Human operators will be freed from this mundane chore to concentrate on more important matters. Control of the system operation will also be performed by a computer. Actions will be taken based upon the information that the computer has received and evaluated.

A personal computer will be used to provide an interface between the machine operator and the control and monitor functions of the system. The system used is an IBM PC AT clone with a 80286 microprocessor operating at 12 MHz. The computer communicates with the outside world via an interface system from Alpha Products Inc. The interface system incorporates a 12 bit A/D convertor, a 16 channel differential multiplexer, an input/output (I/O) interface, and a "smart" stepper motor controller. An additional I/O interface made by Real Time Devices Inc. provides an additional 72 I/O channels.

The interface system also includes a subsystem of 16 custom-designed printed circuit boards (PCB) which buffer much of the sensor information to and from the

Alpha and RTD boards. These PCBs include 8 I/O relay boards, 3 post detection circuit boards, 3 post level circuit boards, 1 weld counting circuit board, and 1 voltage divider circuit board. These PCBs are housed in an Intel machine case. The original power supply for the Intel machine is used to supply power to these PCBs and the Alpha interface system.

4.3 SENSORS

In order to monitor system events, the computer will need to obtain information. This information will be procured through the use of appropriate sensors. There are many types of sensors available today, but only several types will be considered. The types considered are the sensors categorized as current technology by Cook [17]. These sensors are considered because they are easy to implement in a system, use well-developed technologies, and are non-contact.

Photoelectric sensors operate by discharging light energy, usually in the form of infra-red beams, and then by detecting the presence or absence of the light energy. Inductive sensors work by creating an electromagnetic field at the sensor. If a metal part comes within range of this field, the current travelling through the sensor will be dampened, which causes the sensor to alter its output signal. Capacitive sensors work in the same manner as inductive sensors, but operate on a different principle. When a part comes into the active range of the sensor, the capacitance is altered. This creates an oscillation in the sensor circuit which triggers the output signal of the sensor. Because of its operating principle, the capacitive sensor can detect non-ferrous material, unlike the inductive sensor. Ultrasonic sensors operate by emitting a high frequency sound beam and then by detecting the reflected sound beam from an object that has entered within the sensor's operating range.

The sensor type chosen for information acquisition in this application was the photoelectric type. This type was selected because of its relatively low cost, high reliability, long life, and small dimensions. There are several types of photoelectric sensors: retroreflection, specular reflective, diffuse reflection, and thrubeam.

Retroreflective sensors consist of an emitter and detector usually housed in the same assembly. The sensor operates by detecting the presence of a target object that has a reflective element attached to it that is reflecting the emitted light energy back to the photodetector. The retroreflective sensors have advantages such as long range, high contrast ratio, and are easy to set up, while its main disadvantage is that shiny objects will create false positives.

Specular reflective sensors operate in much the same manner as retroreflective sensors except that this sensor relies upon a shiny target surface instead of an attached reflective element. This sensor has the advantages of high contrast ratio and precise target location. The limitations associated with this sensor include the need for precise alignment between the sensor and the target and the type of targets that can be sensed.

Diffuse reflection sensors are similar to retroreflective sensors with the exception that the target object does not require an attached reflective element. The sensor detects an object within its operating range when the detector senses lighted reflected by the surface of the target. The advantages of this sensor type are an easy setup, and that this type of sensor is able to distinguish colored marks. However, this type of sensor can only be used in applications that only require short range operation.

Thrubeam sensors consist of an emitter and detector in separate housings that are aligned opposing each other. An object passing in between the units will block the light beam from the emitter, causing the detector to signal an absence of light. Thrubeam sensors have the advantages of very long range, the highest contrast ratio, and ignore texture and surface color of the detected object. The disadvantage with this sensor type is that two units are needed and need to be correctly aligned.

4.4 POST FLOW CONTROL

The flow of posts from the bowl feeder through the linear feeder would have to be controlled. Proper flowrate would have to be maintained in order to prevent too much flow, which could create post jamming, and too little flow, which would cause weld failures.

The task of controlling post flow would be accomplished through the use of two photoelectric sensors. Thrubeam sensors will be utilized owing to their high reliability, which is a major priority for the system in this project. One of the sensors would be placed within the bowl feeder. This sensor, displayed in Figure 16, would monitor the level of posts inside the bowl feeder. If the post level dropped below a certain height, the sensor would relay the information to the computer. This is important to consider, since if the post level in the bowl feeder drops too low, the post flow rate out of the feeder will decrease.

The other sensor would be placed in the linear feeder, as shown in Figure 17. This sensor would monitor the amount of posts in the feeder. During experimentation it was discovered that having a certain number of posts in the linear feeder was conducive to proper operation. The back pressure from the posts in the feeder would help push the front post into the slot on the wheel. However, too many posts could create jamming problems. Therefore, it will be necessary to control the number of posts in the linear feeder. This control is accomplished by turning on and off the bowl feeder. Due to the nature of this control strategy, delays are present. This delay time is determined by the flow rate out of and the flow rate into the linear feeder, and by the time needed to turn on the bowl feeder. The flow rate out of the feeder is a consistent value, excluding problems such as jamming and misses. However, the flow rate into the feeder will vary over periods of time. This presents a problem. It will be important to determine the average flow rate into the linear feeder.

The location of the sensor in the linear feeder would be critical in creating a stable system. If the sensor is positioned too close to the wheel, the delay will be too great. If the sensor is positioned too close to the bowl feeder, the system will experience "chatter", from the bowl feeder turning on and off too frequently. The

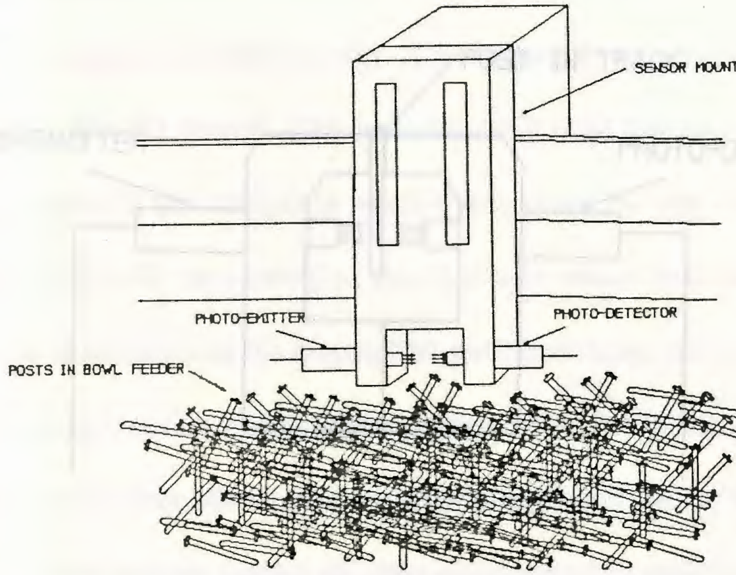


Figure 16 Bowl Feeder Level Sensor

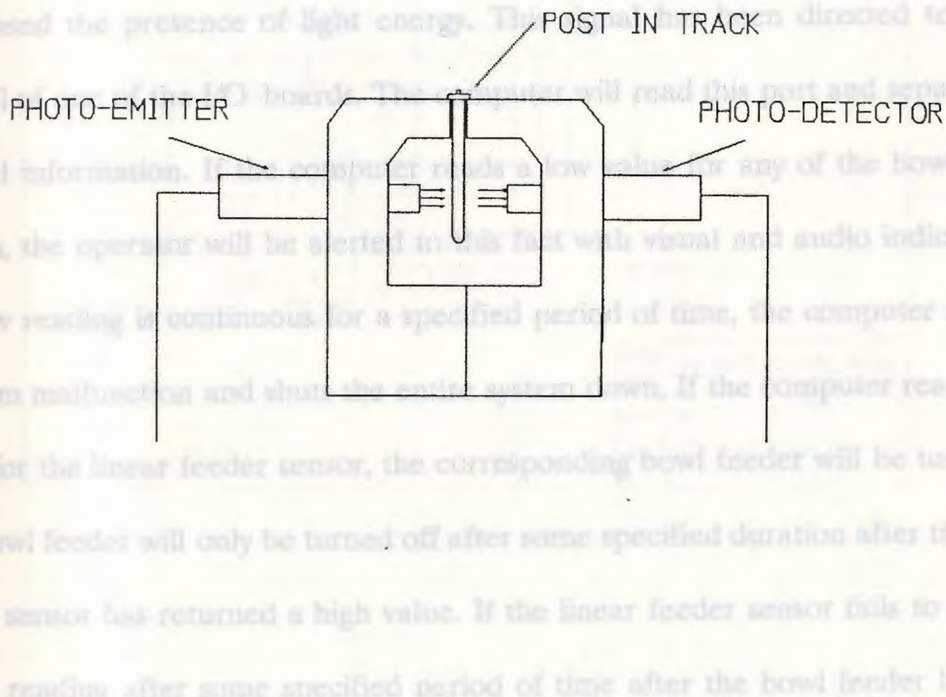


Figure 17 Linear Feeder Level Sensor

ideal positioning of the sensor is far enough away from the bowl feeder such that the delay time for flow rate will not be too large. The location will also have to take into account the minimal number of posts necessary to generate sufficient back pressure on posts entering the cammed grooves of the wheel.

The data that these sensors must be able to transmit is binary, either the post level will be acceptable or unacceptable. This is easily accomplished with the post level sensor circuit shown in Figure 18. The Skan-A-Matic amplifier will produce a TTL compatible signal, either a logic 0 or 1, depending on whether the photodetector has sensed the presence of light energy. This signal has been directed to a port channel of one of the I/O boards. The computer will read this port and separate the channel information. If the computer reads a low value for any of the bowl feeder sensors, the operator will be alerted to this fact with visual and audio indicators. If this low reading is continuous for a specified period of time, the computer assumes a system malfunction and shuts the entire system down. If the computer reads a low value for the linear feeder sensor, the corresponding bowl feeder will be turned on. The bowl feeder will only be turned off after some specified duration after the linear feeder sensor has returned a high value. If the linear feeder sensor fails to produce a high reading after some specified period of time after the bowl feeder has been activated, the computer will shut the entire system down.

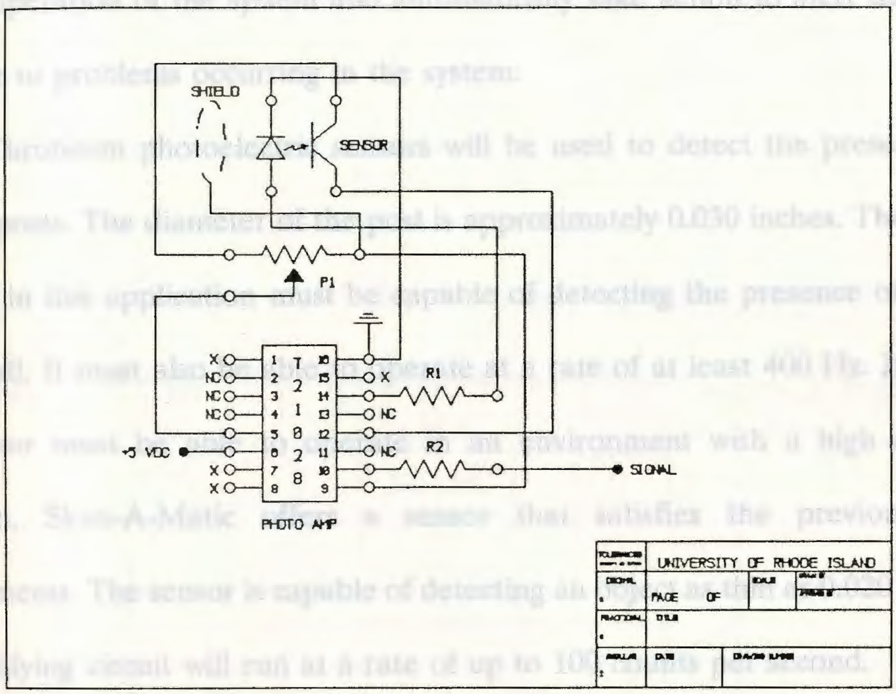


Figure 18 Post Level Circuit

4.5 FAILURE DETECTION

Important events that will need to be monitored include the earring post entering onto the slot in the wheel from the linear feeder interface and the post welded to the metal strip. These events will need to be monitored in order to ensure proper operation of the system and automatically take action to alert the machine operator to problems occurring in the system.

Thrubeam photoelectric sensors will be used to detect the presence of the earring posts. The diameter of the post is approximately 0.030 inches. The sensor to be used in this application must be capable of detecting the presence of an object that small. It must also be able to operate at a rate of at least 400 Hz. In addition, the sensor must be able to operate in an environment with a high amount of vibration. Skan-A-Matic offers a sensor that satisfies the previously stated requirements. The sensor is capable of detecting an object as thin as 0.020 inches and its amplifying circuit will run at a rate of up to 100 counts per second.

In order to detect a post entering the wheel, a mounting bracket is positioned under the radius of the wheel near the linear feeder. On top of the bracket will sit a sensor mount. This mount will place the thrubeam sensors directly opposing each other, as shown in Figure 19. The posts carried by the wheel will pass through the sensors, which will trigger a signal picked up by the computer. The computer will keep track of the number of these signals that is received.

Detection of a welded post will occur in much the same manner. The welded

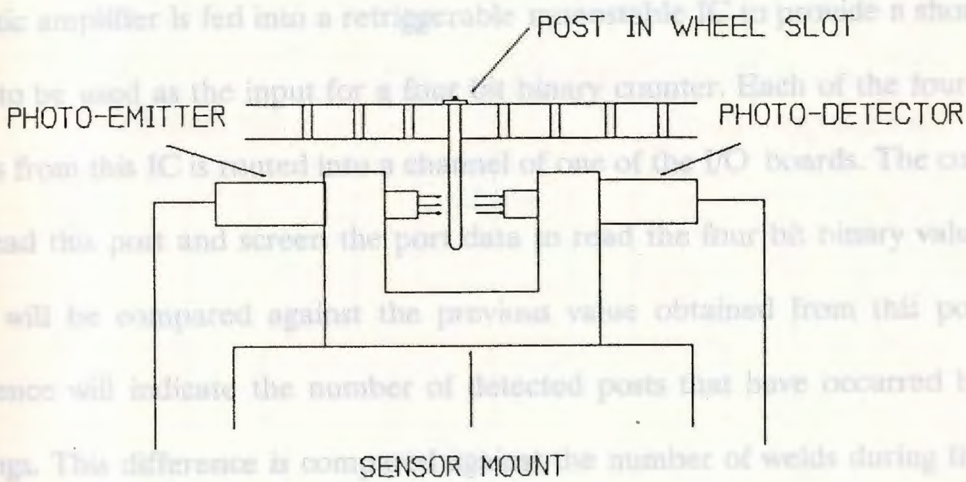


Figure 19 Post Jam Detector Sensor

post will pass through sensors mounted directly beneath the metal strip located after the upper electrode assembly, as displayed in Figure 20. The computer will also keep track of the signals that it receives from this sensor.

The computer will compare the count of these sensor signals against the weld count. If the count is equal, then it is concluded that no failure has taken place. If one of the sensor signal counts is less than the weld count, it is assumed that a failure has occurred.

The data that these sensor circuits must transmit is the count of the detected posts. This task is handled by the circuit in Figure 21. The output signal of the Skan-A-Matic amplifier is fed into a retriggerable monostable IC to provide a short clean pulse to be used as the input for a four bit binary counter. Each of the four output signals from this IC is routed into a channel of one of the I/O boards. The computer will read this port and screen the port data to read the four bit binary value. This value will be compared against the previous value obtained from this port. The difference will indicate the number of detected posts that have occurred between readings. This difference is compared against the number of welds during the same time frame. The difference between these two values indicates the number of missed post detections by the sensors. This value is stored and accumulated until the value reaches a user selectable limit, at which point an alarm will sound and the computer will shut down the system.

It was decided not to monitor the system in real time due to the added expense. Checking for failure detection is accomplished by keeping track of the signal

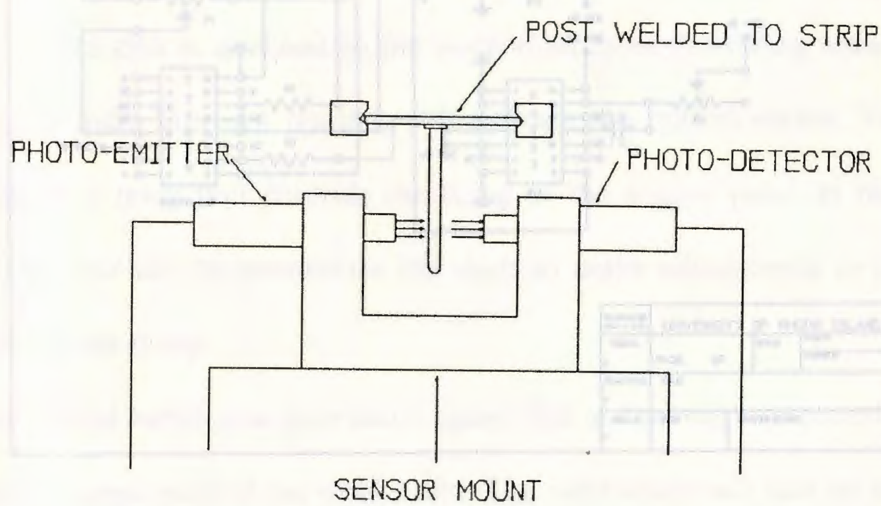


Figure 20 Post Weld Failure Sensor

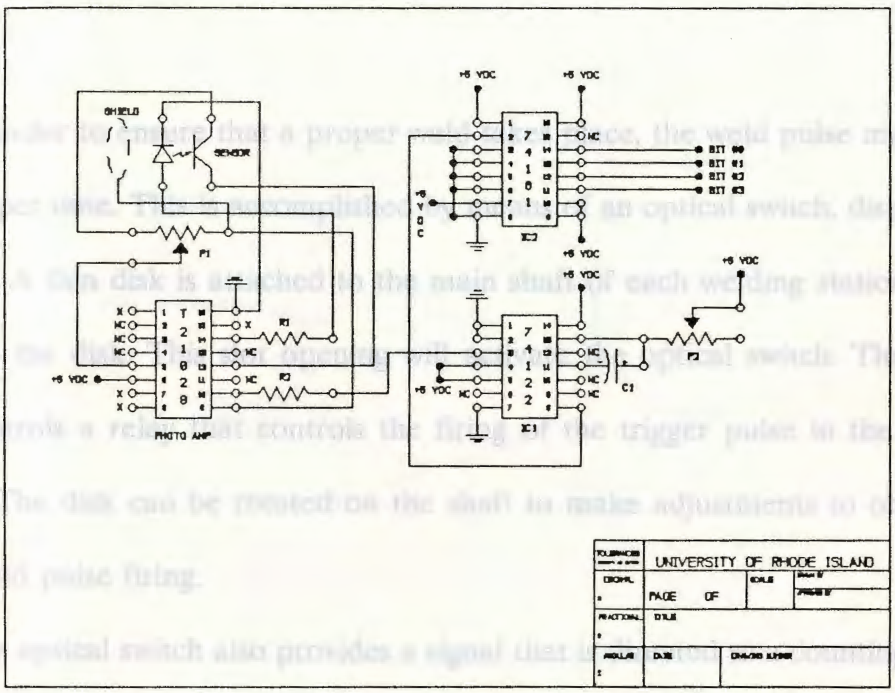


Figure 21 Post Detection Circuit

counts, and then by comparing them. This method is not real time, although the delay in monitoring events is not substantial. This method also does not require the use of interrupts to alert the computer to an event, which would complicate the control program.

4.6 WELD TRIGGERING CONTROL

In order to ensure that a proper weld takes place, the weld pulse must occur at the proper time. This is accomplished by means of an optical switch, displayed in Figure 22. A thin disk is attached to the main shaft of each welding station. A slot is cut into the disk. This slot opening will activate the optical switch. The optical switch controls a relay that controls the firing of the trigger pulse in the welding machine. The disk can be rotated on the shaft to make adjustments to obtain the correct weld pulse firing.

The optical switch also provides a signal that is directed to a counting circuit. The computer keeps track of the weld count. This weld count will also be used in the process of failure detection. The circuit, displayed in Figure 23, used is identical to the one used in the post detection sensor circuit.

4.7 WELDING MACHINE CONTROL

Control of the resistance welding machines is a task that has been delegated

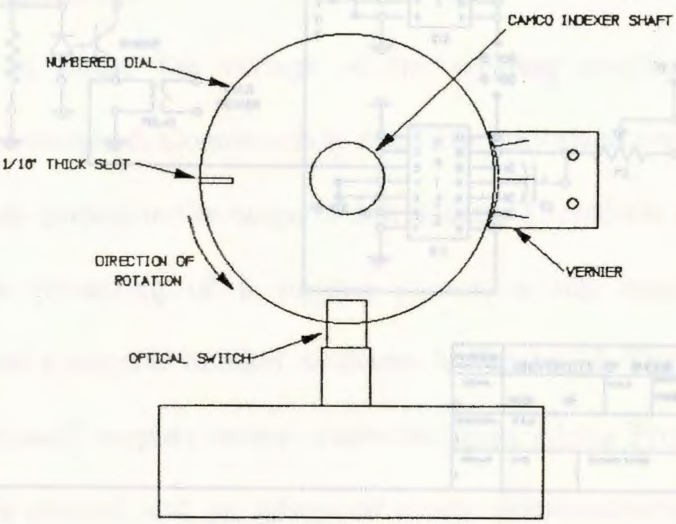


Figure 22 Optical Switch Assembly

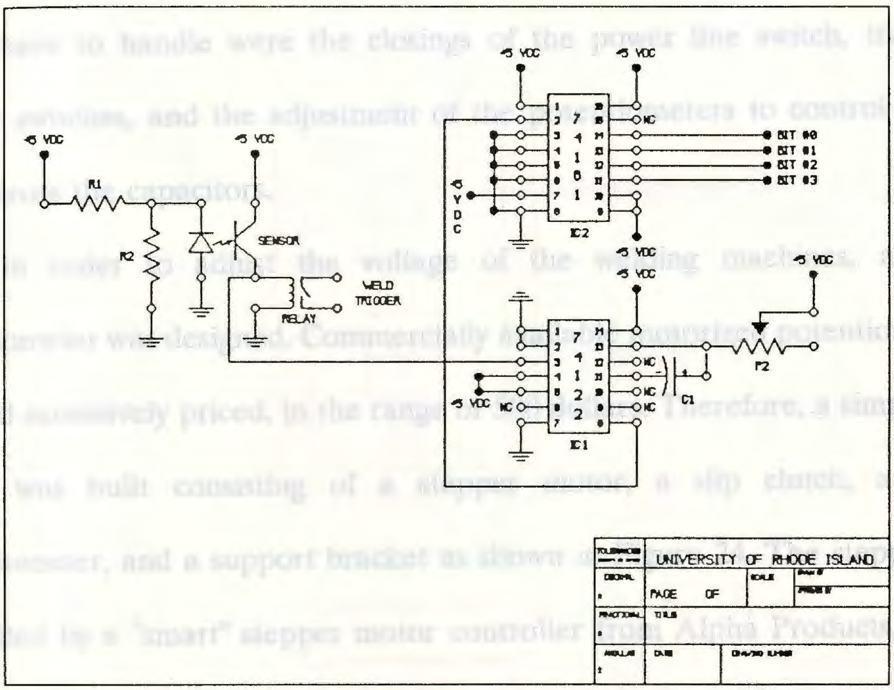


Figure 23 Weld Trigger Circuit

to the personal computer. There are several switches and dials that the operator would otherwise have to adjust manually. Since the welding machines were to be placed under the welding stations, making manual control difficult, and for fast response in the event of an emergency situation, it was decided that the computer should automatically control the welding machines. The tasks that the computer would have to handle were the closings of the power line switch, the discharge resistor switches, and the adjustment of the potentiometers to control the voltage level across the capacitors.

In order to adjust the voltage of the welding machines, a motorized potentiometer was designed. Commercially available motorized potentiometers were deemed excessively priced, in the range of 500 dollars. Therefore, a simple, low cost device was built consisting of a stepper motor, a slip clutch, a four gang potentiometer, and a support bracket as shown in Figure 24. The stepper motor is controlled by a "smart" stepper motor controller from Alpha Products, Inc., which features four axis control and an advanced motor communication scheme which allows the user to send English style commands to the motor controller. The stepper motors have a step resolution of 180 steps for a complete shaft rotation. The potentiometer has a value of 1 mega-ohm which is linearly adjustable over a range of 330 degrees, which varies the capacitor voltage by approximately 80 volts. This translates into a voltage resolution of 0.44 volts per step, which was judged to be an acceptable resolution. The slip clutch situated between the motor and the potentiometer has been employed to prevent the motor from accidently exceeding

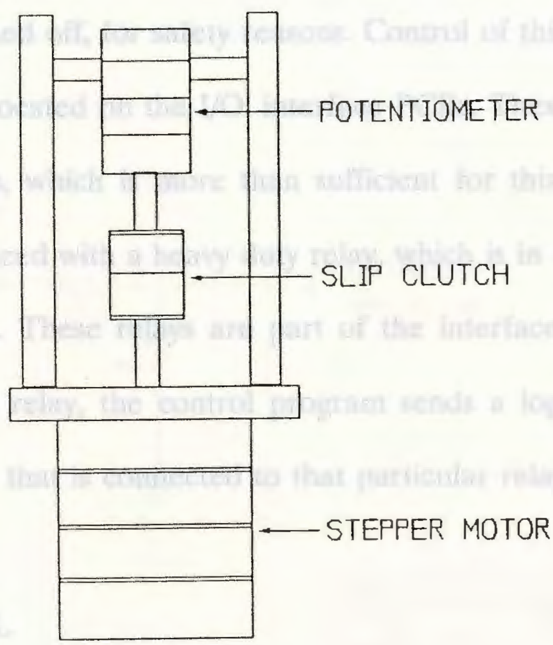


Figure 24 Motorized Potentiometer Assembly

the rotational range of the potentiometer.

Voltage levels for each capacitor are fed back to the computer via a 12 bit A/D converter. The voltage is first decreased by a voltage divider circuit, see Figure 25, before being input into the converter. This is done to protect the converter from high voltage levels.

The discharge resistor switches are needed to quickly discharge the capacitors when the machine is turned off, for safety reasons. Control of this switching action is handled by the relays located on the I/O interface PCBs. These relays are rated at five amps at 250 volts, which is more than sufficient for this application. The power line switch is replaced with a heavy duty relay, which is in turn controlled by one the I/O PCB relays. These relays are part of the interface circuit shown in Figure 26. To activate a relay, the control program sends a logic 1 value to the appropriate port channel that is connected to that particular relay.

4.8 LOOP CONTROL

The metal strip onto which posts will be welded is fed by a roll feed that is driven by the main shaft of the system. The strip is fed into the roll feed directly from the punch press. The punch press and the roll feed will have the same feed rate, 0.430 in x 400 RPM = 172 in/minute. However, feed rate differences will occur between the two units due to incorrect speed settings between the two, belt slippage on the flywheel of the press, and motor control units which do not provide rapid

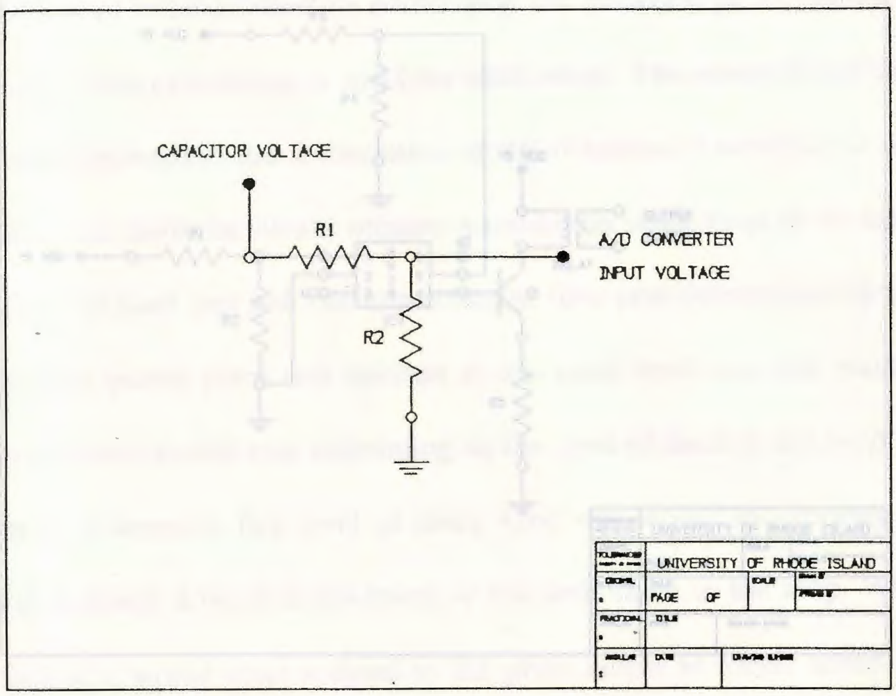


Figure 25 Voltage Divider Circuit

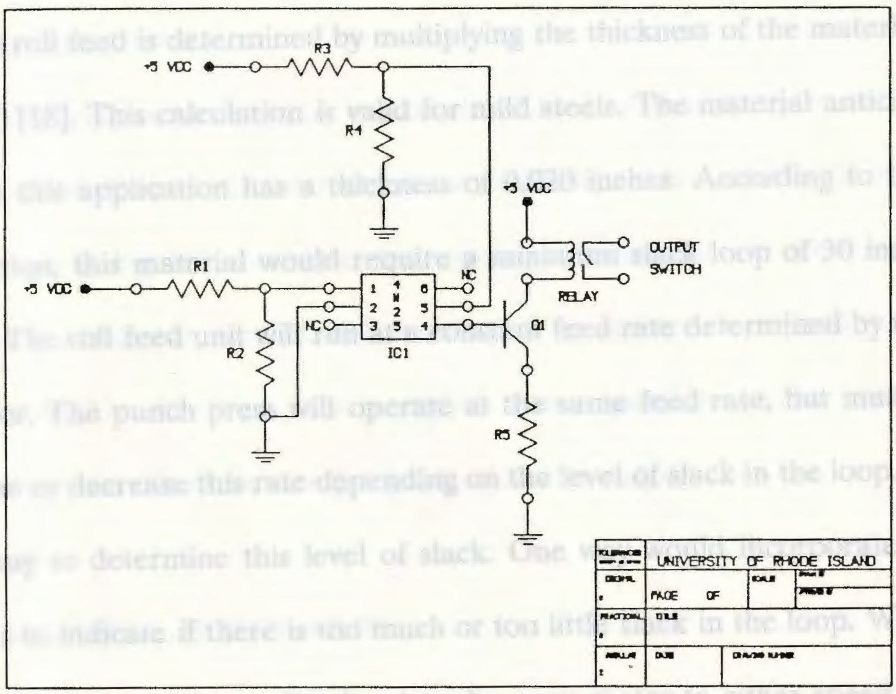


Figure 26 Relay Interface Circuit

compensation to offset differences between the actual speed of the motor and the desired speed. This problem necessitates the use of loop control to regulate the slack of metal strip between the units. The slack of metal strip will make pulling the metal strip easy on the roll feed, and it will also allow for time to take action if there is a problem in the feeding process.

The recommended slack distance of the metal strip between the punch press and the roll feed is determined by multiplying the thickness of the material to be fed by 1500 [18]. This calculation is valid for mild steels. The material anticipated to be used in this application has a thickness of 0.020 inches. According to the previous calculation, this material would require a minimum slack loop of 30 inches.

The roll feed unit will run at a constant feed rate determined by the machine operator. The punch press will operate at the same feed rate, but must be able to increase or decrease this rate depending on the level of slack in the loop. There must be a way to determine this level of slack. One way would incorporate switches or sensors to indicate if there is too much or too little slack in the loop. When a switch was activated it would send a signal to the press motor to either speed up or down, depending on whether the high or low switch was closed. This is an implementation of "bang-bang" control. From previous experience with this type of control in feeding operations, it was decided that this control strategy would be too unstable. Depending on the levels set for the switches, problems could arise. If the satisfactory slack level range was too narrow, chatter could occur in the system from the motor speeding up or down excessively, causing unnecessary wear and tear on the components. In addition, if the time response of the physical system exceeds that of the overshoot rate of the control system, disastrous results could occur.

The control strategy that was decided upon employed an ultrasonic proximity sensor that would send out a proportional voltage signal indicative of the loop height of the metal strip. Figure 27 displays the sensor set-up. This signal would be fed into the control unit for the press motor to continuously vary the motor speed to maintain a specified loop level.

The loop control system was supplied by Machine Parts Inc. of Providence, Rhode Island. It consists of the ultrasonic proximity sensor, a 3 Hp DC motor for the press, a 1-1/2 Hp DC motor for the welding stations and roll feed, motor control units for each motor, and an M-Drive control by Fenner to provide the control for the system. The M-Drive unit is digital motor speed controller that allows the operator to set values for control gains, motor speed, etc.

4.8 CONTROL SOFTWARE

A software program is created to monitor and control events in this system. It was decided that the program would be written in the C programming language because of its ability to use machine resources efficiently, its portability, and its speed [19]. The program is created user-friendly to minimize learning time and it allows for either manual or automatic control. A general flowchart of the control program is shown in Figure 28. Manual control would be necessary for set-up procedures and

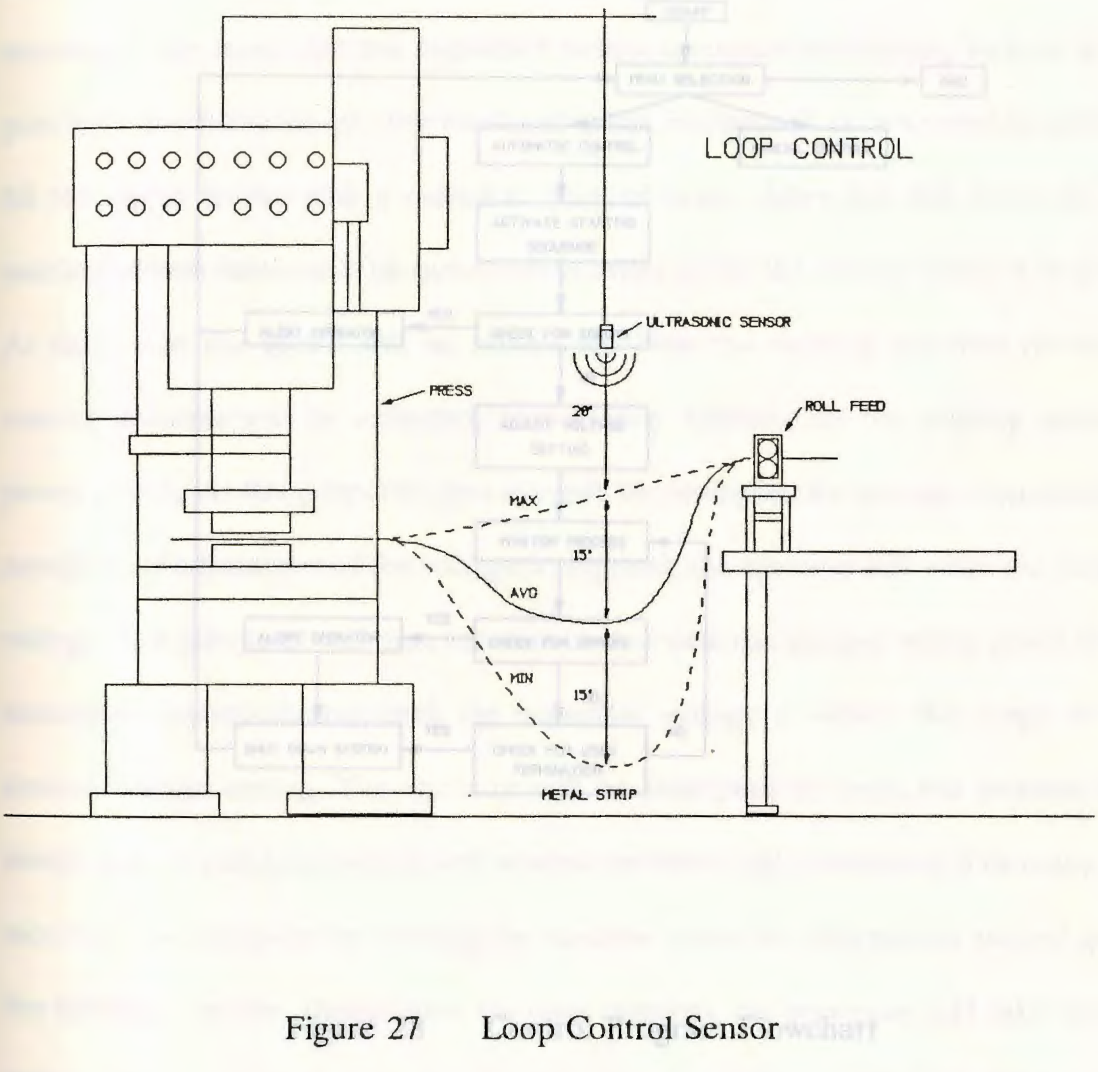


Figure 27 Loop Control Sensor

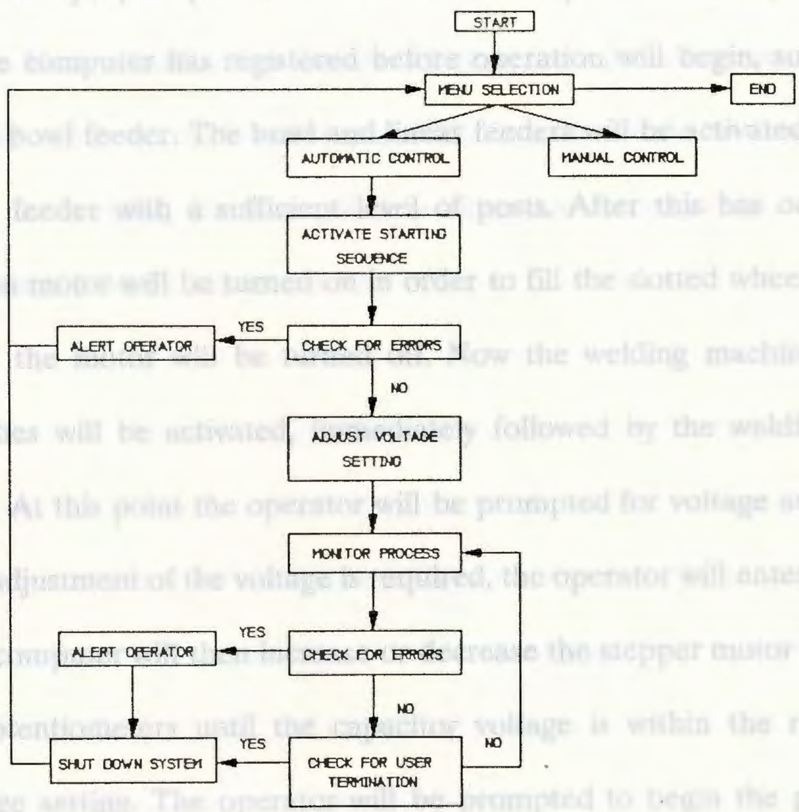


Figure 28   Control Program Flowchart

testing. The operator will be able to activate and de-activate all of the units in the system.

Automatic control would be needed to monitor and control events during system operation. During automatic control, a sequence of events would have to be followed to ensure proper operation. It will be necessary to alert the operator to any errors that the computer has registered before operation will begin, such as a low post level in a bowl feeder. The bowl and linear feeders will be activated in order to fill the linear feeder with a sufficient level of posts. After this has occurred, the welding station motor will be turned on in order to fill the slotted wheel with posts. At that point the motor will be turned off. Now the welding machine discharge resistor switches will be activated, immediately followed by the welding machine power switch. At this point the operator will be prompted for voltage adjustment, if necessary. If adjustment of the voltage is required, the operator will enter the desired voltage. The computer will then increase or decrease the stepper motor count of the motorized potentiometers until the capacitor voltage is within the range of the desired voltage setting. The operator will be prompted to begin the process. The motor control unit is turned on and system operation will commence. The computer monitors the operation by reading the machine ports for information passed on by the interface circuits. Based upon the data received, the computer will take certain actions. If the post level is low in a bowl feeder, the computer will alert the operator to this fact, both visually with a message on the screen and audibly with a siren. If an unacceptable post jamming problem or weld failure problem occurs, the computer will alert the operator and shut the system down. The operator will then be able to examine the cause of the problem and repair it. The computer will continuously display the number of welds, post jams, missed welds, and post level indications for the operator.

To end the production process, the operator can press any key on the keyboard. This is an added safety feature to allow for rapid shutdown. The motor control unit will be turned off. The computer will then deactivate the bowl and linear feeders. Then the welding machine power switches are turned off and the welding machine discharge resistor relays are shut off.

CHAPTER 5

CONCLUSIONS

5.1 CONCLUSION

The jewelry industry will stand to reap great benefits if automation becomes widely implemented in the production of its goods. Automation has proven itself as a cost effective solution in the manufacturing process. It is anticipated that automated assembly applications, such as the one in this project, will demonstrate that many more manual tasks are well-suited for automation.

The accomplishments of this project include the design and development of a high speed small parts feeding system by Kurande. It also includes the modification of a commercial resistance welding machine for high speed operation. A control system utilizing a personal computer and interface hardware have also been developed. The finished system is displayed in Figure 29.

Initially, a prototype consisting of a parts feeding unit and a welding machine was tested in operation. The pneumatic strip feeder used in this system only allowed

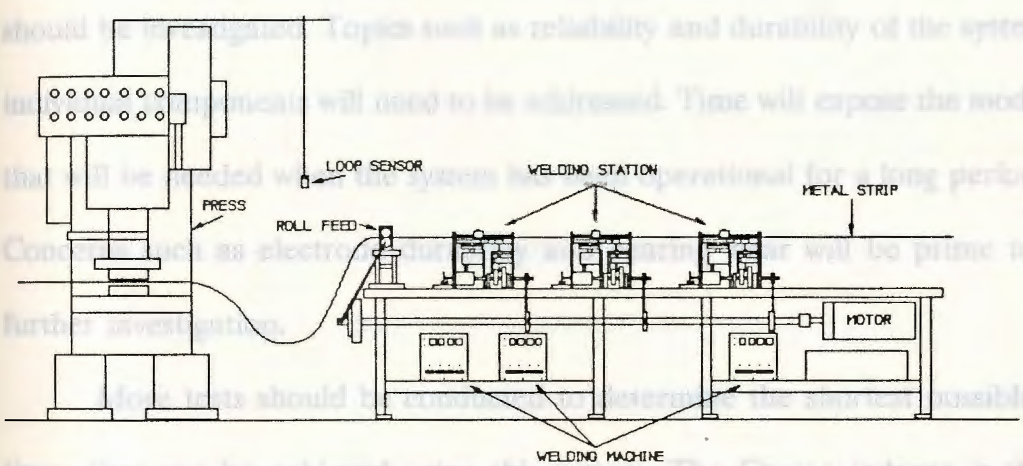


Figure 29 Completed System

for a maximum rate of approximately 200 welds per minute, but results of the testing of this unit were very encouraging. The final system was then tested. Each of the subsystems was tested and demonstrated proper functioning prior to operating the entire system. The unit was then put into operation and has been successful in welding posts to a metal strip at the rate indicated in the proposal.

5.2 FUTURE WORK

There are several topics of further work stemming from this project that should be investigated. Topics such as reliability and durability of the system and its individual components will need to be addressed. Time will expose the modifications that will be needed when the system has been operational for a long period of time. Concerns such as electrode durability and bearing wear will be prime targets for further investigation.

More tests should be conducted to determine the shortest possible welding times that can be achieved using this system. The Camco indexer is the known limiting factor, only allowing a recommended maximum rate of 500 RPM. It would prove interesting to discover if the maximum welding rate could be pushed that high and still retain satisfactory reliability.

Investigation should also include searching the market for high speed welding machines. The modifications made to this welding machine have made it capable of very high speed operation. Larger capacitors could be added for applications requiring greater energy input, without significantly reducing speed as initial results have proven.

REFERENCES

[1] Groover, M. P., Automation, Production Systems, and Computer-Aided Manufacturing, Prentice-Hall Inc., New Jersey, 1980.

[2] Goebel, R., "Requirements for Modern Assembly-Systems, Explained with the Aid of Realized Systems", Proceedings of the 3rd International Conference on Assembly Automation, Stuttgart, Germany, May 1982, pp. 57-79.

[3] Yang, B., Design of an Automatic Assembly System For Jewelry Industry Applications, M.S. Thesis, University of Rhode Island, 1986.

[4] Asfahl, C. R., Robots and Manufacturing Automation, John Wiley and Sons Inc., New York, 1985.

[5] Dorf, R. C., Robots and Automated Manufacturing, Reston Publishing Company, Inc., Virginia, 1983.

[6] Kurande, H., Design of a High Speed Feeding System, M. S. Thesis, University of Rhode Island, 1991.

[7] Tweedale, J. G., Welding Fabrication - Volume II, American Elsevier Publishing Company Inc., New York, 1969.

[8] Cary, H. B., Modern Welding Technology, Prentice-Hall Inc., New Jersey, 1979.

[9] Weisman, C., Welding Handbook - Volume I, American Welding Society, Florida, 1976.

[10] Frungel, F. B., High Speed Pulse Technology - Volume I, Academic Press, Inc., New York, 1965.

[11] "Resistance Welding Systems", Unitek Equipment Division, California, 1985.

[12] Sosoka, J., "Control Pulse Polarity for Weld Strength", Elektronics Magazine, April 13, 1962.

[13] Senturia, S. D., and B. D. Wedlock, Electronic Circuits and Applications, John Wiley and Sons, Inc., New York, 1975.

[14] Brotherton, M., Capacitors: Their Use in Electronic Circuits, D. Van Nostrand Company, Inc., New Jersey, 1946.

[15] Heller, S., Understanding Silicon Controlled Rectifiers, Hayden Book Company, Inc., New York, 1969.

[16] Grabbe, E. M., S. Ramo, and D. E. Woolridge, Handbook of Automation, Computation, and Control - Volume III, John Wiley & Sons, Inc., New York, 1961.

[17] Cook, J. W., "Applying Sensors to Automatic Assembly Systems", IEEE Transactions on Industry Applications, Vol. 27 No. 2, March/April 1991, pp. 282-285.

[18] Walker, E., Automation for Press Feed Operations: Applications and Economics, Marcel Dekker, Inc., New York, 1986.

[19] Waite, M., Microsoft QuickC Programming, Microsoft Press, Washington, 1988.

APPENDIX A

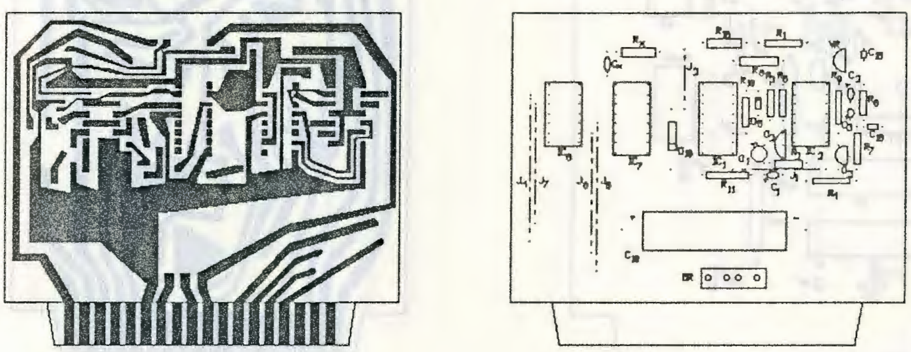
A.1 CONTROL PROGRAM SOFTWARE

The control program was written in the C programming language and is designed to run on IBM compatible personal computers. The program is broken down into several source code files: DAMA.H, DAMA.C, VOLTAGE.C, MANUAL.C, MONITOR.C, CONTROL.C, and ONOFF.C. DAMA.H is the include file which declares important variables and sets names for the port addresses. DAMA.C is the main program. VOLTAGE.C contains subroutines for welding machine voltage display and control. MANUAL.C contains the manual control subroutines. MONITOR.C contains the automatic control subroutines. CONTROL.C includes the input/output control test subroutines. ONOFF.C contains the subroutines to activate and de-activate switches. These files are compiled using Microsoft QuickC ver. 2.0 to create the executable file, DAMA.EXE.

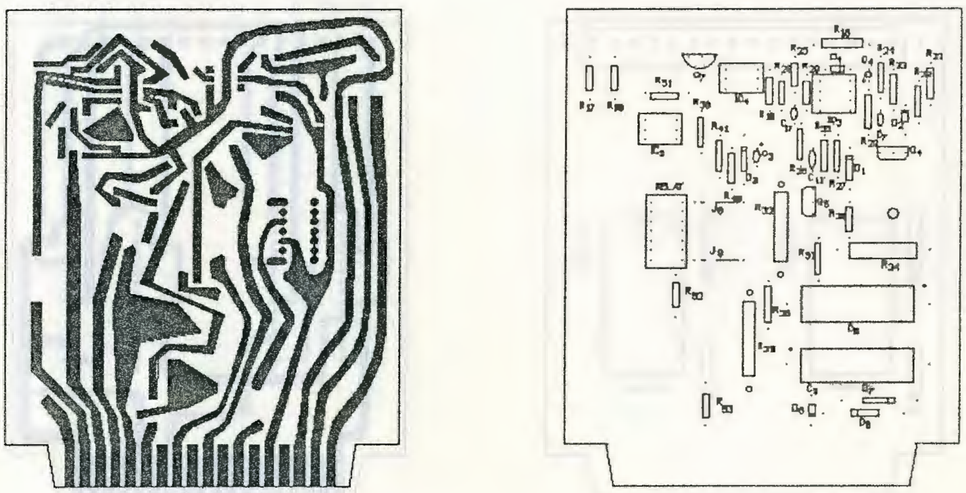
APPENDIX B

B.1 PRINTED CIRCUIT BOARD DESIGNS

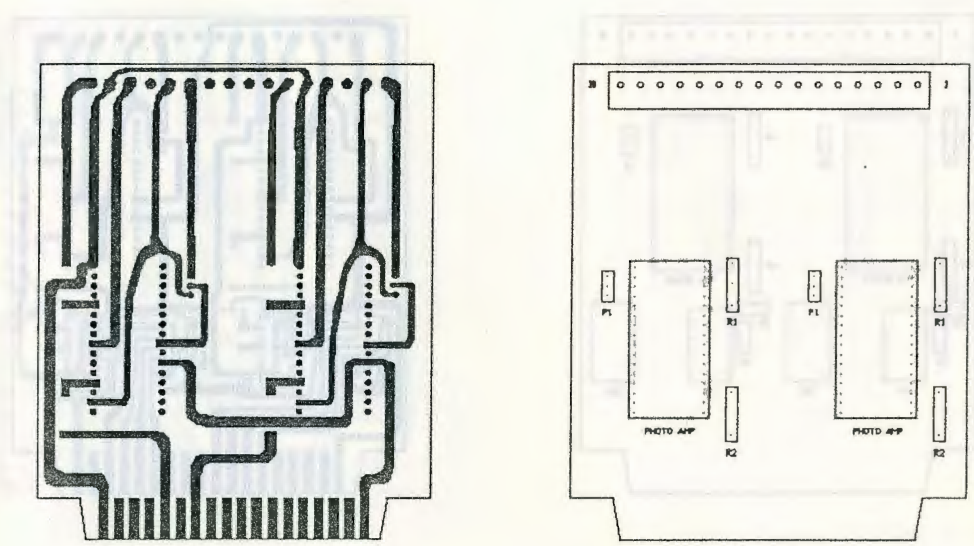
Included within this section are the layouts of the printed circuit boards designed in this project. The designs were created using EasyCAD ver. 2.0 drafting software produced by Evolution Computing. The boards were manufactured and assembled in-house.



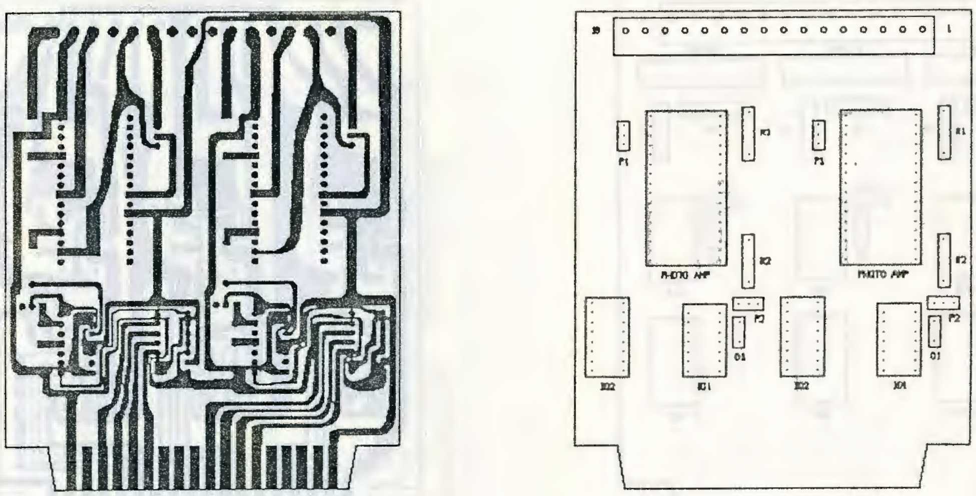
Trigger Pulse Circuit PCB



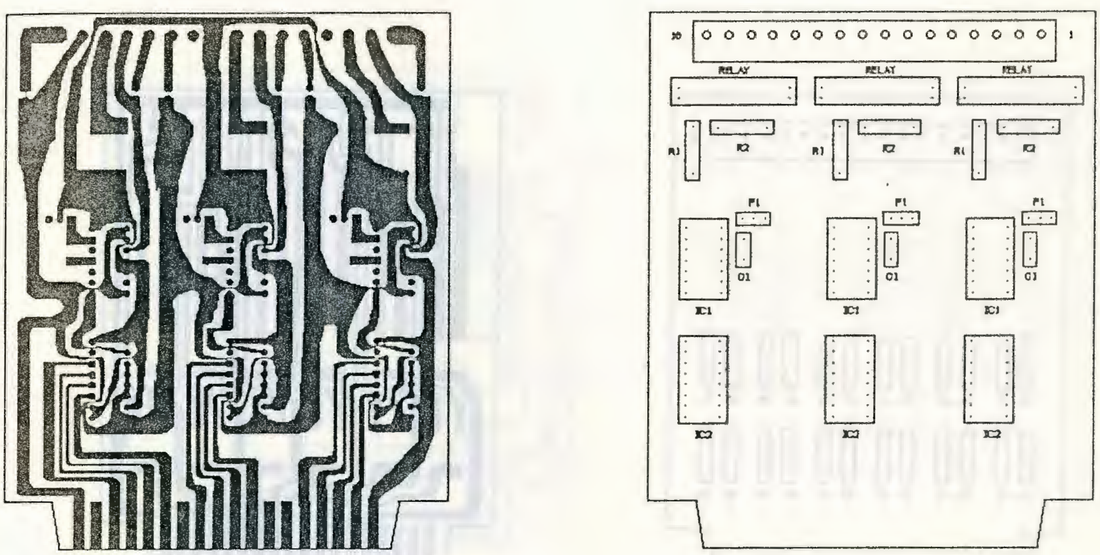
Resistor-Capacitor Control Circuit PCB



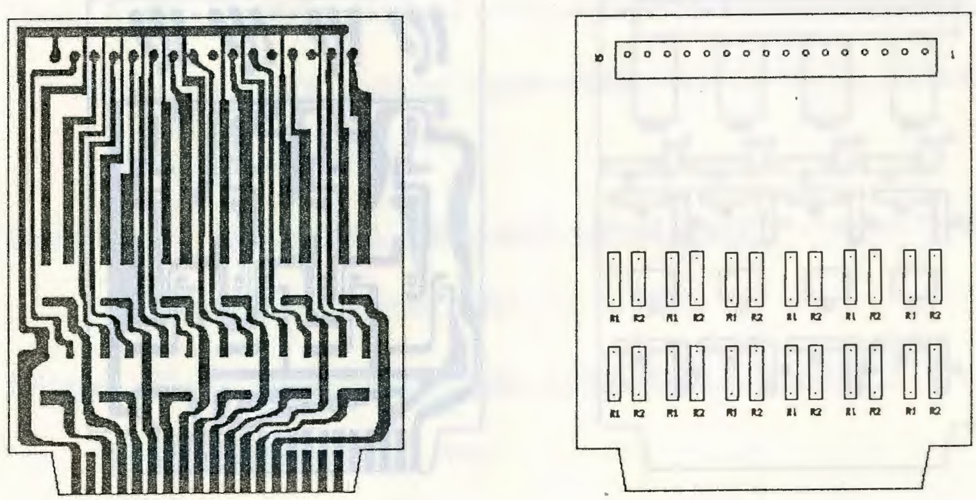
Post Level Detection Circuit PCB



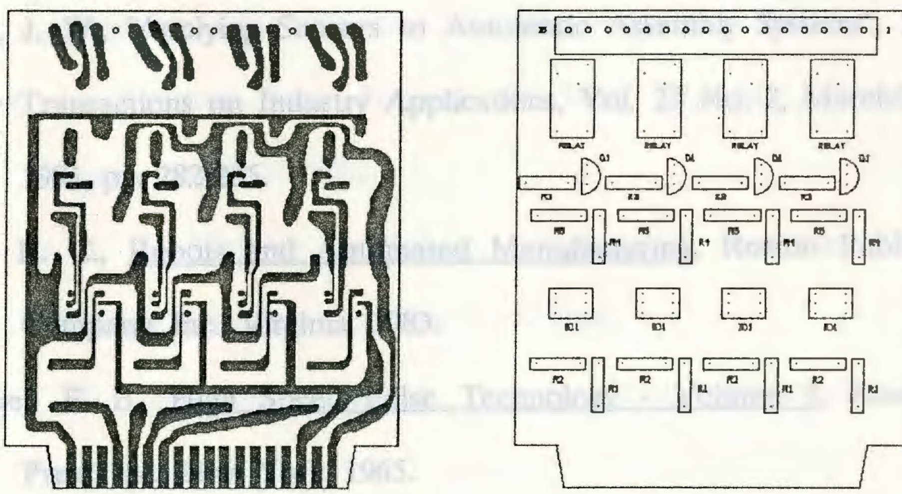
Post Detection Circuit PCB



Weld Trigger Circuit PCB



Voltage Divider Circuit PCB



Relay Interface Circuit PCB

BIBLIOGRAPHY

Asfahl, C. R., Robots and Manufacturing Automation, John Wiley and Sons Inc., New York, 1985.

Brotherton, M., Capacitors: Their Use in Electronic Circuits, D. Van Nostrand Company, Inc., New Jersey, 1946.

Cary, H. B., Modern Welding Technology, Prentice-Hall Inc., New Jersey, 1979.

Cook, J. W., "Applying Sensors to Automatic Assembly Systems", IEEE Transactions on Industry Applications, Vol. 27 No. 2, March/April 1991, pp. 282-285.

Dorf, R. C., Robots and Automated Manufacturing, Reston Publishing Company, Inc., Virginia, 1983.

Frungel, F. B., High Speed Pulse Technology - Volume I, Academic Press, Inc., New York, 1965.

Goebel, R., "Requirements for Modern Assembly-Systems, Explained with the Aid of Realized Systems", Proceedings of the 3rd International Conference on Assembly Automation, Stuttgart, Germany, May 1982, pp. 57-79.

Grabbe, E. M., S. Ramo, & D. E. Woolridge, Handbook of Automation, Computation, and Control - Volume III, John Wiley & Sons, Inc., New York, 1961.

Groover, M. P., Automation, Production Systems, and Computer-Aided Manufacturing, Prentice-Hall Inc., New Jersey, 1980.

Heller, S., Understanding Silicon Controlled Rectifiers, Hayden Book Company, Inc., New York, 1969.

Kurande, H., Design of a High Speed Parts Feeding System, M. S. Thesis, University of Rhode Island, 1991.

"Resistance Welding Systems", Unitek Equipment Division, California, 1985.

Senturia, S. D., and Wedlock, B. D., Electronic Circuits and Applications, John Wiley and Sons, Inc., New York, 1975.

Sosoka, J., "Control Pulse Polarity for Weld Strength", Elektronics Magazine, April 13, 1962.

Tweedale, J. G., Welding Fabrication - Volume II, American Elsevier Publishing Company Inc., New York, 1969.

Waite, M., Microsoft QuickC Programming, Microsoft Press, Washington, 1988.

Walker, E., Automation for Press Feed Operations: Applications and Economics, Marcel Dekker, Inc., New York, 1986.

Weisman, C., Welding Handbook - Volume I, American Welding Society, Florida, 1976.

Yang, B., Design of an Automatic Assembly System For Jewelry Industry Applications, M.S. Thesis, University of Rhode Island, 1986.