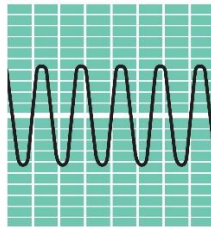


RESISTANCE WELDING APPLICATIONS AND CONTROLS



Original 1989

A - Revised 1997

B - Revised 1998

C - Revised 2000

D - Revised 2001

E - Revised 2006

F - Revised 2014

G - Revised 2016

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RESISTANCE WELDING

Also refer to RWMA Bulletin #5, Resistance Welding Control Standards
(See References, Page 62)

Resistance welding is one of the simplest, lowest cost, surest means of metal joining. An understanding of the resistance welding process is basic to making good welds. The machines, controls and fixtures are only the tools necessary to help make the weld. The process is doing the real work.

So, can technology solve resistance welding problems? Possibly, but not by itself.

Can knowledge of the resistance welding process help solve resistance welding problems? **ABSOLUTELY!**

Therefore, with a good knowledge of the resistance welding process, can technology help improve production capabilities of resistance welding equipment? Yes, if properly applied.

The road to a good weld is paved with Process Knowledge.

DEFINITION AND SHORT HISTORY

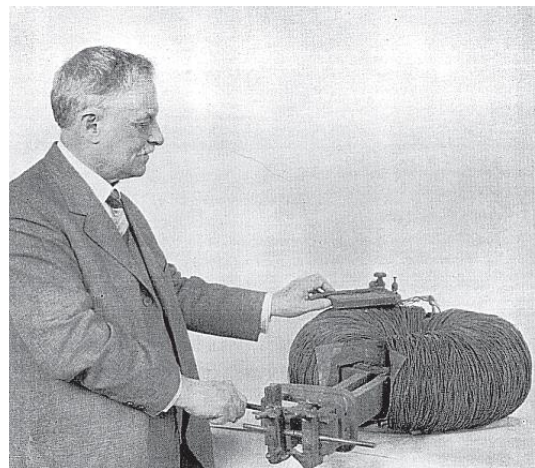
Since the “invention” or discovery of resistance welding, over 120 years ago, the definition of the process has remained unchanged.

Resistance Welding is a method of joining metals. To join two metals by resistance welding, it is necessary only to clamp them together under pressure and pass through them an electric current for a specific time. The heat generated creates a plastic state and produces fusion at the interface surfaces.

Although Resistance Welding is now over 120 years old, the joining of metals by the application of heat and pressure is much older. Phoenician artisans “welded” metals together with forge and hammer over 3000 years ago. The blacksmith also used a forge and hammer, heat and pressure.

What has changed dramatically is the technology and flexibility used in the resistance welding controls and control systems. Although any of the technologies to be discussed have the capability to produce a good weld, the range and accuracy of these various control systems may vary. During this discussion an attempt will be made to provide a better understanding of the advantages and limitations of each system along with the practical applications of the various systems.

The process of resistance welding was “invented” in 1877 by Mr. Elihu Thomson (1853-1937), founder and president of Thomson Laboratory, Lynn, Mass. Thomson was a designer and manufacturer of motors and transformers. Thomson Laboratory later merged with Edison General Electric Company to become General Electric Company. Thomson was Vice President and Director of Research for G.E.



ELIHU THOMSON AND HIS ORIGINAL
“JEW’S-HARP” WELDING TRANSFORMER

Figure 1.

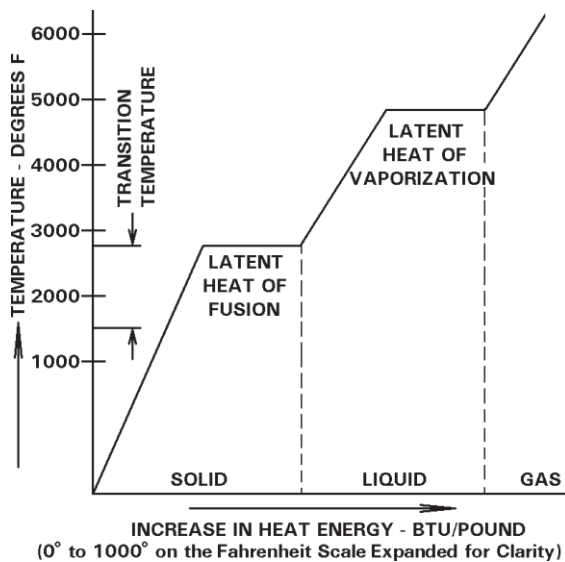
The “discovery” of resistance welding occurred while Thomson was teaching a class in electricity at Central High School in Philadelphia, demonstrating the operation of a spark coil. At the time, Thomson was Professor of Chemistry and Mechanics at the school (1876-1880).

The first practical demonstration of resistance welding was performed at the Franklin Institute in Philadelphia in 1879 and was “perfected” in 1886. It was in 1886 that the first production resistance welding machine was manufactured; a Thomson-Gibb machine.

HOW A RESISTANCE WELD IS MADE

The basics of resistance welding are quite simple. It is the application of heat energy and pressure to produce a weld. It is the proper association and application of the basics that are our real concern in resistance welding. Simply stated, heat energy is added to a system to raise the temperature to reach the plastic, or near molten, state of the materials to be welded. The changes of state of material, due to these applications of heat energy, can be explained by using water as an analogy to steel. By definition the basic functions of resistance welding are pressure, current and time.

Steel, as it is seen at most times, is in the solid state. The solid state of water is ice. As heat energy is added to ice, the ice melts and becomes liquid water. As heat energy is added to the water it becomes a gas, or steam as we recognize it. The same changes are true with a piece of steel. Recognize that both the amount of heat energy and temperatures to reach these changes of



THREE STATES OF MATTER (AS APPROXIMATED BY STEEL)

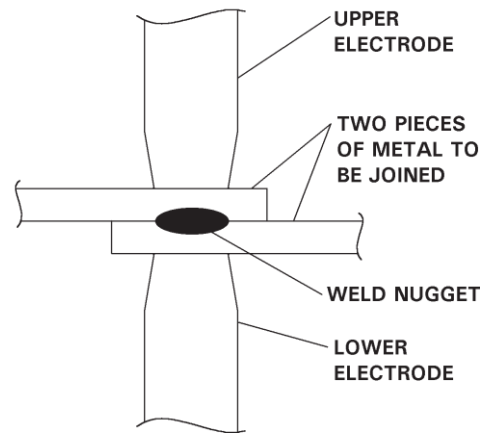
Figure 2.

state are much greater for steel than water. Water melts at approximately 32F; steel at approximately 2800F. Water boils, becomes a gas, at 212F; steel at approximately 5000F. During each change of state, heat energy must be added to cause the change of state, although during this time there is no change in temperature. Figure 2. For zinc coated steel (galvanized steel), see Figure 27 on Page 28.

The heat energy needed to change a solid to a liquid is called the Latent Heat of Fusion. The heat energy needed to change a liquid to a gas is the Latent Heat of Vaporization. Resistance welding deals with the heat energy necessary to raise the temperature of the solid to the point of the Latent Heat of Fusion and then terminating the application of heat energy before the solid is converted completely to a liquid. If the steel is converted to a liquid metal, expulsion will result. This is represented by “sparks” at the area of heat energy application.

The Latent Heat of Fusion is essentially the end of the “plastic” range of the metal. Steel has a relatively long “plastic” or transition temperature range. Aluminum and most other non-ferrous metals have a much shorter “plastic” range. This is one important reason that greater control of the resistance weld is required for most metals other than steel.

The term “Resistance Welding” comes from the fact that it is the electrical property of resistance to the flow of current of the metal being welded that causes heat to be generated when current flows through it. This is the source of the heat energy in a resistance weld. To make a resistance weld, the two pieces of metal to be joined are squeezed together by the electrodes on the welding machine so they are in good electrical contact. Then electric current is passed through them, heating them until they begin to melt at the spot where they are in contact. The metal from the two pieces then flow together forming a weld nugget. The current is then turned off and the weld nugget solidifies, forming a solid metallic connection between the two pieces. Figure 3.



WHERE THE WELD IS MADE
Figure 3.

There are two basic laws of physics involved in resistance welding:

OHM’S LAW, the relationship between the voltage, current and resistance in an electrical circuit. That is: $E=IR$. Where E is the voltage, I is the current and R is the resistance in the circuit. The R in Ohm’s Law is the R in Resistance Welding. Ohm’s Law is the Law that makes resistance welding work. Unfortunately, a violation of Ohm’s Law is almost always the reason why resistance welding does not work at any given time.

JOULE’S LAW, a unit of work energy, is the heat energy expended by an electric current of 1 ampere flowing through a 1 ohm resistance for 1 second. That is $H=I^2RT$, where H is the heat energy, I is the current squared, R is the resistance in the circuit and T is the time the current is allowed to flow. The weld control can only regulate the current (I) and the time (T). R is a variable associated with the machine set up and proper maintenance.

The effects of Ohm’s Law and Joule’s Law on resistance welding will be covered in more detail later in the text.

$$E = IR \quad H = I^2RT$$

THE THREE IMPORTANT FACTORS IN MAKING A WELD
CURRENT, PRESSURE AND TIME - (P C T)

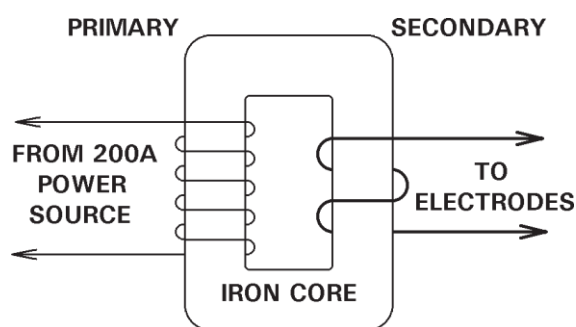
Important to the proper formation of the weld nugget between the pieces of metal being welded is the resistance of the metal, the magnitude of current, the length of time current flows, and the force squeezing the parts together. The heat energy is expressed as the square of the current times the resistance of the material times the weld time ($H=I^2RT$), Joule’s Law. The optimum value of these parameters varies with the type of metal, the metallurgy, its thickness, and its strength. Always start with the material to be welded. This is the known factor that determines the values of pressure, current, and time required to make a good weld. As an example, for commonly used low-carbon steel, 1/16" thick, a typical value of current may be about 10,000 amps; a time of approximately 1/4 second (15 cycles, at 60 Hz); and about 600 pounds of electrode force can be used to make a good weld. Resistance welding schedules are available through the American Welding Society, Resistance Welding Manufacturing Alliance, and from most welding machine manufacturers. See Page 54 for a sample chart. Always start with the material.

HOW ADEQUATE WELD CURRENT IS OBTAINED

Using the above example, current of 10,000 amps is not readily available from any standard electrical outlet. 15 to 20 amps is the maximum current available from common household and office outlets. Even in factories where large amounts of electrical energy are used, 200 amps is typical of the current available from electrical distribution circuits. Therefore, to get the 10,000 amps needed for resistance welding, some device must be used to step the current up from the relatively low level available from the power line to a higher value.

The device used is a welding transformer. Transformers are usually thought of as stepping voltage up or down, but current is also transformed in the same way. A single phase transformer consists of two coils of wire, called the primary and secondary, wound around an iron core. Power is transferred from primary to secondary via the magnetic properties of the iron.

See Figure 4. The factor by which the current and voltage is stepped up or down is equal to the ratio between the number of turns of wire in the coils forming the primary and secondary windings of the transformer. The total energy through the transformer is a constant.

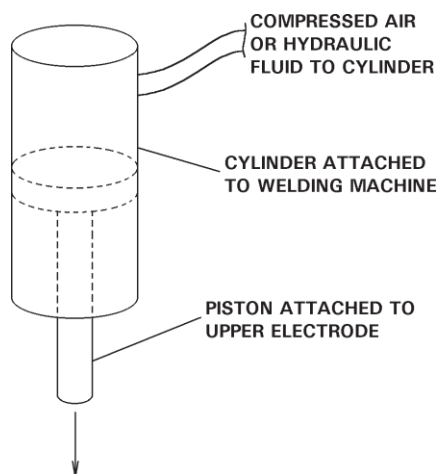


SIMPLIFIED DIAGRAM OF
A WELDING TRANSFORMER

Figure 4.

In the preceding example, where 10,000 amps were required, a transformer could be made with 100 turns on the primary and 2 turns on the secondary; a “turns ratio” of 50:1. A 200 amp current in the primary would then be transformed (stepped up) to 10,000 amps (200 amps X 50 turns) in the secondary, enough to do the welding job. In a like manner the voltage will be stepped down from, say 500 volts on the primary to only 10 volts on the secondary.

PRESSURE. HOW THE ELECTRODE FORCE IS OBTAINED



SIMPLIFIED DIAGRAM OF
THE WELD FORCE SYSTEM

Figure 5.

Another critical factor in resistance welding is the force squeezing the metal parts together (Electrode Force). This force is necessary to assure good electrical contact between the parts being welded, and to hold the parts steady until the near molten metal forming the welded joint has time to solidify. Depending on the size and type of welding machine, various methods of developing the electrode force are used. It is most common to use compressed air in a cylinder and piston arrangement. The cylinder is rigidly attached to the welding machine frame, and the moveable piston is connected to the upper electrode. Hydraulic and mechanical systems are also available.

Compressed air or hydraulic fluid introduced into the cylinder develops a force on the piston which, in turn, pushes the electrode down against the metal to be welded. Figure 5. The amount of force applied depends on the area of the piston and the pressure of the compressed air or hydraulic

fluid. In the preceding example where 600 pounds of electrode force was required, a five inch diameter piston would require an air pressure of 30 pounds per square inch to produce the force. A line pressure of 85# would be required to provide a total force of 600 pounds with a 3" diameter cylinder. See Page 14 for the Force Equation, and pressure vs. force examples.

TIMING THE WELD

Many methods have been used to control the time of a resistance weld. Even some mechanically controlled machines are still operating quite well, when less control sophistication is required. Weld controls can be grouped as three basic types: (1) mechanical and electro-mechanical; (2) analog, both vacuum tube and solid state; and (3) digital, both discrete component and microprocessor-based (including mini-computers). The following discussion on timers will describe the various types of controls available starting on Page 6.

HOW THE WELD IS CONTROLLED

The length of time the welding current flows through the two pieces of metal to be welded is very important. The device used to turn the current on and off is a critical part of the system. A mechanical device might be considered as a switching device, but would not be reliable because of the relatively slow speed and inaccuracy of operation. In the preceding example, the current must be on for only 1/4 second (15 cycles at 60Hz). It is very difficult to turn a switch on and off again in 1/4 second, and even more difficult to do it consistently. Therefore, electronic devices with no moving parts are used to switch the current on and off. Two such devices are used. The ignitron tube, which has been used for many years, is one, and the silicon controlled rectifier (SCR) is the other. Both operate by virtue of the fact that a small electrical signal applied to the device allows it to turn on in a small fraction of a second and conduct a large amount of current. Removing the electrical signal allows the device to turn off again. Fast turn-on and turn-off are possible because there are no mechanical moving parts. Ignitron tubes operate on the principle of ionization of mercury vapor, while silicon controlled rectifiers operate on solid-state semiconductor principles similar to transistors. Early systems used mechanically actuated contactors. The use of Ignitron tubes over the past few years has declined rapidly, few are in use today.

Basically, the weld control is a switch to turn the welding transformer on and off, to supply the secondary current required to help generate the heat to make a weld.

THE RESISTANCE WELDING CONTROL

It may be concluded from the preceding paragraphs that it is important to apply the welding current at the proper time during the operation of the welding machine. This is the function of the welding control; in fact, the purpose of a welding control is to coordinate the application of welding current with the mechanical motion of the welding machine. On most machines, the control system signals the electrodes when to close and when to open. On some machines, the opening and closing of the electrodes is accomplished by a mechanically actuated system. The control also signals the welding current when to start and when to stop. The welding control may be thought of as the “brains” and the machine as the “muscle” of the overall resistance welding system. The weld control is merely a switch in the primary of the welding transformer that can also provide machine programming.

MECHANICAL AND ELECTRO-MECHANICAL TIMERS

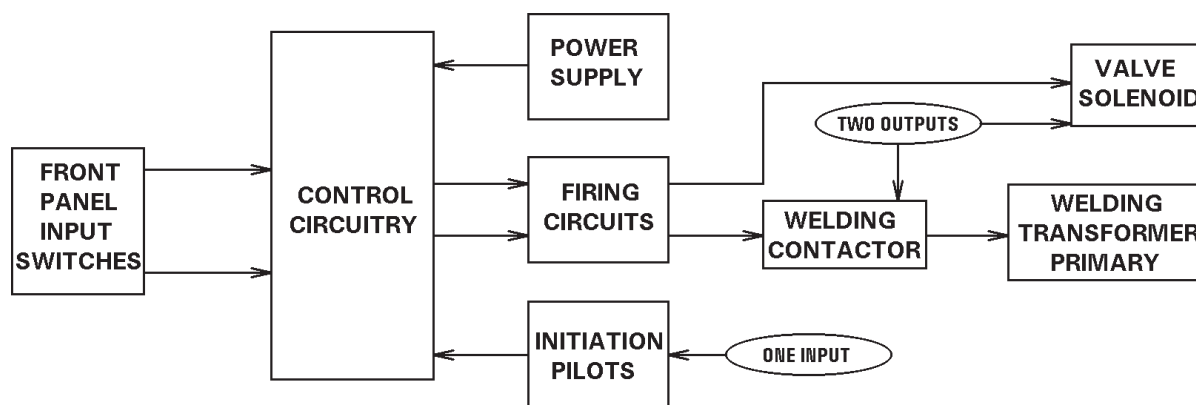
The method used very early in resistance welding to control the power to the transformer was either a mechanical or electro-mechanical type contactor. Timing was also controlled by one of several mechanical or electro-mechanical means. Rotary, split cam timers were used, as well as pneumatic timers, springs and manually operated switches. These types of timers are seldom seen in production today.

ANALOG TIMERS: VACUUM TUBE AND SOLID STATE

With the introduction of analog, resistor-capacitor (RC) time controls, users eventually gained the ability to provide better timing adjustment of the welding current. The time duration could be adjusted by a front panel switch or potentiometer, calibrated in cycles of the line frequency. This was a distinct improvement over mechanical timing. Timing accuracies of better than $\pm 10\%$ were difficult to attain and frequent calibration and service was required on these timers. Some vacuum tube and solid state analog controls are still in use today.

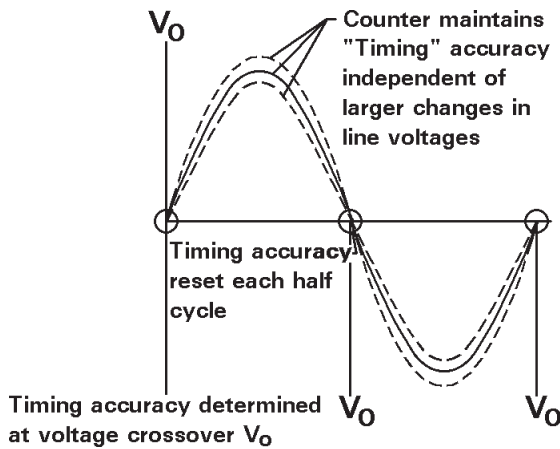
DIGITAL TIMERS: DISCRETE AND MICROPROCESSOR-BASED

There are two types of digital timers, discrete logic and microprocessor-based. Both use digital counting techniques; however, the discrete logic control is hardware driven whereas the microprocessor-based control is software driven. Simply stated, a digital circuit is either turned on or turned off; either the 0 (off) state, or the 1 (on) state of the logic, and it will never be anywhere in between. Timing accuracies are greatly improved. Using the analogy of a relay to explain the operation of a digital circuit, the relay contacts are either open (0) or closed (1).

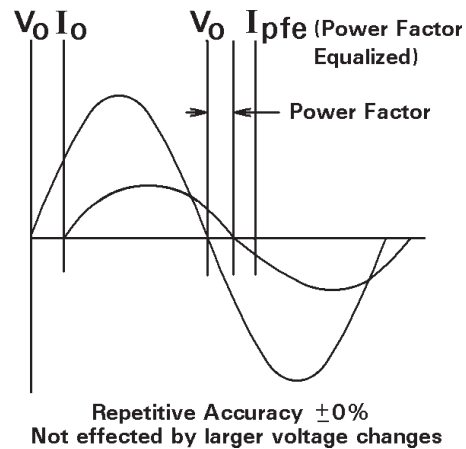


BLOCK DIAGRAM. TYPICAL BASIC ELECTRONIC CONTROL CIRCUIT
Figure 6.

A digital counting circuit counts the transitions occurring on a periodic wave function such as an alternating line voltage. The counting technique provides to the control an absolutely accurate base and repeatability. Both the count and phase shift current delay adjustment of the welding control are synchronized to the zero crossing of the line voltage, Figures 7 and 8. Since there is only an ON and OFF state in the counting circuits, the control is immune to component aging, component tolerances, severe ambient temperature changes or severe line voltage fluctuations.



DIGITAL CONTROL TIMING ACCURACY
Figure 7.



DIGITAL PHASE SHIFT CURRENT ADJUST
Figure 8.

The only difference between the current and count timing is that the count timing uses the zero crossing point of the line voltage to decrement the count until it reaches zero. Figure 7. The current timing, however, uses the zero voltage crossing to synchronize a high frequency timer that digitizes the AC waveform. After counting an appropriate number of timer transitions, based on the preset percent current adjust, the circuit turns the contactor on for the remainder of that half cycle of the line voltage. This is known as phase shift current control or percent current adjustment. Figure 8. With each new half cycle of the line voltage the sequence starts over, exactly duplicating the previous half cycle. Phase shift (percent current adjustment) and power factor are discussed later.

An additional feature often provided with digital controls is a dynamic automatic power factor equalization circuit, which will be discussed in detail on Page 20. The automatic power factor equalization circuit provides a means of maintaining a constant and accurate relationship between the front panel switch setting of the percent current (phase shift heat control) and the actual percent current at the electrodes. Figure 8. The use of an automatic power factor equalization circuit eliminates the need to adjust or recalibrate the control for changes in the power factor of the machine. This is true on installation of the control, changes in tooling, changes in the configuration of the secondary of the machine, or when replacing control components for service.

DISCRETE DIGITAL LOGIC CONTROLS

Digital resistance welding controls were introduced using discrete digital logic circuits to overcome many disadvantages of the analog control. In most cases the control circuitry was reduced to a single circuit board, since the size and number of components required for digital controls could be reduced. Manufacture, installation, and service was simplified and reliability increased substantially.

MICROPROCESSOR-BASED CONTROLS

The next evolution in control technology involved the application of the microprocessor to control circuitry. The same techniques used in the discrete logic controls were transferred from hardware to software for microprocessor-based controls. Flexibility is increased due to the use of multifunction hardware under the control of the software package. The microprocessor's ability to perform mathematical calculations also allows for an increase in tracking accuracy of the percent current setting to actual current over a greater range of machine power factors. In addition, hardware that may have previously been located on an outboard option assembly is now located on the control board. Expandability and versatility are increased while the number of components can be reduced.

CONCLUSIONS

The three basic types of control technologies – mechanical, analog, and digital – are all used to perform the same process functions. Each is capable of making a good weld. The main difference between the technologies is accuracy and flexibility. All of the technologies are in use in industry today; however, the older mechanical and analog units are being replaced as maintenance costs become prohibitive and replacement parts become more difficult to obtain.

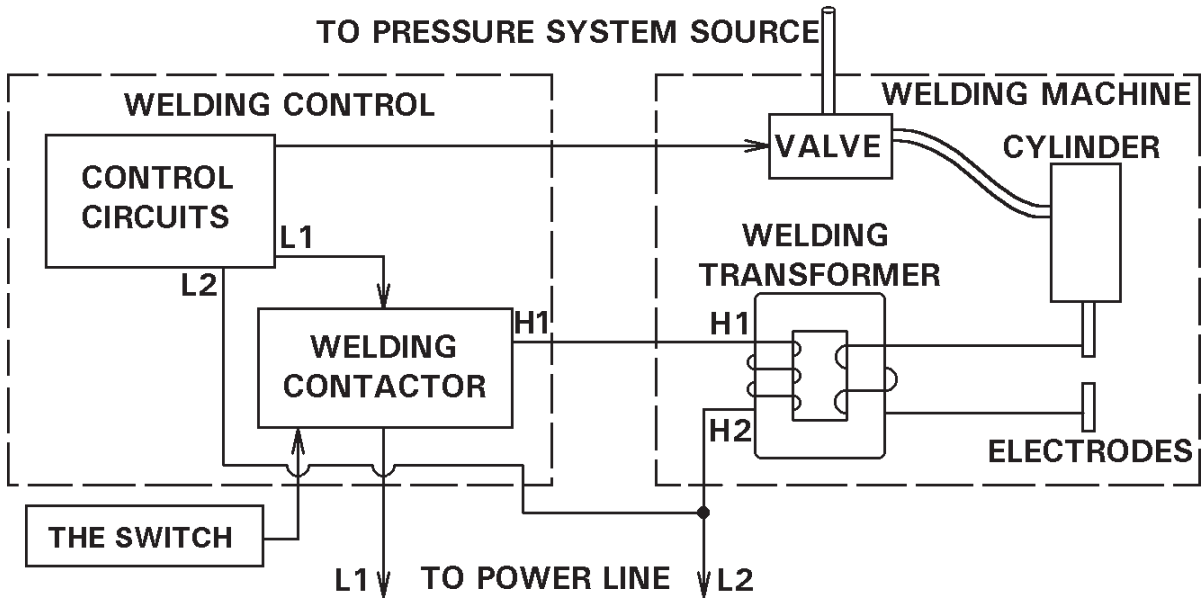
Welding control technology has changed while the process it controls has merely been refined. The control has become so accurate that the tolerances of other components of the process such as material, pressure, and electrode condition contribute a significantly greater error into the process than does the control.

Microprocessor-based controls can be programmed to store many schedules that can be recalled in seconds to minutes by front panel switch access. Although the control may be reprogrammed in minutes, it often takes hours to re-setup a machine.

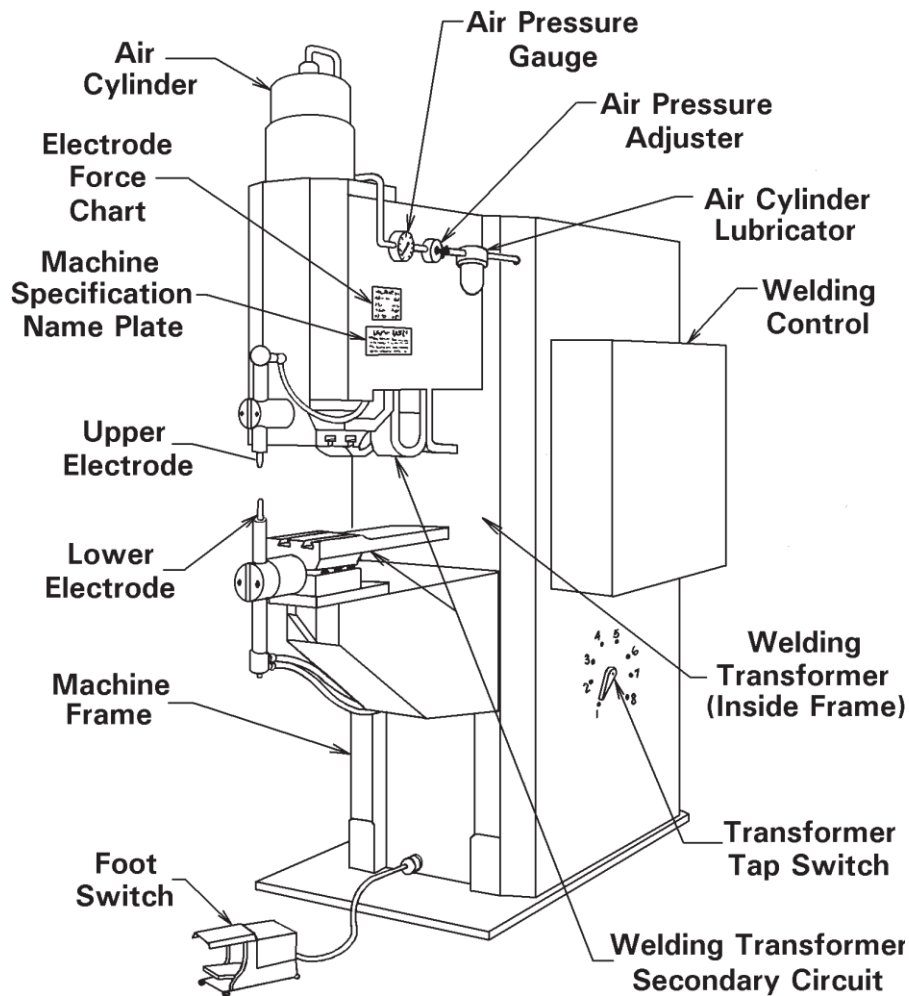
Selection of a resistance welding control today is limited only by the level of sophistication required by the user for weld production versus the relative cost of the control equipment.

HOW THE WELDING CONTROL IS CONNECTED TO THE WELDING MACHINE

Since the basic welding control provides control of the welding current and may control machine motion, it may produce two control signals; one to turn the contactor (SCRs or ignitron tubes) on or off (for current control) and one to turn an electrically operated valve on or off (for machine control). On some mechanically actuated controls, no valve output signal is required. On more complex, microprocessor-based controls, multiple valve outputs can be or are provided. The SCR or ignitron tube contactor basically performs a switching function and is connected in series with the welding transformer in much the same way any switch is connected in series with its load. Note also that the contactor is connected in the primary rather than the secondary circuit of the transformer, because the current requirements are lower in the primary. See Figures 9 and 10 on Page 9.



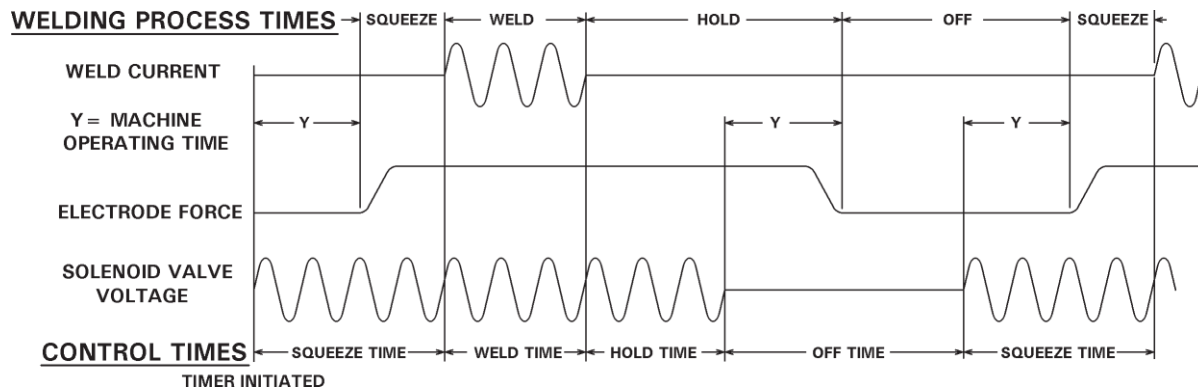
SIMPLIFIED DIAGRAM. MACHINE AND CONTROL HOOK-UP
Figure 9.



PARTS OF A TYPICAL PRESS TYPE WELDING MACHINE
Figure 10.

BASIC WELDING SEQUENCES AND DEFINITIONS

Figure 11 explains, with line drawings, a typical basic spot welding sequence. The “Welding Process Times” at the top describe the welding machine operating time intervals, while the “Control Times” line at the bottom refers to the front panel settings on the welding control.



TYPICAL SINGLE PHASE SPOT WELDING SEQUENCE

Figure 11.

See also Page 26, Spot Sequence

The following definitions may help in understanding this drawing:

Squeeze Time is the welding process time interval between the initial application of the electrode force on the work and the first application of weld current. Note that this is the process definition. The control definition is the time interval between sequence initiation and the beginning of weld current. Squeeze Time is necessary to delay the turn on of weld current until the electrode force has built up to the required welding force. The control Squeeze Time must be empirically set to meet the mechanical motion of the pressure system. If welding current is turned on before the required force is attained, there will be metal expulsion. If welding current is on before the electrodes meet the workpiece, the resulting arcing will cause extreme metal expulsion and may cause damage to the tooling and create a possible hazard to personnel. Weld schedules are available in the RWMA and AWS manuals.

Weld Time is the time during which welding current is applied to the work in making a weld. Weld Time is measured in cycles of line voltage, as are all timing functions. One cycle is 1/60 of a second in a 60Hz power system. In the U.S. the line frequency is universally 60Hz (60 cycles per second). In other parts of the world, 50Hz is more common. Know the material to be welded so that a proper weld time can be selected.

Hold Time is the time during which electrode force is maintained on the work after the last cycle of welding current ceases. Hold Time is necessary to allow the weld nugget to solidify before releasing the welded parts. This is a forging process. For some metals, Hold Time may be critical, for example, HSLA steels and aluminum.

Off Time is the time during which the electrodes are off the work in a repeat cycle. The term is only applicable where the weld sequence is repetitive (control set to “REPEAT”). Off Time is the time necessary to move the work between weld sequences.

NOTE: Please also refer to RWMA Bulletin #5 for a complete list of welding control function definitions (See References, Page 62).

WELD CURRENT AND PHASE SHIFT CURRENT CONTROL

In resistance welding two means are used to vary the heat energy at the electrodes. One is the tap switch setting of the welding transformer and the other is percent current adjustment of the welding control. This adjustment is also called phase shift current control, or phase shift heat control.

The heat energy at the electrodes is the product of the area under the voltage curve and the resultant current curve during the weld time. In most resistance welding applications, AC line voltages are applied to the welding transformer. The wave form is sinusoidal. The wave form starts at a zero voltage point and rises to a maximum positive value, then decreases to zero. The wave form then crosses zero and decreases to a maximum negative value before returning to zero. One positive and one negative transition make up one cycle. At 60HZ one cycle is 1/60th of a second or 16.67ms. There are 60 cycles in one second.

Changing the transformer tap is typically the coarse adjustment. Figure 12. The fine adjustment is made using the phase shift heat control circuitry of the weld control, which is used to delay the turn-on of the current at some point after voltage zero (see Figure 14).

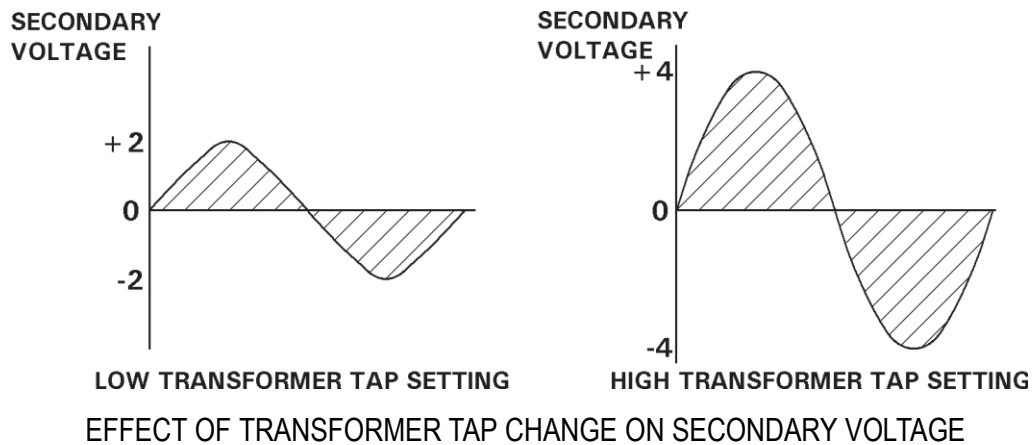
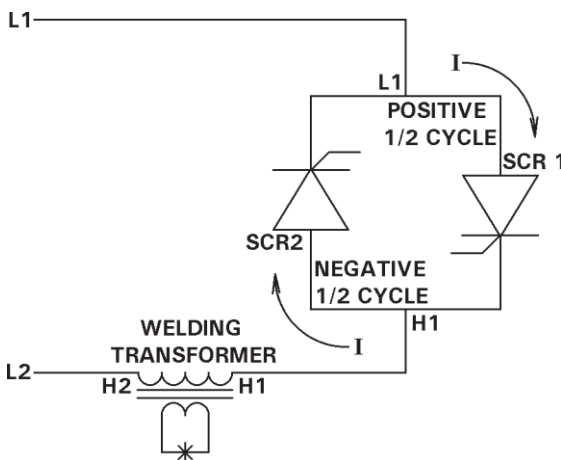


Figure 12.



SIMPLIFIED DIAGRAM OF CURRENT IN AN SCR CONTACTOR Figure 13.

The energy to the welding transformer is conducted through the welding contactor in the welding control. Only electronic contactors are capable of providing phase shift current control. Electronic contactors use two devices, usually SCRs or ignitron tubes, connected in inverse parallel. For our discussion, the example will be the SCR contactor. Figure 13.

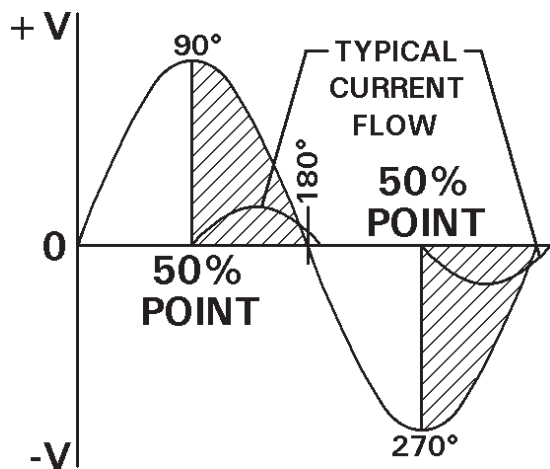
A welding contactor, in its simplest form, is merely a latching switch. Electronic contactors are latching in nature. Once the contactor is turned on, it will stay on until the current through it or the voltage across it decreases to zero. SCR and ignitron tube contactors are bi-polar switches. Two devices are required, one to conduct on the positive half cycle and the other to conduct on the negative half cycle of the voltage wave form.

To control the heat energy to the electrodes using an SCR contactor, the amplitude of the voltage at the electrodes does not change. Voltage change is accomplished by adjusting the welding transformer tap switch. The amount of time the current flows through each individual SCR, during each half cycle, can be changed by adjusting the welding control's phase shift current adjustment. Remember, the welding control phase shift current adjustment DOES NOT change the amplitude of the voltage at the electrodes.

The welding transformer tap switch changes the amplitude of the voltage wave form. The phase shift current control is used to adjust the time the current is turned on in each half cycle of the voltage wave form. Phase shift current control, in effect, modulates the width of the current pulse in each half cycle.

Electronic weld controls typically have circuitry that track the AC line voltage. Most controls will base the initiation of timing (Squeeze, Weld, Hold or Off) on the positive half cycle transition. Circuitry is also required to track the positive, negative and zero condition of the line voltage for complete control operation.

The condition of the line voltage (positive, negative or zero) is critical to the operation of a phase shift current control circuit. For example: if it is desired to set the phase shift current control to deliver 50% of the available heat energy of a particular welding transformer tap setting to the transformer, the welding current must be turned on at 50%, the 90 and 270 points



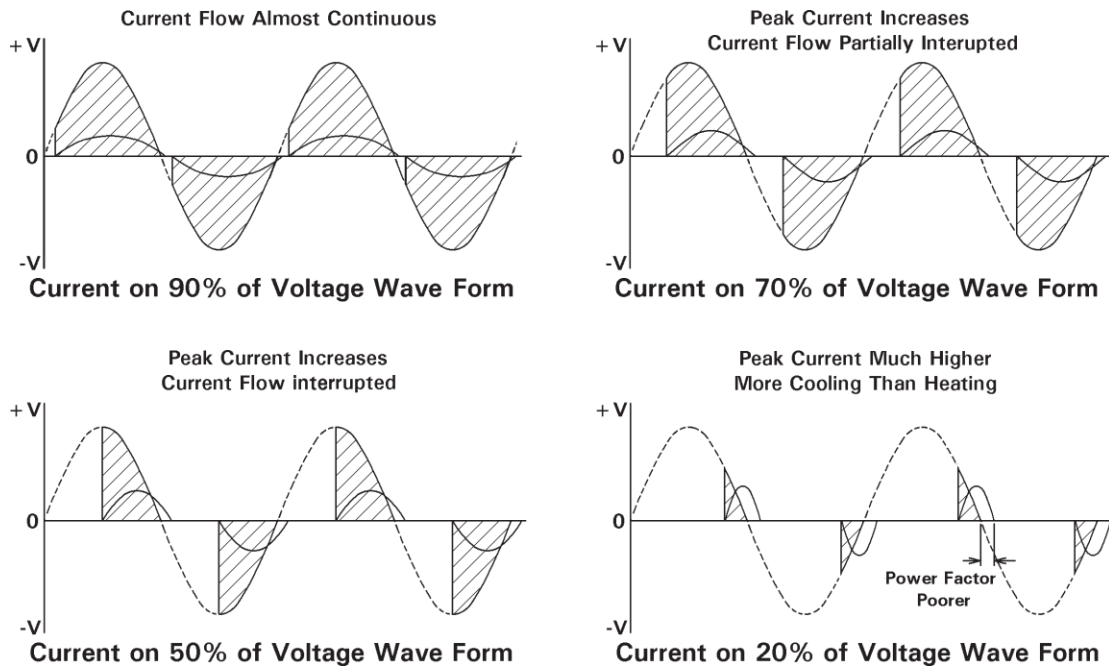
BALANCED VOLTAGE WAVE FORM AT 50% PHASE SHIFT CURRENT SETTING

Figure 14.

of the line voltage wave form (see Figure 14). This is accomplished by turning the electronic welding contactor on, in each half cycle, at the 50% point of the voltage wave form. In order to maintain balanced voltage to the transformer, an equal number of both positive and negative half cycles MUST be delivered to the transformer. Figure 14.

The overall accuracy of the phase shift current control in an analog control is usually not better than the 10% tolerance of potentiometers used for the energy adjustment. Digital phase shift current controls can adjust the turn-on of the current to within less than 3% absolute accuracy and 0% repetitive accuracy. Adjustment is usually made in 1% incremental steps.

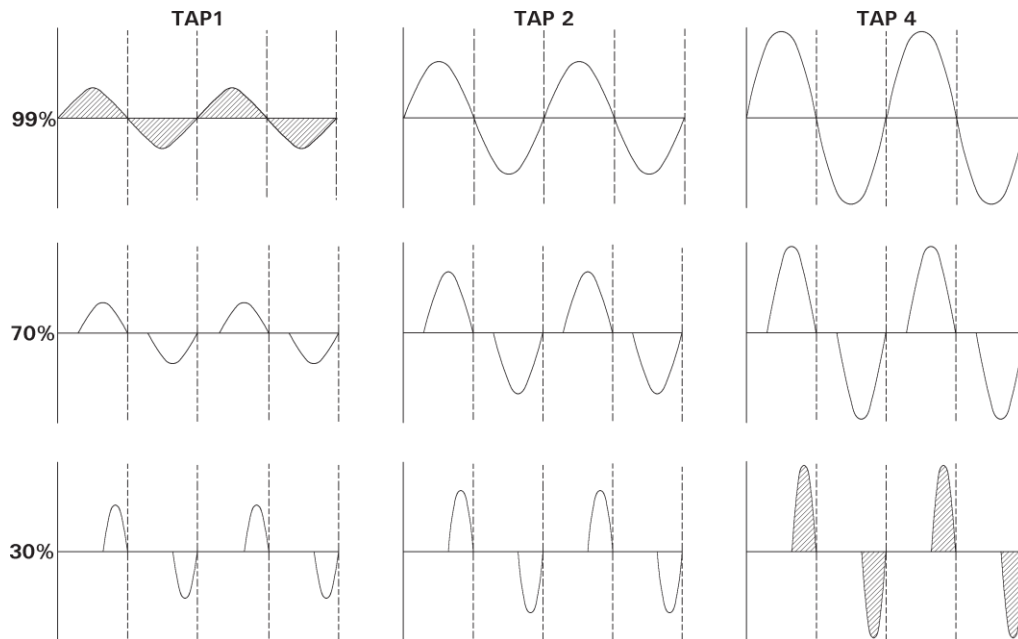
Figure 15 on Page 13 shows the relationship of the percent current for different values of the welding control phase shift current adjustment. Percent current adjustment of the weld control determines the percentage of the current available at a given tap switch setting. Low percent current settings are NOT normally recommended. Adjust the tap switch so that proper welding current can be obtained with the percent current usually set between 70% and 90%. It will be noted that at a 20% current setting there is more cooling than heating. A poor setting for good welding practice. It is recommended that the only time the percent current should be set below 70% is when the tap switch is on its lowest tap setting and 70% current is still too high. Further discussion regarding the percent current adjustment relative to weld quality, power factor and thermal considerations of this adjustment will follow. See also Page 24 for weld set-up procedures.



EFFECT OF CHANGES IN CONTROL PERCENT CURRENT ADJUSTMENT

Figure 15.

Figure 16 illustrates the relative relationship between the tap switch setting of the welding transformer and the phase shift current setting on the weld control. It can be seen that at a 30% phase shift setting on tap 4 of the transformer, the energy available for the weld is about the same as the 99% phase shift setting on tap 1 of the transformer. The area under the current curves are about equal. Operating on the lowest tap of the transformer and the highest phase shift setting on the control will produce the most efficient electrical and thermal operating conditions for the machine. See also Pages 24, 25 and 51.



PERCENT CURRENT CHANGE SETTING OF THE CONTROL AS RELATED TO CHANGES IN THE TRANSFORMER TAP

Figure 16.

ELECTRODE FORCE

Electrode force is most commonly provided by pneumatic or hydraulic systems. This force is the result of pressure applied to the piston of a cylinder connected directly to the welding head. The actual amount of electrode force depends on the effective line pressure, weight of the head, and the piston diameter. Most welders have electrode force charts on the side of the machine, tabulating air pressure vs. electrode force. If there is no chart available for the machine, use the following formula to calculate the approximate total weld force:

Electrode Force $F = \pi \times D^2/4 \times P$ or $.78 \times D^2 \times P$ (.78 is approximately equal to $\pi/4$)

D is the Piston Diameter in inches

P is the Line Pressure in pounds per square inch

Electrode Force (F) is in pounds.

To calculate the Line Pressure required to produce a desired electrode force, this formula can be reconfigured as follows:

$$\frac{\text{Electrode Force}}{.78 \times D^2} = \text{Line Pressure (P)}$$

For example, to attain a 600# total weld force for various cylinder diameters:

A 3" diameter cylinder would require approximately 85# line pressure.

A 4" diameter cylinder would require approximately 50# line pressure.

A 5" diameter cylinder would require approximately 30# line pressure.

These formulas and examples do not allow for dead weights and friction in the cylinder or ram of the machine. When changing electrode force on air operated machines, from one value to a greatly different value, it may be wise to readjust the speed control valve on the welder also. Too slow an approach wastes time and may require a longer squeeze time. Too fast an approach impacts the electrodes on the workpiece and shortens the electrode life. The impact force may also damage the electrode holders or head and can damage the workpieces as well. When projection welding, high impact may flatten the projection before welding, resulting in poor projection welds, even when all other settings are correct (see Page 49).

A solenoid valve is used to actuate the piston in the weld cylinder. The solenoid valve is typically an electrically operated valve in the compressed air or hydraulic line connected to the cylinder on the welding machine. When the welding control applies voltage to the valve, it opens, allowing compressed air or hydraulic fluid to enter the cylinder to develop the electrode force.

RESISTANCE WELDING CONTACTORS

The primary function of a resistance welding control is to act as the switch (contactor), closing the primary circuit of the resistance welding transformer to the power line. Three different types of contactors have been used in resistance welding:

Mechanical

Electro-mechanical

Electronic

MECHANICAL CONTACTORS

The first mechanism used to close the primary circuit to a welding transformer was the mechanical contactor. Mechanical contactors are not now commonly used in production applications.

ELECTRO-MECHANICAL CONTACTORS

Electro-mechanical contactors were simply mechanical contactors actuated by connecting the mechanical contacts to an electric solenoid. Electro-mechanical contactors are also not now commonly used in production applications.

ELECTRONIC CONTACTORS

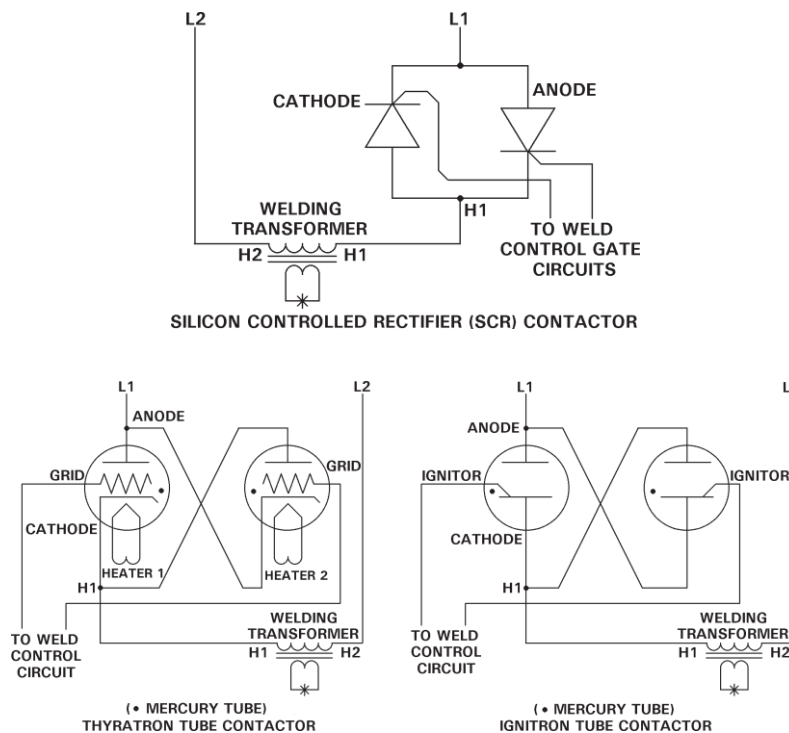
Three electronic contactors have been used in resistance welding:

Thyratron Tube (No longer commercially available)

Ignitron Tube (Limited use)

Silicon Controlled Rectifier (SCR)

Each electronic device (thyatron tube, ignitron tube or SCR) can only conduct current in one direction. Therefore, electronic contactors are composed of two conducting devices connected in inverse parallel, electrically “back-to-back,” to form the AC bi-polar switch to complete closure to the resistance welding transformer. Contactor circuits are as shown in Figure 17.



SIMPLIFIED DIAGRAM OF ELECTRONIC WELDING CONTACTORS

Figure 17.

THYRATRON TUBE CONTACTORS

The thyatron tube contactor is a thermally excited mercury vapor vacuum tube contactor. These tubes are, essentially, no longer commercially available.

IGNITRON TUBE CONTACTORS

The ignitron tube contactor uses two electrically excited mercury vapor vacuum tubes. The mercury in the ignitron tube is electrically excited to vaporize when a voltage signal is applied to the ignitor of the tube causing the tube to conduct. Ignitron tubes most commonly used as contactors are B, C, Jumbo C (C-1/2) and D. The A tube is seldom used today. Size E and F tubes have also been used.

The use of ignitron tubes is limited to existing controls in the field. Ignitron tube contactors are quite large and can occupy more than 5 times the space of a comparable SCR contactor.

Another disadvantage of the ignitron tube is that it will not conduct at the zero cross of the line voltage. Ignitron tubes require a moderately high energy level to cause the mercury to vaporize and for the tube to conduct. Ignitron tube contactors cannot be initiated below a 20% phase shift (480V) or 40% phase shift (240V).

Ignitron tubes must be water cooled. The relationship between the outlet water temperature and inlet temperature is important in determining water flow. All contactors should be equipped with a temperature limit switch to protect the contactor from overheating. The following table lists the tube manufacturer's recommendations for cooling ignitron tubes:

TUBE MANUFACTURER'S COOLING RECOMMENDATIONS

Typical cooling requirements at 500 VAC operation in GPM.

Maximum water outlet temperature 50C (122F).

Minimum suggested water hose length, tube to tube and tube to ground is 18".

IGNITRON TUBE SIZE				
WATER INLET				
TEMPERATURE	B	C	C ½	D
15C (59F)	1/4	3/8	1	1-1/2
30C (86F)	½	½	1-1/2	2
40C (104F)	1-1/2	1-1/4	1-1/2	3

Water Flow in Gallons per Minute (GPM)

Table 1.

SILICON CONTROLLED RECTIFIER (SCR) CONTACTORS

The SCR, like the ignitron tube, is an electrically excited device. However, the medium to be excited is a solid state silicon wafer in the SCR, rather than liquid mercury in the ignitron tube. The electrical signal from the control is applied to the gate of the SCR causing the silicon to become a conductor. Two SCRs connected in inverse parallel are required to form a contactor. SCR contactors are furnished by control manufacturers in ranges from about 70 amps to 300 amps as air cooled contactors. Water cooled contactors range from about 600 amps to about 5000 amps. The failure mode of an SCR contactor is almost always a short circuit. The contactor, at this point is ALWAYS CONDUCTING electric current.

SCR contactors are able to conduct, essentially, at the point where the line voltage crosses at zero voltage. For this reason, an SCR contactor can be phase shifted to near zero. For most

welding applications, the practical limit is usually set at about 20% by most manufacturers. The practical application for welding below 50%, much less 20%, is limited to very special applications. The SCR also has a greater thermal efficiency than the ignitron tube.

Although some SCR contactors may be air cooled, most SCR contactors do switch high currents, requiring water cooling to dissipate the heat. Larger SCR contactors are furnished with external water cooled heat sinks to remove the heat from the SCR. Again, all contactors, air or water cooled should be equipped with a temperature limit switch to protect the contactor from overheating. The following table lists the cooling requirements published by the SCR manufacturers for various size SCR contactors.

MANUFACTURER'S RECOMMENDED
SOLID STATE COOLING REQUIREMENT

Minimum suggested water hose length, SCR to SCR and SCR to ground is 18".

70 to 300 Amp contactors	— Air cooled - be sure openings in cabinet are kept free from obstructions. Note: Some high duty cycle 300 ampere contactors may be water cooled.
600 and 1200 Amp contactors	— Minimum 1 GPM at 40C (104F) maximum inlet water temperature. Note: There are some air cooled 600 ampere contactors.
Larger than 1200 Amp contactors	— Minimum 1 ½ GPM at 40C (104F) maximum inlet water temperature.

Table 2.

BE SURE POWER TO WATER COOLED CONTACTORS IS TURNED OFF WHEN WATER IS TURNED OFF. With voltage applied most water will ionize and begin to conduct current between heat sinks on many contactors. This current is sufficient to heat the water past the boiling point, creating steam and possibly causing the rubber hose to burst. The water spraying over the high voltage circuits can cause considerable damage to the contactor and most likely, the control circuitry as well. Never use metallic or other conductive tubing to plumb a water cooled resistance welding contactor. Heater hose has a very high carbon content and should not be used for contactor plumbing. It is recommended that all water cooled SCR contactors be plumbed with a minimum 18" water hose.

Some water cooled SCR contactors employ electrically "cold" heat sinks. That is, water does not contact the high voltage portion of the SCR. For electrically "cold" heat sinks, power on without water flow is not a concern, but for most water cooled contactors:

**WATER OFF ! POWER OFF
POWER ON ! WATER ON**

Even where electrically “cold” heat sink contactors are used, it is still recommended to use 18" of hose. Also follow the procedure of “Water Off - Power Off”. In this way any confusion over contactor plumbing and operation is eliminated.

FOR ALL WATER COOLED CONTACTORS

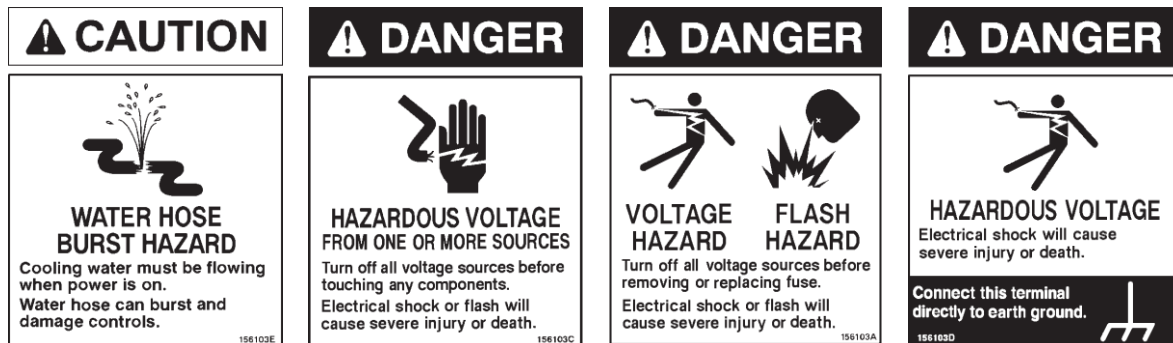
For all water cooled contactors, be sure water is turned ON and FLOWING before placing welder in operation. An open drain is recommended for best operation. If a closed return system is used, be sure the return line is properly sized and fully open so that back pressure will not reduce water flow below recommendations. A sight flow indicator is recommended on closed circuit systems.

**WATER OFF – POWER OFF
POWER ON – WATER ON**

Water cooling for the contactor should be run in a plumbing circuit separate from water used to cool either the welding transformer or electrodes. Water run serially from the transformer or electrodes to the contactor may become too hot to sufficiently cool the contactor. Contactor failure may result.

DANGER: Voltages on all contactors are LETHAL. DO NOT change fuses with power on. Serious injury may result.

RWMA WARNING LABELS FOR WELDING CONTROLS:



(Used only on controls with water cooled contactors)

These and other RWMA Warning Labels are applied to all welding controls. See RWMA Bulletin #1. Please observe these warnings of CAUTION and DANGER to avoid any instance of severe personnel injury or death that may result from contact with Hazardous Voltages or improperly grounded equipment. See also RWMA Bulletin #5 (refer to Page 62 for ordering information).

WELDING CONTACTOR SIZING

Resistance welding transformers carry a nameplate listing a KVA rating. The KVA rating of a resistance welding transformer is a thermal KVA rating, not an electrical KVA rating. The 50% Duty Cycle rating of a transformer provides that with the transformer turned on for 30 seconds and turned off for 30 seconds, the transformer can operate continuously without exceeding its thermal rating. Although several characteristics of the transformer construction may vary, there is a “rule of thumb” which can usually be used to size a resistance welding contactor to a welding transformer:

$$\frac{\text{Transformer Nameplate KVA X 1000}}{\text{Nominal Line Voltage}} \times 3 = \text{Maximum Instantaneous Demand Current}$$

The multiplier of (3) in this formula assumes a reasonable secondary configuration with a machine power factor of about 40%. The Maximum Instantaneous Demand Current is the maximum current the contactor might attempt to conduct under a worst case condition.

For example. Using a 75 KVA transformer, at 230 VAC:

$$\text{Max. Current Demand} = \frac{75 \times 1000}{230} \times 3 = 978 \text{ Amperes}$$

or a 250 KVA transformer operating at 460 VAC:

$$\text{Max. Current Demand} = \frac{250 \times 1000}{460} \times 3 = 1630 \text{ Amperes}$$

To properly size the contactor, two other parameters must be considered: welding duty cycle and contactor conduction time. Conduction time, in cycles of the line frequency, is the time the welding transformer is conducting weld current; the Weld Time setting on the control. The welding duty cycle is the Weld Time divided by the sum of all other machine times, including the Weld Time, machine sequence time and all loading and unloading times.

$$\frac{\text{CYCLES per WELD X WELDS per MIN.}}{3600 \text{ CYCLES per MIN.}} = \text{MACHINE DUTY CYCLE}$$

For spot welders, the machine duty cycle seldom exceeds 10% and is usually about 1%. For seam welders, the machine duty cycle is often near 50%, but is usually about 30%. Tube mills will run at essentially a 100% duty cycle.

Many control manufacturers and most SCR manufacturers publish charts of Duty Cycle versus Demand Current for various conduction times for many sizes of SCR and ignitron tube contactors. Figure 18 is a sample Demand Current vs. Percent Duty Cycle Chart for a 30 cycle conduction time. If the conduction time is less, the curve will rise on the left side of the chart. If the conduction time is greater, the curves will drop below the curves, as presented, on the left side of the chart. Contact your contactor or control manufacturer for the specifications of the contactor in use in your control.

RWMA is presently establishing standards for SCR contactor ratings.

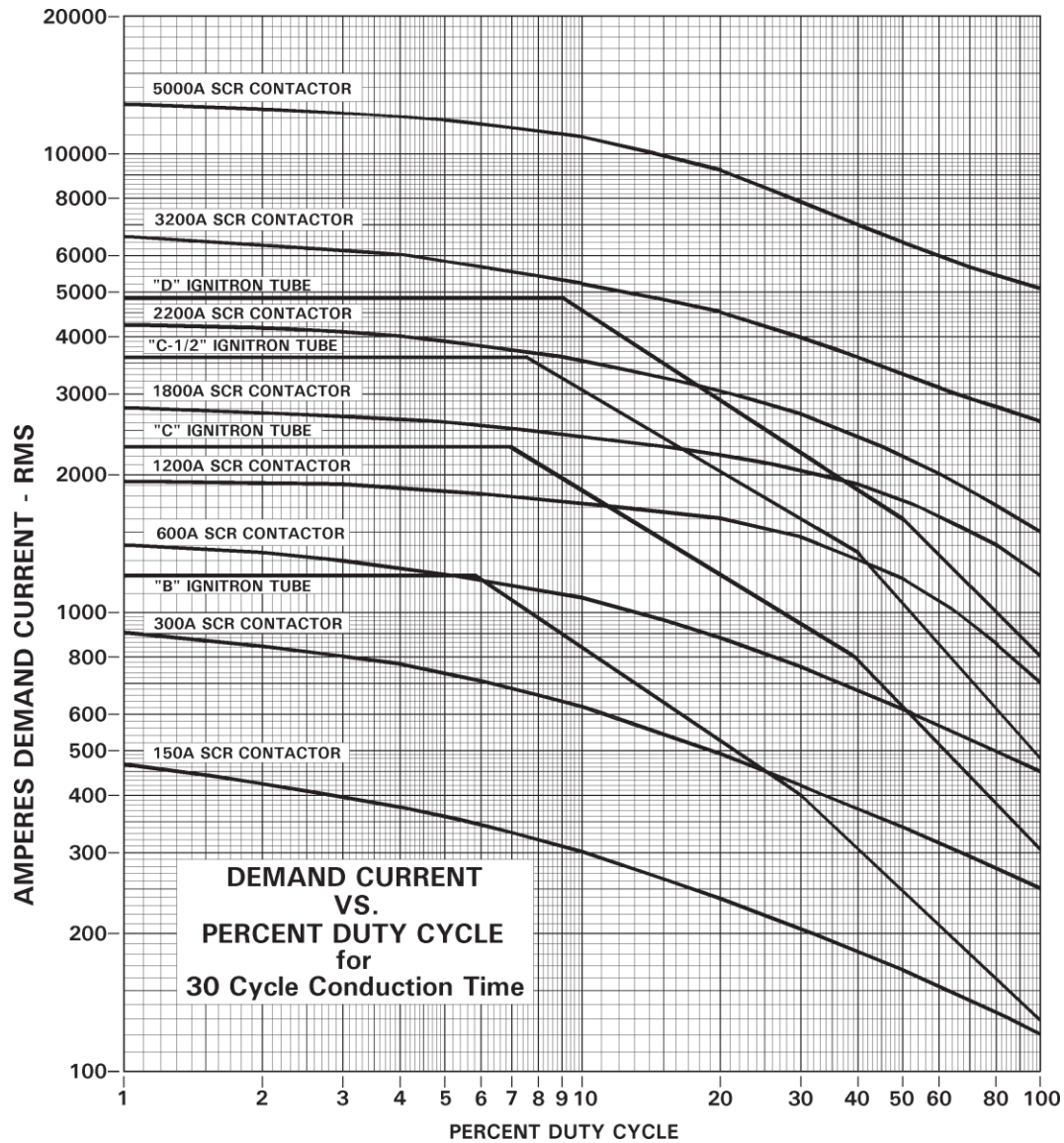


Figure 18.

POWER FACTOR AND PERCENT CURRENT

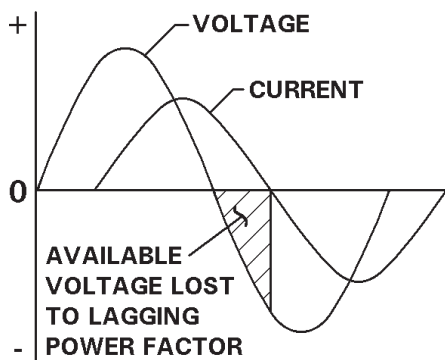
POWER FACTOR

In resistance welding, the weld transformer is the device used to transform and isolate the high line voltages on the primary of the transformer from the lower voltage on the secondary windings. Transformers are constructed by winding wire on an iron core. Refer back to Figure 4. This also is the basic construction of what is called an inductor. Inductors, in electronic circuitry, try to keep the current through their terminals constant. For instance, when a motor, which is made up internally with coils of wire wound around steel, is abruptly removed from the power source, a spark can be drawn across the disconnecting contact or plug. This is because, at the instant the motor (inductor) sees the change in current on its terminals, it does all it can, by dumping whatever stored energy it contains in its core, to keep the current constant in the motor. Since the current path is gone, the voltage increases dramatically until the spark is seen.

Another fact that needs to be understood is that at the exact moment that voltage is applied to an inductor, current will not actually flow until some time later.

The inductive effect is not something desired in resistance welding, but it is there. With the knowledge gained in the section on phase shift and the previous short introduction to inductors, an understanding is gained as to why the inductive effect is a concern in resistance welding. An SCR contactor will be used as an illustration. The same phenomenon is true of an ignitron tube or thyatron tube contactor.

When a contactor is turned on, voltage is applied to the weld transformer primary. Some time later current will begin to flow. Figure 19. After the positive half cycle of the voltage wave form goes through zero and begins to go negative, current will continue flowing through the weld transformer in a positive direction. This current keeps the positive SCR on until the current through it gets to zero. At this time the negative SCR can begin to conduct. The shaded area in Figure 19 shows the area of the voltage curve when current cannot flow in the opposite direction. This relationship of the voltage to the “lagging” current is called power factor.



VOLTAGE VS. CURRENT WITH A LAGGING POWER FACTOR

Figure 19.

Power factor is a dynamic variable in resistance welding. Secondary configurations, typically, have the most influence on power factor. For instance, small, very close-coupled secondaries may have a power factor as high as 80%. A rocker arm or press welder machine with a medium length throat may have a power factor around 40%. Some seam welders and very deep throat machines may have power factors as poor as 20%.

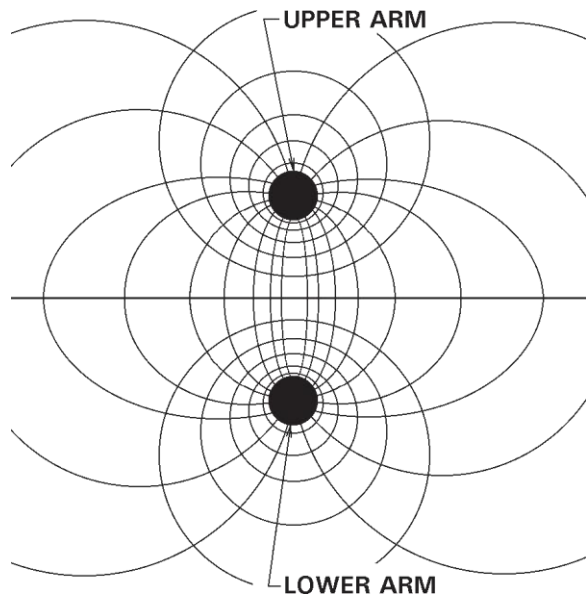
Magnetic items in the throat also contribute to poorer power factors. This may even be the part to be welded. Power factor is dynamic and can change from weld to weld, as well as during the weld.

Power factor affects the weld control’s heat control calibration. As can be seen from Figure 19, the shaded area subtracts from the available voltage area. The remaining area is all that is available to produce heat energy at the electrodes.

To provide a linear dial setting for percent current, the phase shift heat control must be recalibrated for the area of available voltage. Control manufacturers provide either an automatic, dynamic power factor adjustment in the control or a manual power factor adjustment to match the control power factor calibration to the machine power factor. Automatic power factor circuits in the control can overcome some changes in the secondary of the machine. Making sure the machine is properly set-up is more advantageous. Power factor circuitry cannot overcome imbalance in the secondary of the welding machine.

ALSO NOTE:

The control power factor calibration should not be confused with plant or factory power factor correction. Resistance welding equipment typically have poor power factors and contribute adversely to the overall plant power factor. Automatic power factor equalization circuits on weld controls will not help improve plant power factor, but will, however, help improve the electrical, mechanical and thermal efficiencies of the welding machine.



MAGNETIC FIELD AROUND
SPOT WELDER ARMS

Figure 20.

The inductance in the secondary of the welder is the ghost in resistance welding. It can't be seen, but it is there. The geometry of the secondary circuit of the welding machine greatly influences the output performance of the machine. The larger the secondary circuit becomes, the greater the magnetic losses due to the increased inductance in the secondary. Also, any ferrous metal introduced into the secondary circuit will absorb some of the magnetic energy, further increasing the secondary losses, thereby further reducing the performance characteristics of the welder. As the secondary circuit size increases, there is also a very slight increase in resistance which is usually a negligible loss compared to the magnetic or inductive losses. The magnetic fields of the secondary are quite large as is shown in the accompanying diagram. Figure 20.

The magnetic fields reduce in intensity with distance, but are greatest within the secondary loop of the machine.

A change in the size of the secondary circuit from about 12" x 8" to about 24" x 18" will reduce the effective current rating by over 50%. A large amount of magnetic material placed into the throat of the welder could reduce the welding current another 15% to 20%. Since the heat energy necessary to make the weld is a function of the square of the current, the effective losses can be up to 75%, for this rather extreme example. The control and transformer may not always be able to make up the difference. These losses also increase the cost of electric energy used by the welder, including a possible increase in demand charges by the electric utility.

An example of these losses may be calculated as follows for a change in secondary size from 12" X 8" at 10,000 amps to a 24" X 18" secondary. The formula is:

$$I_{\text{New}} = I_{\text{Old}} \times \sqrt{\frac{L \times H \text{ (Old)}}{L \times H \text{ (New)}}} = 10,000 \times \sqrt{\frac{12 \times 8}{24 \times 18}} = 10,000 \times \sqrt{\frac{96}{432}} = 10,000 \times .47 = 4,700 \text{ AMPS}$$

Here there is a loss of over 50%. Use the smallest secondary loop dimensions required to accommodate the parts to be welded. This is the most efficient way to operate the welding machine.

WARNING: Keep all steel tools and objects out of the secondary of the machine. These tools or objects can become dangerous missiles when the transformer begins to conduct. The magnetic field will drive these objects out of the secondary, often at high speed, sufficient to cause injuries.

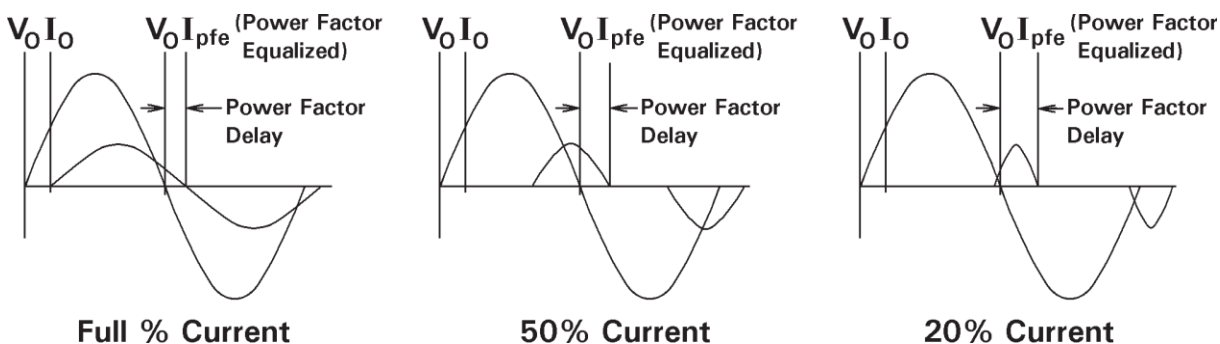
Again it is suggested for machine setup, use the smallest secondary circuit size or loop which will accommodate the parts to be welded. Besides being assured of consistently better welds, there can be an energy savings on the plant electric bill at the end of the year. Correct machine set-up is of great importance. All parts of the welder work together, for a good or a bad performance.

The inductance in the secondary loop, as previously explained, causes the current to lag the voltage in time. The greater the inductance, the greater the lag. The more magnetic material in the secondary circuit, the greater the lag and the poorer the power factor. Ideally, the welding contactor should be turned on in phase with the voltage and the current. Since this cannot be accomplished with the poor power factor of the welder, it is possible to minimize the effect by adjusting the firing point of the control to agree with the firing point of the current in the secondary of the welder. Many older electronic controls provide only for manual adjustment of the “power factor” of the control to the welder. Setting the “power factor” of these controls can only be done properly by using instrumentation. Manual power factor adjustments are usually set for a “worse case” condition. Thus the welder does not operate at maximum efficiency. Automatic power factor equalization circuitry overcomes this problem by dynamically adjusting during the weld.

PERCENT CURRENT AND POWER FACTOR ADJUSTMENT

Almost all digital controls provide for an automatic power factor adjustment circuit. The power factor adjusting circuit in the weld control merely adjusts the turn-on of the weld contactor to agree with the power factor of the machine as set up. As noted, no improvement in plant power factor is actually being attained. The “power factor” of the control is merely being “equalized” to meet the power factor of the welding transformer and secondary configuration of the machine during the time the weld is being made.

The power factor circuit of the control, either manual or automatic, is associated with the weld control phase shift heat control circuit. Full “heat” is attained when the phase shift heat control, or percent current adjustment, is at 100% (99% on digital controls) and the power factor of the control and machine are equal. Figure 21.



VOLTAGE VS. CURRENT WITH CHANGE IN PERCENT CURRENT
(Power factor change exaggerated for clarity)

Figure 21.

The power factor of a welder is dynamic. The power factor of the machine will change from set-up to set-up, part to part, and even during the weld. Whether the power factor of the control is properly set to agree with the power factor of the machine will not measurably affect the plant power factor. It is only the relative performance of the machine which will be improved by having the power factor relationship between the control and the machine properly set.

As mentioned before, the percent current, or phase shift, should be set as high as possible. From a practical stand point, on the initial set-up of the machine, with properly dressed electrodes, the percent current should be set to about 70% to 75% or higher. This setting value allows for an

increase in adjustment of the heat control to compensate for electrode wear (mushrooming) to overcome the reduction in current density as the diameter of the electrode increases. The effects of a change in current density will be discussed more fully on Page 49.

When new, properly shaped electrodes are installed, replacing the “mushroomed” electrodes, the percent current should then be returned to the original setting to prevent overwelding.

Setting the percent current above 50% will provide a more economical operation of the machine and will help reduce maintenance on the machine and control. If the percent current must be set lower than 50% to attain good weld quality, it is suggested that the transformer tap switch be lowered so that the percent current can be increased at least to 50% to 75%. If the welder is operating on the low tap and the percent current must be set below 50% to attain good weld quality, the machine is too large for the job. If possible, a smaller machine should be selected under these circumstances, so that a proper tap switch and percent current setting can be used.

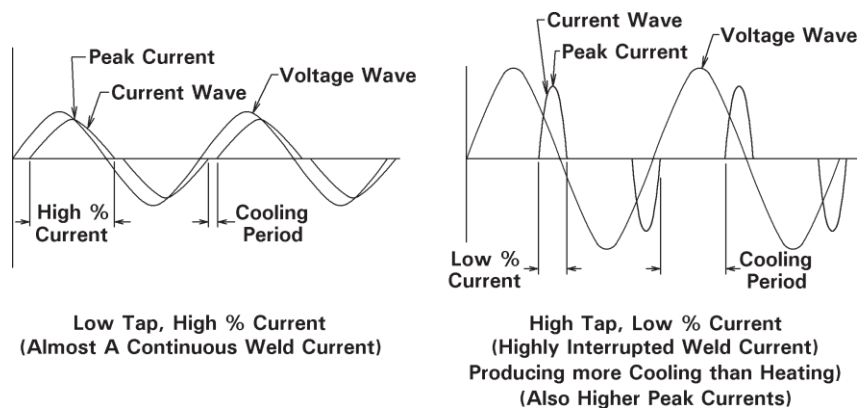
The relationship of the weld time and percent current to the welding transformer tap is also an important consideration in operating a resistance welding machine. The transformer tap switch setting should be selected for the lowest tap for which a weld can be made on the material selected. An explanation of this relationship is shown below.

THREE RULES FOR A WELDING SET-UP WHICH APPLY UNIVERSALLY

1. Use the **LOWEST** tap on the welding transformer.
2. Use the **HIGHEST** percent current setting on the weld control.
3. Use the **SHORTEST** weld time setting on the weld control.

These rules will help create good welds consistently and provide for the most efficient use of the machine, electrically, mechanically, and thermally.

There are also good and practical thermodynamic reasons for following these rules. By using a low transformer tap setting and a high percent current setting on the weld control, the weld current through the material to be welded will be almost continuous. If, however, to attain the same weld, a higher weld transformer tap is selected, a lower percent current setting will be required with the result that current will flow for a smaller portion of the time in each cycle of weld. This produces a heating and cooling effect resulting in a less efficient use of the total weld energy. Figure 22.



EFFECT OF TAP SWITCH CHANGE VS. PERCENT CURRENT ADJUST TO FORM THE SAME WELD NUGGET

Figure 22.

It will be noted in Figure 22, that for a low setting of the phase shift current adjustment, the peak current has increased dramatically in order to provide the same total heat energy to form, essentially, the same weld nugget. The average current, or heat producing value of the current, does not change. Even though the high peak current value does not contribute to making a better weld, every component in the primary and secondary circuit of the welder can be adversely affected by the high peak current: the incoming power lines, the circuit interrupting device (circuit breaker or disconnect switch), the welding contactor, the welding transformer, the transformer tap switch, all control and machine primary wiring, and the complete secondary circuit down to and including the workpiece. Machine maintenance will also increase.

For best welding results, an attempt should be made to keep the peak to average current ratio to about 2 to 1 or 2 ½ to 1. The low tap setting in Figure 22 represents a proper ratio of about 2:1. The higher tap setting Figure 22 could have a ratio of about 5:1. Operating a welder with this high a ratio will eventually do severe damage to the welding contactor and may electrically and mechanically damage both the primary and secondary circuits of the welder.

Welding at a low tap switch setting and high percent current setting on the control is also thermally more efficient. From Figure 22, it can be seen that for the high tap switch setting and low percent current setting the current is actually “off” more than it is “on” during each cycle of weld. More energy will be required at this setting to overcome the cooling effect between the period of weld current conduction within each cycle. Both the part to be welded and the water cooled electrodes are removing heat from the weld. See Figure 57, Page 51 for a more detailed example.

The total energy into the weld is the product of a current function, the material and interface resistance and the weld time ($H = I^2RT$, Joule’s Law). A weld control provides two adjustable parameters for controlling the energy to the weld. Assuming a correct transformer tap selection, correct welding pressure and electrode selection; the two control parameters, percent current (I) and the weld time (T) are the variables in the equation, assuming a constant cold resistance (R). The welding control will maintain excellent control over I and T, but has no control over R directly. With additional optional pressure control accessories, limited control can be attained over (R).

In almost every instance it is better to adjust the percent current than the weld time. The current is a squared function, so a small change in the percent current results in a larger increase in the total power, or heat energy, into the weld. Increasing time has a lesser effect on the total power and may introduce another source of energy loss. As the weld time is increased, the thermal considerations of the system come into play. The workpieces are thermal conductors and will begin to conduct heat energy away from the weld area during the longer weld time. The water cooled electrodes also become more efficient in conducting heat away from the weld as time is extended. See Figure 57, Page 51. Therefore, for the best weld performance:

Use the LOWEST transformer tap,
at the HIGHEST percent current,
for the SHORTEST time.

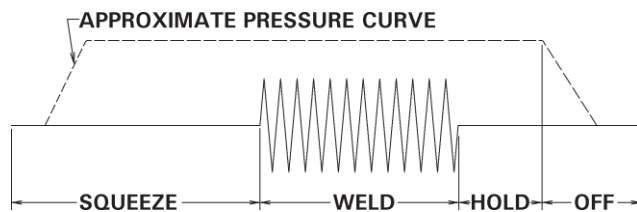
This will help make the best weld consistently,
mechanically and thermally.

TYPES OF CONTROL SEQUENCES

Also refer to RWMA Bulletin #5, Resistance Welding Control Standards (See References, Page 62)

SPOT SEQUENCE

The most commonly used weld control sequence for resistance welding is the basic four function weld schedule: squeeze, weld, hold, and off times, called a Spot Sequence. Figure 23. The spot sequence as a control, or as a sequence selection in a microprocessor-based control, probably represents 80% of all welding control sequences used. The spot welding sequence can be used for welding mild steel, sheet or wire; most copper-based alloys; nickel-chromium alloy steels; and nickel-based alloys. With optional accessories or programs, high carbon steel, aluminum and coated steels can be welded very satisfactorily. Refer to the weld schedule tables in the RWMA Manual. For nickel-based steel (stainless steel) a Spot Sequence using about half the



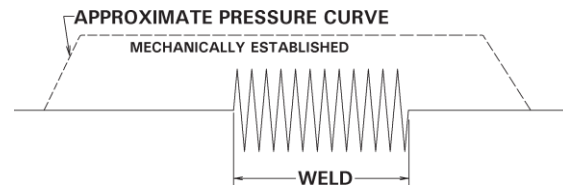
SPOT SEQUENCE TIMING DIAGRAM

Figure 23.

weld time and twice the electrode force listed in the spot sequence tables for mild steel will usually produce good welds without destroying the stainless properties of the steel. The spot sequence can be used for basic spot welding, projection welding and crosswire welding. Refer also to the definitions and Figure 11 on Page 10.

WELD TIME ONLY

For some machines that are fully mechanically sequenced, a control will require only weld time and a percent current adjustment. Figure 24.

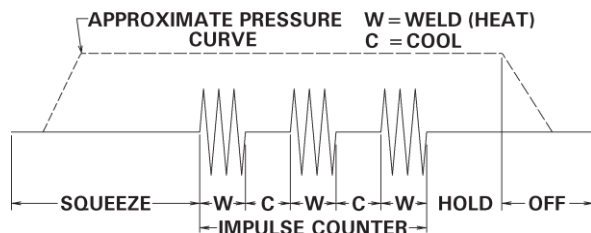


WELD TIME ONLY DIAGRAM

Figure 24.

MULTIPLE IMPULSE (PULSATION) SEQUENCE

The Multiple Impulse (pulsation) sequence with percent current adjustment, is probably the second most widely used control sequence for resistance welding applications. The pulsation sequence is similar to the spot sequence, with the exception of the ability to interrupt the weld current with a cooling period for a specific number of weld (heat) impulses. Figure 25. The interrupted weld sequence times are defined as Weld (when the weld current is on) and Cool. Older controls may display the terms Heat and Cool on the dial plate, rather than Weld and Cool.



PULSATION SEQUENCE TIMING DIAGRAM

Figure 25.

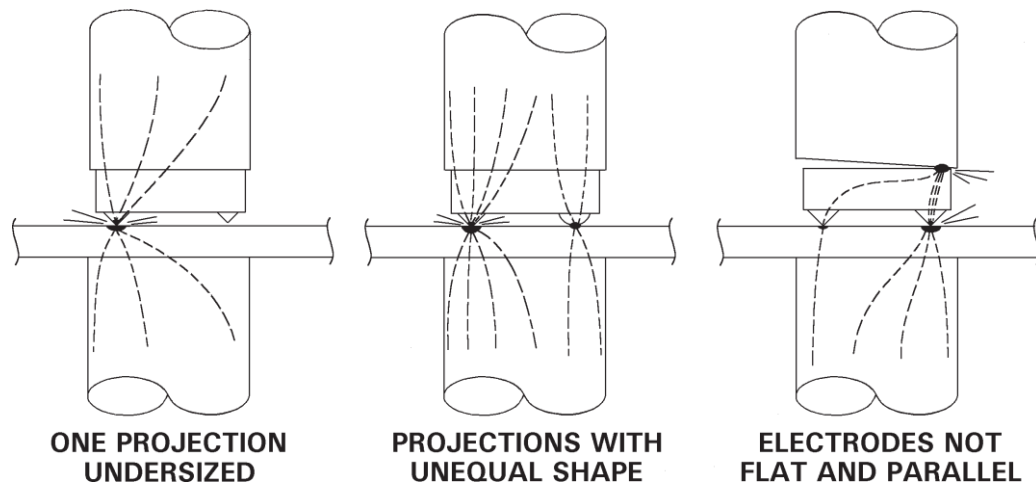
The Weld and Cool times and the number of weld impulses can be predetermined and set by front panel selection on the weld control.

PROJECTION WELDING WITH PULSATION

Pulsation welding techniques can be applied to projection welding, particularly to help set down large or multiple projections. When welding large or multiple projections, the current requirements may be quite high. For multiple projections, each projection will require about the same current and pressure as a single spot weld. For example, with three projections, current and pressure should be increased by a factor of about 3. See page 49.

Unfortunately, the pressure system of the welder might not be adequate to follow-up and properly set down the larger projection at the rate the current through the projection is melting the material. The result is often a poor weld with a large amount of metal expulsion (flashing). By using pulsation techniques, the total heat energy of the weld will be applied over a longer time, allowing the pressure system of the machine to provide the follow-up necessary to properly set down the projection to make a good weld. Upslope control, which will be discussed later, can also be used to improve projection welding applications.

With multiple projections it is often difficult to maintain tooling that will provide absolutely equally shaped projections. Although the differences in height or size of the projection may be small, the potential for unequal, parallel current paths through the projections are significant (Kirchoff's Law of Distributive Networks will be discussed later, Page 44). If the current paths are not reasonably equal, the resulting total weld may not meet specifications. Again, pulsation welding techniques may help to assure a more equal and uniform set down of the projections to create properly formed weld nuggets at each projection. Figure 26.

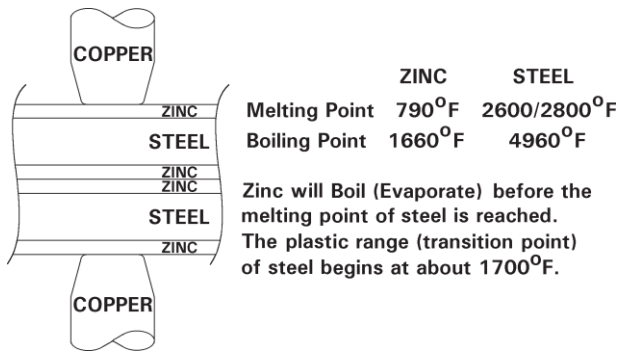


CAUSES OF POOR PROJECTION WELDS

Figure 26.

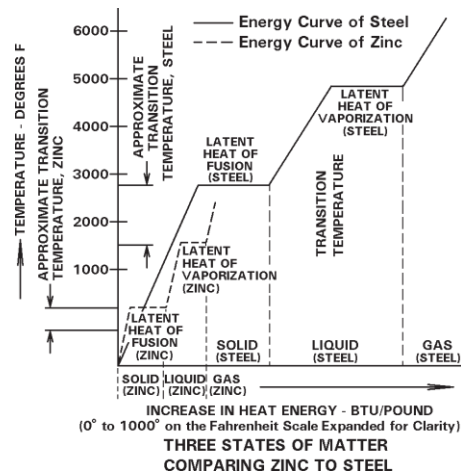
WELDING GALVANIZED STEEL WITH PULSATION

Pulsation welding techniques (Multiple Impulse Welding) are also successfully used for welding zinc coated steel. The major problem presented when attempting to weld galvanized steel is that the melting points of the two metals, zinc and steel, are dramatically different. Further, the boiling point of zinc is less than the melting point of steel. In order to weld steel to steel through the zinc coating, the temperature of the zinc will be raised well above its boiling point; at this temperature the zinc is literally evaporated. Witness the white powder that can form when welding galvanized steel; this is oxidized, vaporized zinc, forming zinc oxide. Refer to Figure 27, Page 28.



PROPERTIES OF GALVANIZED STEEL
(Thickness of Zinc Layers exaggerated for clarity)

Figure 27.



Rather severe expulsion of both zinc and steel may also result as the zinc is evaporated. The pressure system of the welder cannot easily follow-up to close the secondary fast enough to overcome the gap between the electrodes and the steel, made by the evaporated zinc.

Another problem inherent in welding galvanized steel with copper electrodes is the formation of brass on the surface of the electrodes. Resistance welding is a means of joining metals with heat and pressure. Brass is manufactured by amalgamating zinc and copper with heat under pressure. Now a brass-making machine also exists, as well as a resistance welder, when welding galvanized steel. Unfortunately, brass has a higher resistance to the flow of electric current than the copper of the electrode. The net result is that the high resistance of the brass at the face of the electrode begins to create additional heat at an excessive rate. The increased heat at the face begins to overheat and anneal the copper electrode. The softer copper begins to collapse (mushroom) at a greater rate. The mushroomed electrode has a larger diameter, reducing the current density. Increasing the current will help maintain the correct current density to make the weld, but will create more heat. The greater heat will create more mushrooming, which will require a higher current to make the weld, which will create more heat, which will...etc., etc., etc. See also Page 50 regarding electrode face size and current density.

This sequence of events sounds self-defeating, but there are solutions. With pulsation welding, the first weld impulse can be selected to provide sufficient heat energy to melt through the zinc, without creating excessive oxide and an open secondary. After a short cool interval, the next weld impulse will usually be sufficient to make a proper weld, steel to steel. Two weld impulses are usually adequate for welding up to 16 gauge steel. 14 gauge steel may require three heat impulses. The result is a better weld and longer electrode life. Metal expulsion can be reduced to zero with pulsation welding. The slightly extended welding time of a pulsation sequence may be but a fraction of the time necessary to dress and maintain electrodes when pulsation is not used.

Dispersion strengthened copper electrode caps can further extend electrode life. Weld current steppers are also used to help extend electrode life by advancing the weld current in predetermined increments at predetermined times, empirically matched to increase the current to the change in current density required to overcome the mushrooming of the electrodes. Again, see Figure 55, Page 50. Upslope control, which will be discussed later, with relation to welding aluminum, can also be used for welding galvanized steel. The upslope function provides for starting the weld current at a low enough level to melt through the zinc, subsequently increasing the current to a value sufficient to make the steel to steel weld. Figure 27.

Some users combine two, three or all four options when welding galvanized steels. Other programs can also be used such as Preheat, Delay and Weld, a form of Upslope and Pulsation.

PULSATION WELDING, UNDERSIZED MACHINE

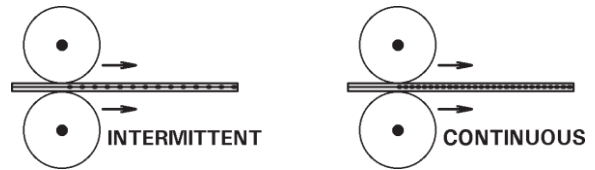
Pulsation welding can be used to increase the effective capacity of a welding transformer. A pulsation sequence, weld and cool, provides a cooling period in the transformer that can essentially reduce the effective thermal duty cycle of the transformer. In this manner the capability of a machine designed to meet the production requirements of welding 16 gauge material could possibly be extended to weld 14 gauge or heavier material without damage to the welding transformer. Production rates, of course, will be lower.

Although this may not be the most efficient use of a machine, the technique is used when short production runs are necessary in job shop applications where the investment in a larger, properly sized machine, cannot be justified.

SEAM WELDING

The seam welding machine is built with wheels between which the weld is formed. The wheels roll on the surface of the metal to be welded; the metal is passed between the wheels to form the seam weld.

Seam welding controls are used on seam welding machines. The two sequences provided by a seam welder control are continuous current or intermittent current. The intermittent mode is similar to pulsation with the exception that there is no impulse counter. The weld impulse and the cool time continue from initiation of the control until the initiation circuit is opened. Figure 28.



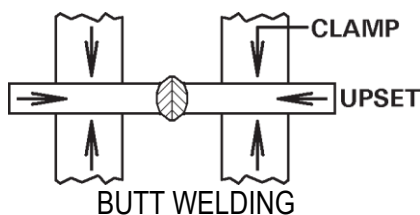
INTERMITTENT AND CONTINUOUS SEAM WELDERS

Figure 28.

Some machines are built to weld essentially continuously, such as tube mills and some barrel and drum welders. For these machines a control with only a percent current adjustment is required. No timing is needed.

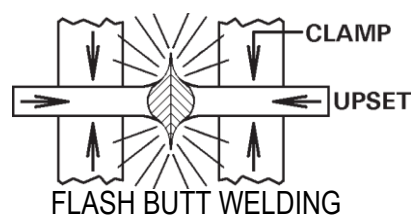
BUTT WELDING/FLASH BUTT WELDING

The butt welding control sequence is similar to the spot weld sequence with the addition of a second clamping valve. Two pieces of metal are clamped by the electrodes, brought together during a squeeze time and then are upset welded together. Figure 29. A post heat or anneal function may be added between the weld and hold for some applications. This may also be done by a separate initiation of the control and re-clamping the part for the annealing. For flash butt welding, essentially all welding is controlled by the machine and the machine is mechanically sequenced. Figure 30. A post heat or anneal function may be added after the welding is complete. This function is most often initiated by a separate initiation switch after the parts are re-clamped for the annealing sequence.



BUTT WELDING

Figure 29.

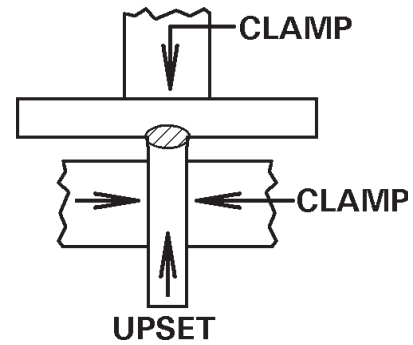


FLASH BUTT WELDING

Figure 30.

“T” WELDERS

The weld sequence for a “T” welder can be either spot or pulsation, as may be required. Successful operation of a “T” welder depends more on the proper clamp placement on the “T” section of the parts to be welded. The clamp must be placed as close to the cross piece as possible to reduce heat loss to the weld area, by overheating the “T” section. Figure 31.



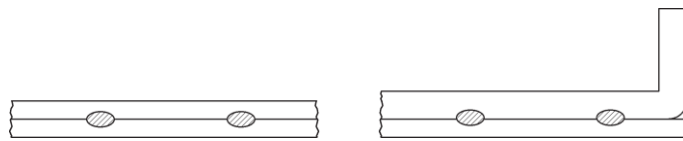
“T” WELDING
Figure 31.

A butt weld type sequence, including the clamp functions, is most often used for “T” welders.

OPTIONS

DUAL COUNT/DUAL CURRENT

The most common option used in connection with a resistance welding control is dual count/dual current (dual weld/dual heat). Often in a welding set-up it is required to provide welding current for two different welding conditions. For example, after providing a weld set-up for welding two pieces of 16 gauge steel, a 14 gauge bracket is also to be added to the weldment. Figure 32. Rather than set-up two welders or make two separate weld set-ups, it is possible to add a dual count/dual current option to the control, or program the dual function into microprocessor-based control, to provide for two schedules in one control in one set-up. On most discrete component controls squeeze, hold and off times are common to both sequences. An extra pilot switch is the only additional hardware required to access the dual function.



DIFFERENT PARTS WELDED USING DC-DC
Figure 32.

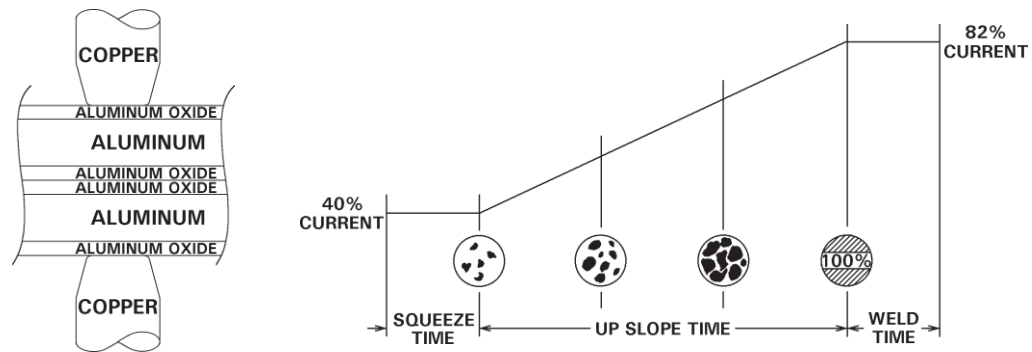
Three to eight schedules are quite common with most control manufacturers. Some microprocessor-based controls have provisions to access 64 sequences and more.

UPSLOPE OPTION

The proper option for welding aluminum is Upslope. The welding conditions for aluminum are similar, at first appearance, to welding galvanized steel. The parent metal is coated on both sides, except the coating on aluminum is an insulator, not a conductor. There will always be an oxide coating on aluminum, no matter how well it is prepared prior to welding. Aluminum oxide is not only a very good insulator, it is also a very hard and abrasive material. Aluminum oxide is used to make grinding wheels.

To weld aluminum, it is therefore necessary to first mechanically break through the oxide before full welding current can be passed through the aluminum. Upslope is the solution. Figure 33. Due to the high conductivity (low resistance) of aluminum, a high current of short duration is necessary to make a satisfactory weld. On first contact of the electrodes to the aluminum workpieces, only a small area of metal to metal contact may actually be made between the

electrodes and the aluminum through the aluminum oxide coating. Under these conditions, the actual current density may be extremely high and upon initiation of the weld current, severe metal expulsion may occur. See Page 49 for a discussion of current density.



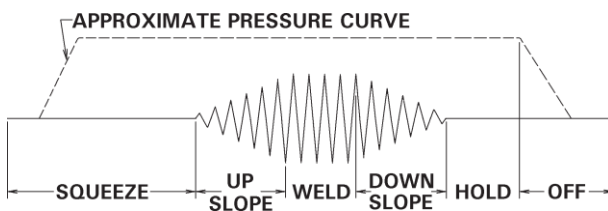
APPROXIMATE AREA OF ELECTRODE FACE IN CONTACT WITH THE ALUMINUM WITH RESPECT TO UPSLOPE TIME AND CURRENT DENSITY
(Thickness of Aluminum Oxide exaggerated for clarity)

Figure 33.

With Upslope Control, the current in the weld can be automatically phase shifted from a lower value to a higher value for a given period of time while the force applied to the electrodes continues to break through the oxide. Figure 33. The Upslope is empirically set to increase the current to coincide with the change in current density as the electrode pressure and the presence of the welding current break through the oxide.

As previously mentioned on Page 27, Upslope can also be used to help set down large or multiple projections properly without expulsion.

Downslope is another option often used in conjunction with Upslope for welding aluminum. Figures 34 and 35. Because aluminum is also a very good thermal conductor, heat is carried



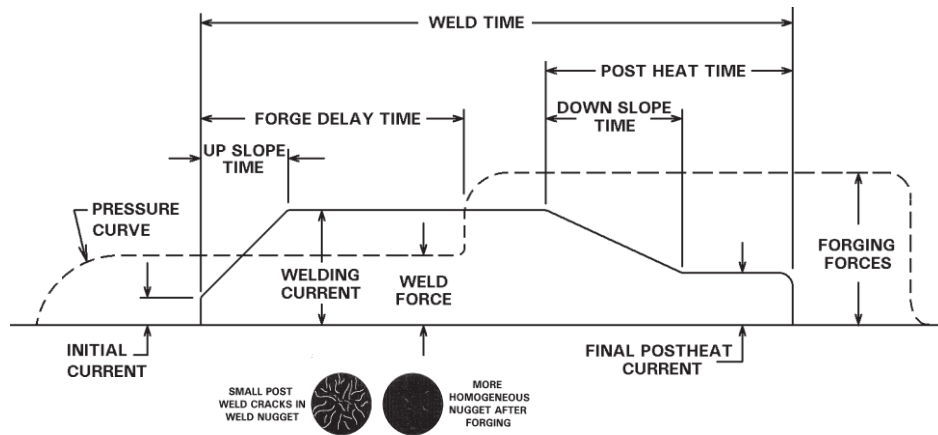
UP/DOWN SLOPE SEQUENCE TIMING DIAGRAM

Figure 34.

away from the weld area quite rapidly through the parent metal surrounding the weld nugget as well as through the water cooled electrodes. For this reason, small chill cracks often appear in the aluminum weld nugget after the weld has cooled. With Downslope, heat energy continues to be applied to the weld. The current is tapered down over a short period of time to help prevent too rapid cooling of the weld nugget.

FORGE DELAY TIME OPTION

Forge Delay Time is an option used to add additional force to a weld through a second solenoid valve actuated in sequence, during weld time or hold time. A forging pressure, applied near the end of the weld time or during hold time, can forge the weld nugget, providing a more homogeneous weld of higher mechanical strength. Both Downslope and Forge Delay can be used with Upslope for obtaining higher quality welds in aluminum. Forging can also be applied, for other higher conductivity metals to help provide a more homogeneous weld nugget.



TIME DIAGRAM ILLUSTRATES COMPLETE FUNCTIONS, INCLUDING UPSLOPE AND DOWNSLOPE, POST HEAT, AND FORGE

Figure 35.

PREHEAT/POSTHEAT OPTIONS

Preheat functions are most often used to preheat larger weldments prior to the application of the full weld current. There are times when it may be necessary to raise the temperature of a weldment 200°F to 300°F above room temperature prior to welding to assure that the weld current, when applied, will bring the work temperature up to the temperature of the latent heat of fusion of the material to be welded in order to form an acceptable weld nugget. Figure 36.

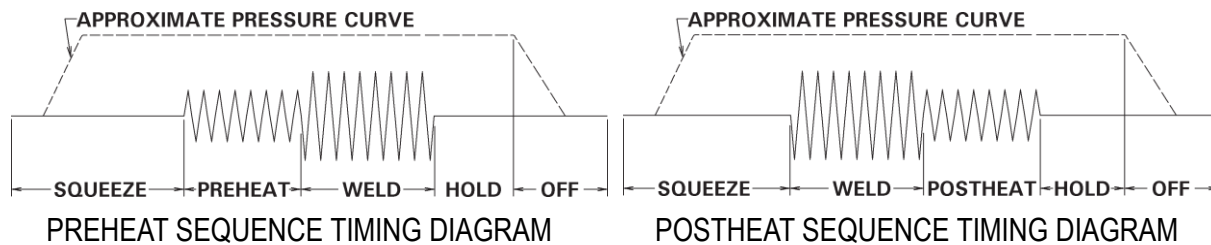
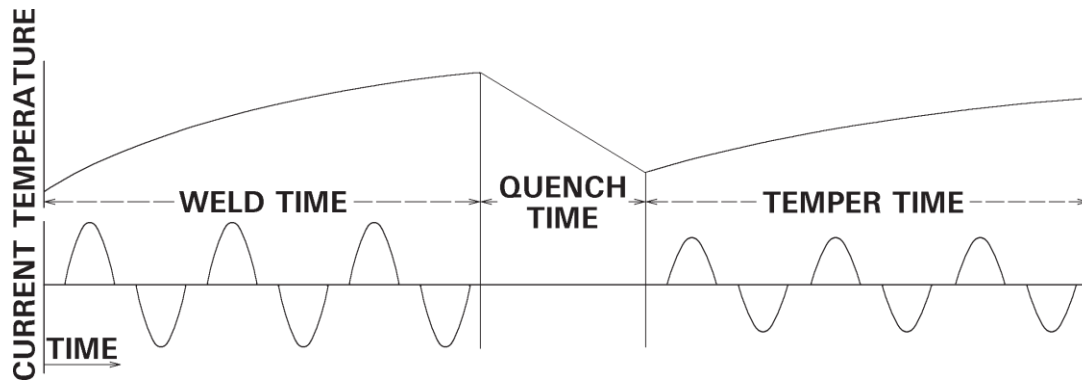


Figure 36

A postheat function can also be used to continue adding a lesser amount of heat energy to a weld nugget to reduce the chilling factor as the weld nugget cools. A Downslope option is also a postheat function. Note that too long a setting of hold time can chill welds in non-ferrous metals, producing non-homogeneous welds.

QUENCH/TEMPER OPTION

The Quench and Temper option is used almost exclusively for welding high carbon steel. Mild steel, such as 1010, has a carbon content which is not adversely affected by the heat of a resistance weld. Even 1015 or 1020 steel will usually produce an acceptably strong, ductile weld without additional post-heat treatment. Type 1025 and higher carbon steels usually require some form of post-heat treatment to partially cool and anneal the steel to maintain ductility in the weld. The Quench and Temper option provides the cooling period (quench) and annealing heat (temper) to provide the necessary metallurgical post-heat treatment to maintain ductility in the weld area. Figure 37.



A WELD CYCLE OF A HEAT TREATED WELD FOR THIN GAUGE MATERIAL,
TEMPERATURE VS. WELD TIMES

Figure 37.

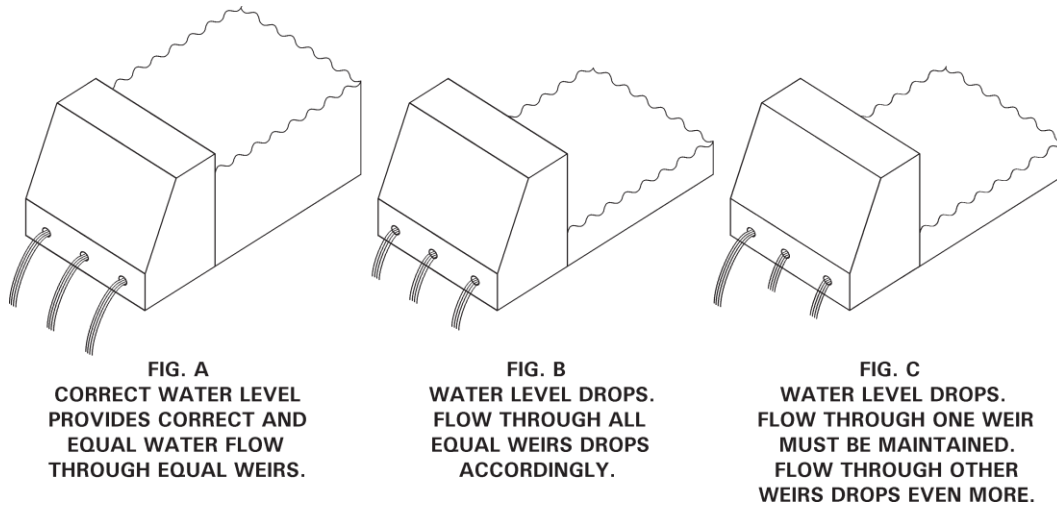
Microprocessor-based controls make programming of multiple options very convenient. But caution should be taken to use only those options necessary to make a specific weld. Using a number of options may extend the welding time envelope without necessarily improving weld quality.

AUTOMATIC VOLTAGE COMPENSATION

Power companies providing electric energy to industry do maintain fairly high standards on their power. The frequency is extremely accurate. Welding controls today provide ± 0 error in timing in the control functions by basing the timing of the control on the cross-over time of the line frequency established by the power companies. However, due to many factors, the voltage may vary from time to time. A voltage drop at the electrodes of a resistance welder may be sufficient to prevent a proper weld nugget formation. Load variations within the plant are also very common and are more often, the primary reason for voltage fluctuations at any machine. Resistance welders are more susceptible to voltage changes than other factory equipment.

For welding mild steel, generally, a change in voltage of about 20% will not adversely affect the weld quality and voltage compensation is usually not required for welding mild steel. Voltage compensators can maintain a $\pm 2\%$ or $\pm 3\%$ output voltage at the secondary for up to 20% changes in the primary line voltage. If the plant voltage fluctuation is consistently as great as 20%, efforts should be made to re-work the plant power system to overcome the basic problem, a poor power source. A voltage compensator on a welder connected to a poor power source may actually aggravate the situation more than solve a problem.

The automatic voltage compensator works through the control phase shift circuit. When a voltage drop is sensed, the control will advance the phase shift circuit to provide additional energy to the weld to overcome the voltage loss at the electrodes. This energy must come from the same line which has experienced the drop. The voltage compensator is, therefore, taking more energy from the power source for that particular welder at the expense of all other equipment on the line. There "ain't no free lunch." Voltage compensation should be used selectively, not generally. If the total power is poor, correct the power problem.



COMPARING THE POTENTIAL ENERGY AT A WATER DAM AND THE
FLOW THROUGH THREE WEIRS WITH A CHANGE IN POTENTIAL
(VOLTAGE) IN THE PLANT POWER

Figure 38.

Voltage compensators can be very helpful in isolated instances where welding equipment is being used in an area where heavy equipment may be started at random, momentarily pulling down an otherwise stiff power source. A welder in a press room, where presses are jogged for set-up, is a good example of a potentially extreme voltage change. Even though the normal line drops may be only 3% to 5%, when a press is jogged for set-up, an instantaneous drop of 20% or more may occur. This could result in a bad weld for a welder on the same line. This is a proper application of a line voltage compensator. General use of voltage compensators may not be necessary. Correcting the line problem is the better solution.

AUTOMATIC CURRENT COMPENSATION (CONSTANT CURRENT)

Automatic Current Compensation or Automatic Current Regulation or Constant Current options are also available for resistance welding. All three names are used interchangeably.

Maintaining a constant current usually provides control over only one of many variables in the welding process. Although the current in the secondary will be the current anywhere in the secondary, the point of greatest resistance to the current flow will be the point at which the heat energy will be dissipated (Joule's Law). To attempt to form a weld nugget, even with constant current control, this point may not be at the interface between the two workpieces. Constant current controls work, but they are not a cure for improper welder maintenance and set-up. See references to further discussion relative to Figures 49, 50, 55, and 57.

First set up to make a good weld. Then set the current necessary to maintain the weld.

A constant current control works effectively well on AC machines where ferrous material is being moved in and out of the secondary, maintaining the welding current at the interface of the materials to be welded to within 2% or 3% of the set value.

Another constant current control feature is a current read-out which can be very helpful for future set-ups as long as all other weld parameters are set properly.

The constant current control operation may be able to mask some changes in some process parameters, but cannot overcome poor set-up, shunt current effects, excessive electrode mushrooming, unbalanced secondary conditions or most fluctuations in the pressure system. In many instances, the dynamic automatic power factor circuitry offered in most digital welding controls will provide most of the adjustment required for changes in the condition of the secondary circuit of the welder. Remember, for constant current to work properly, the welding machine must first be set up properly to make a good weld.

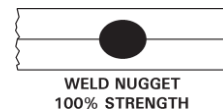
A resistance welding control can only provide control over two functions of Joule's Law ($H=I^2RT$), current (I) and time (T). The welding control cannot absolutely compensate for changes in the resistance (R) at the electrodes. If the current and time are maintained constant, which the control can do, but if the resistance varies, the resultant heat energy output will also vary. It will vary with R even when I and T are constant. Refer to Figure 49 on Page 45.

Even when I and T are maintained constant, H can vary dramatically. The accuracy of T is ± 0 . The accuracy of a constant current will hold I to within 2% to 3% variation at most. However, depending on set-up, R can vary from 20% to 500%.

For example, when welding 16 Ga. (.062) mild steel, a selection of 12,000, 9,000 or 6,800 secondary amperes is available from the table. The weld heat can be maintained by also varying time and/or resistance.

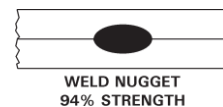
Example I: 12,000 amperes at 14 cycles (.2333 sec.) and 800# force (about 1 Ω resistance)

$$\begin{aligned} H = I^2RT &= 12,000^2 \times 1 \times .2333 \\ &= 144,000,000 \times 1 \times .2333 \\ &= 33,600,000 \text{ Joules} \end{aligned}$$



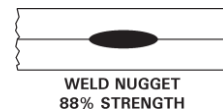
Example II: 9,000 amperes at 20 cycles (.3333 sec.) and 600# force (about 1.245 Ω resistance)

$$\begin{aligned} H = I^2RT &= 9,000^2 \times 1 \times .3333 \\ &= 81,000 \times 1.245 \times .3333 \\ &= 33,600,000 \text{ Joules} \end{aligned}$$



Example III: 6,800 amperes at 30 cycles (.5000 sec.) and 400# force (about 1.453 Ω resistance)

$$\begin{aligned} H = I^2RT &= 6,800^2 \times 1.453 \times .5000 \\ &= 46,240,000 \times 1.453 \times .5000 \\ &= 33,600,000 \text{ Joules} \end{aligned}$$



$$H = I^2RT \quad \mathbf{H = I^2RT} \quad H = I^2RT \quad \mathbf{I \& T \text{ are constant, R is the variable.}}$$

All of the above assumes the same size shape and material for the electrodes. The same cleanliness of the electrodes and material and the proper alignment of the electrodes and fit up of the parts must also be maintained. Class 2 electrodes with a 1/4" face were used to make these welds.

$$\mathbf{H = I^2RT}$$

Figure 39.

The overall strength of the weld may vary by about 12% from the 12,000 ampere setting to the 6,800 ampere setting. The heat loss in the material and electrodes due to the longer time creates the change, Figure 57, Page 51. All welds are within specifications set by RWMA and AWS. See Page 7-14, Table 3 in the RWMA Manual and Table 3, Page 125 in the AWS Manual.

Selecting the correct transformer size for welding 16 Ga. mild steel is important, but for some shops the correct size transformer to produce 12,000 secondary amperes may not be available. A welder with a lower secondary current can be used successfully by changing the other weld parameters accordingly, as expressed by Joule's Law.

Constant current monitoring of the selected current can still be of help in making good welds.

A constant current control also cannot compensate for changes in the size and shape of the electrodes (mushrooming). Changing the size and shape of the electrodes changes the current density. As the electrode enlarges, the amperes per unit area decreases, the weld gets poorer. Refer to Figure 55, Page 50 for the effects of change in current density on weld quality.

Recommended Practices

Please refer to page 7-5 of the RWMA Manual

Recommended practices for single-impulse spot welding of low carbon steel, as prepared by The American Welding Society Resistance Welding Committee (AWS), are given in **Table 7.2**. This represents the composite experience and recommendations of some of the largest operators in the country.

It must be remembered that low carbon steel may be satisfactorily welded over wide ranges of time, current and pressure, and too low a value of one of these variables may, in part, be compensated for by the others. For instance, if the machine welding current is not great enough, this deficiency may be offset by an increase in "weld time" or decrease in force applied.

A given set of welding conditions or schedule that produces the best results for one operator may not be suitable to another. Therefore, recommended practice should be considered as a starting point from which any operator may make adjustments to suit his particular requirements.

An operator's first requirements may be maximum tensile-shear strength, whereas, another operator's first requirement may be a minimum of surface indentation. Both of these requirements cannot be obtained from the same settings.

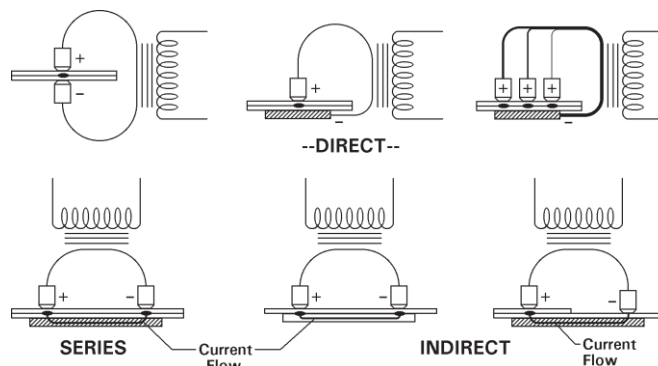
Also schedules, Figure 60, Page 54..

OTHER OPTIONS

There are other options available with resistance welding controls to meet specific weld requirements which are not of general use and for which information is available from the machine or control manufacturer of your choice.

WELDING MACHINES AND CONTROLS

The discussion so far has assumed direct welding with a single point, single phase AC welder. There are other types of single phase welders. Two common types of special single phase machines are the cascade (sequenced multiple transformer) welders and the multigun (sequenced multiple valve) welders. Both types of machines may use special controls programmed to provide multiple welds to be made in a single set-up. Some users incorporate a programmable logic control (PLC) with single function controls to accomplish the multi-function sequence. Microprocessor-based controls often include multiple programming. Although some multiple machines provide for multiple direct welds, most incorporate series or indirect welding of wire or thin sheet metal. Figure 40.

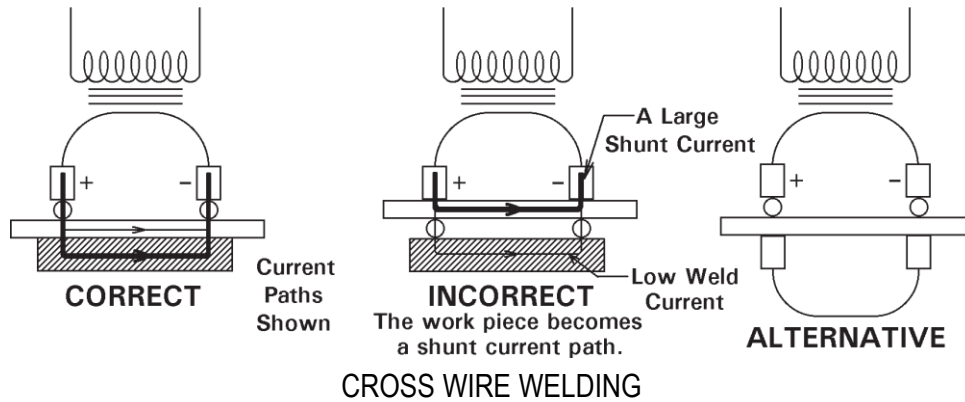


TYPES OF SPOT WELDS

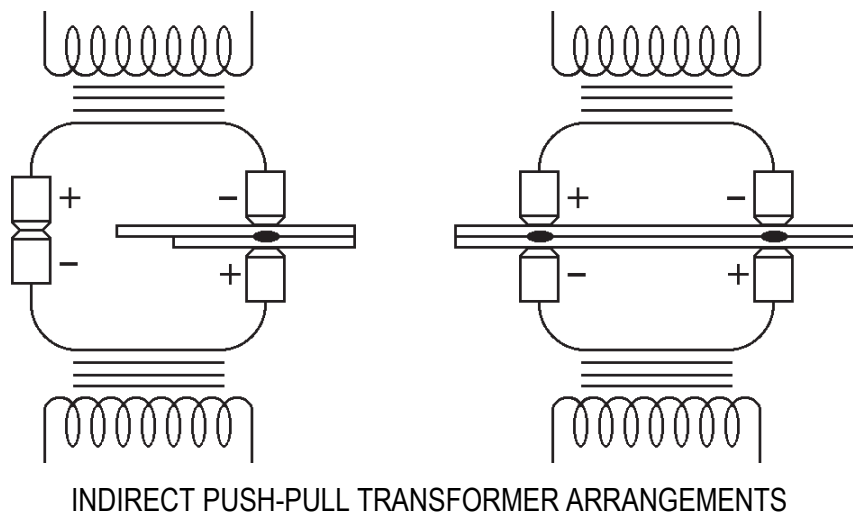
Figure 40.

Series welding of sheet metal is usually limited to 16 gauge material. Be sure that the spot weld spacing conforms to the recommended practices for the material thickness being welded. See Figure 60, Page 54. In a series weld, two welds are being formed simultaneously, one at each electrode, through the material to be welded and through a common conducting back-up. Indirect welding can be used on heavier gauge material.

Crosswire welding can also be accomplished when welding a number of crosswires in parallel in either a direct weld or series weld. Figure 41. The number of wires to be welded is limited to the current balance through the various wires and the KVA of the transformer. The welds farthest from the center of the secondary will be somewhat smaller. At the extreme, some outside wires may not weld. Series welding of cross wires is not limited to wire size. Crosswire welding is a form of projection welding.



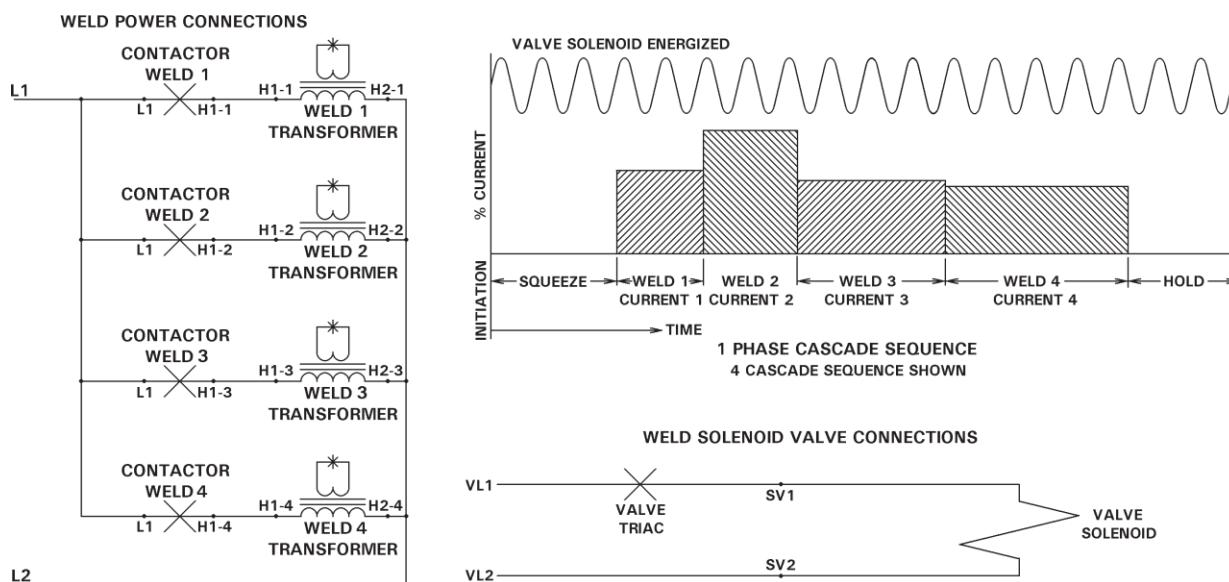
Indirect welding may also be accomplished by using a “Push Pull” transformer arrangement. This arrangement is essentially the same as shown for the indirect welds above, except the common lower platen is replaced by another transformer. The welding arrangement will provide a higher secondary voltage since the secondary voltages of the two transformers are additive. This arrangement is often used on large panels to reduce secondary cable lengths and the adverse effect of inductance. Figure 42.



CASCADE CONTROLS

In the illustrated four cascade control system, Figure 43, four transformers are used and all solenoids and welding guns are actuated simultaneously. At the end of squeeze time, the control automatically initiates the weld 1 contactor, then the weld 2 contactor, followed by weld contactors 3 and 4 and then hold time. Each weld sequence can be provided with an independent adjustment of weld time and percent current. Cascade type welding machines can be built with multiple transformers in parallel per contactor and with multiple parallel secondaries. The major advantage gained is reduced loading and unloading time over a single function machine. Figure 43 illustrates the timing sequence of a cascade control and the power connections. Some microprocessor based controls also provide programs to vary the contactor sequences.

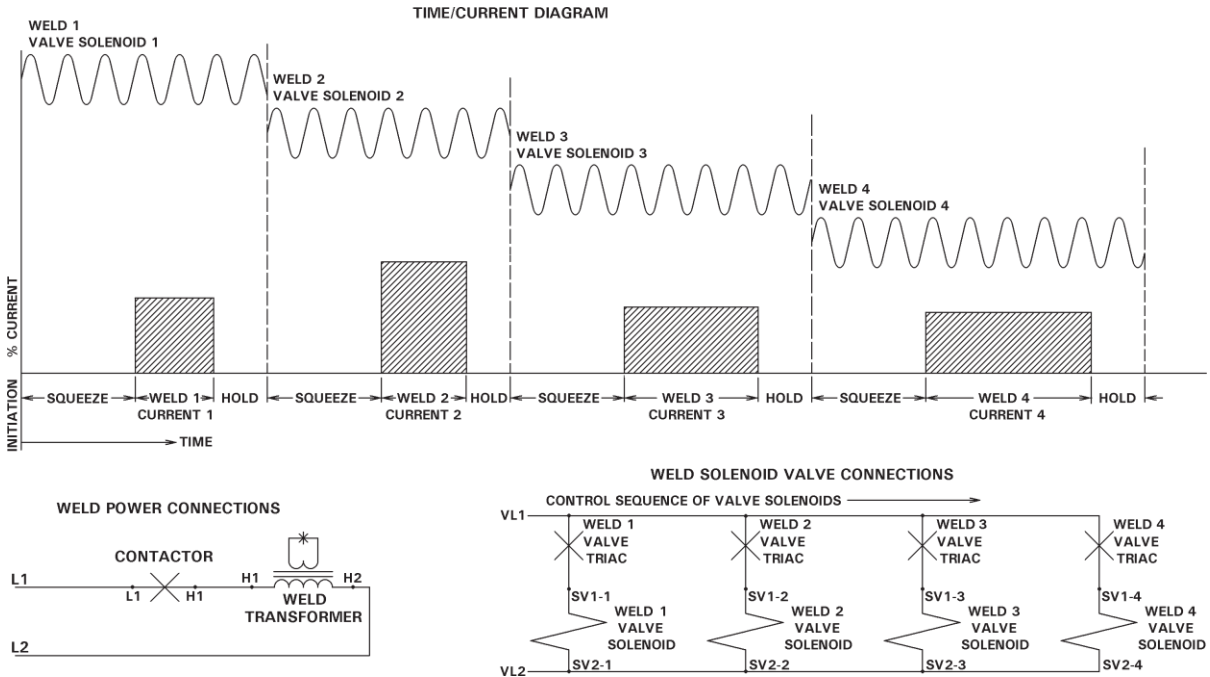
Cascade controls for up to eight transformers are fairly common. Larger systems are available.



SINGLE PHASE CASCADE SEQUENCE
Figure 43.

MULTIGUN CONTROLS

The multigun machine incorporates only a single transformer, or multiple transformers in parallel, and the control sequences the gun solenoids instead of transformers as in the cascade control. Squeeze and hold time in the sequence are used as each gun solenoid is actuated. Each sequence may have an independent adjustment for weld time and percent current. The multigun machine is slower than cascade machines, but is less costly since it typically incorporates only one transformer. Figure 44. Most microprocessor-based controls can provide programs to vary the valve sequences also.

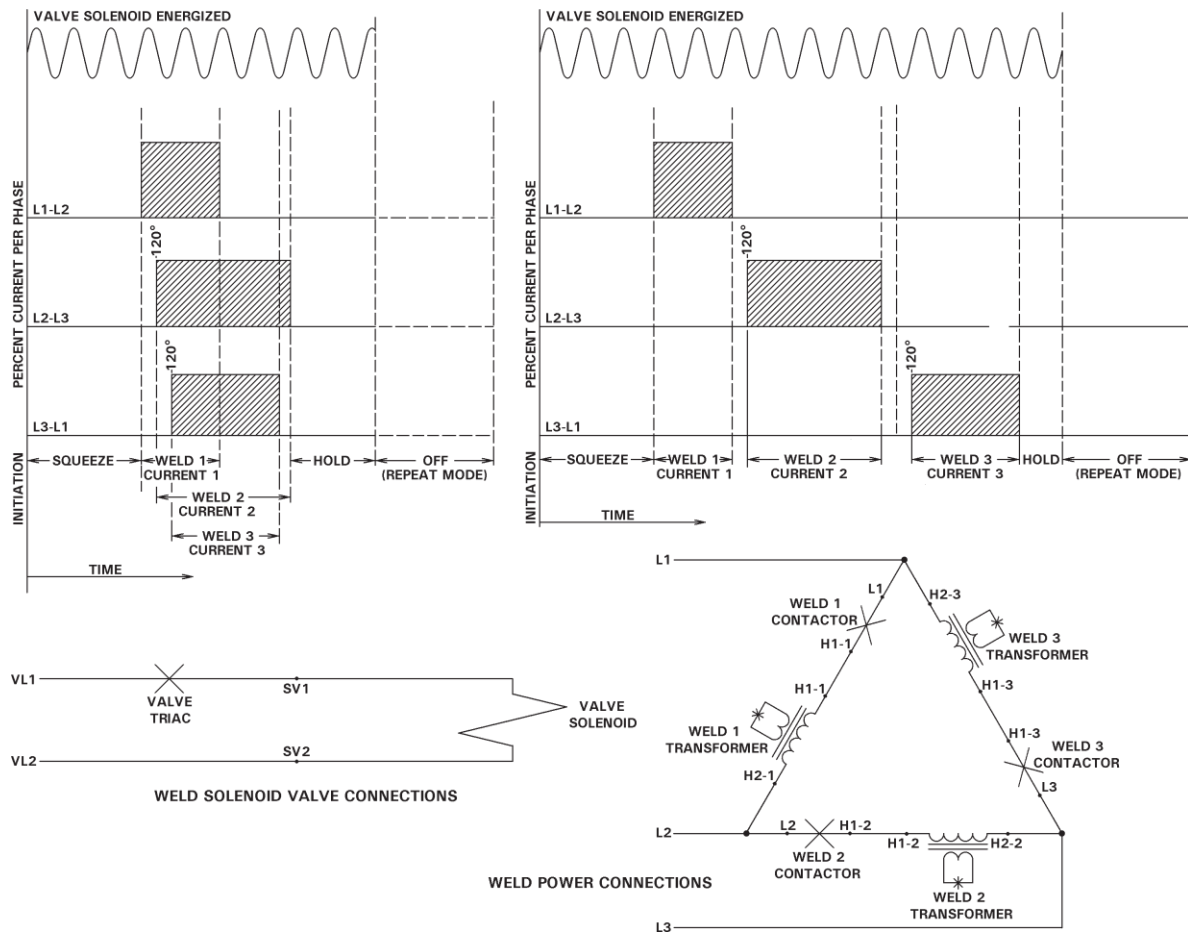


SINGLE PHASE MULTIGUN SEQUENCE

Figure 44.

LOAD DISTRIBUTION CONTROLS (LDC)

A modification of the single phase, multi-transformer control is the three phase Load Distribution Control (LDC). For load distribution, three single phase transformers are distributed across three phase circuits as independent single phase circuits. In this configuration the load is distributed and essentially balanced across three phases helping to provide a more uniform plant load distribution. The secondaries of an LDC may be connected independently for either direct welds or series welds. Figure 45.



THREE PHASE LOAD DISTRIBUTION CONTROL (LDC)
Figure 45.

The Load Distribution Control can be initiated in cascade or simultaneously across all three phases. The greater load balance occurs in the simultaneous mode. Independent weld and current adjustment for each transformer are usually provided in the control.

INVERTER CONTROLS FOR MID FREQUENCY TRANSFORMERS

Inverter controls, converting 60Hz to 180Hz to 2000Hz, are usually manufactured for welding guns, most often for robotic welders and small high speed machines. Although the inductance of the welding transformer increases with the increase in frequency, the amount of iron and copper required to manufacture a mid frequency transformer decreases dramatically. The weight and size reduction makes this transformer ideal for the mechanical movement response time of a robot. The control, however, becomes substantially larger and more complicated when incorporating the circuitry required to convert the line frequency of 60 Hz to about 180Hz to 2000Hz. The control is almost always mounted remotely from the robot and transformer.

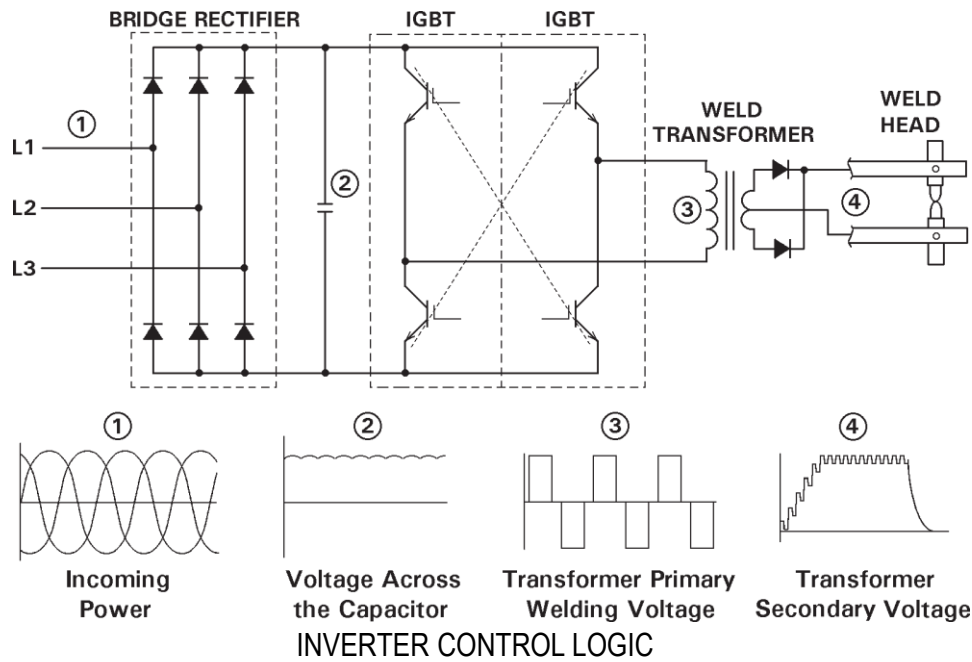


Figure 46.

Inverter style controls are typically powered via three phase AC line voltages. The line voltage is fed into a three-phase bridge rectifier which converts the AC voltage to DC ①. The DC output is then fed to a capacitor to smooth the ripple voltage from the bridge rectifier circuit ②. The DC voltage is then supplied to the contactor/switch. This switch may be constructed from high current transistors or IGBTs. In this section the polarity of the DC supply is continually reversed to create a peak to peak voltage equal to two times the DC voltage at the frequency required ③. The welding transformer (designed to operate at the voltage and frequency of the inverter) then steps down the voltage to usable resistance welding voltages. The secondary is immediately coupled to a single phase full wave rectifier. The DC output is then applied to the welding secondary ④. Figure 46.

Both the control and machine have increased complexities over single phase systems. However, there is a saving of about 65% in power consumption, even though the machine and control costs may be 200% to 300% higher than a single phase AC system. The inverter system operates at, essentially, unity power factor. There are no real inductive losses in the secondary of these systems. The set-up procedures for the control for an inverter system are similar to those for a single phase AC or single phase DC system.

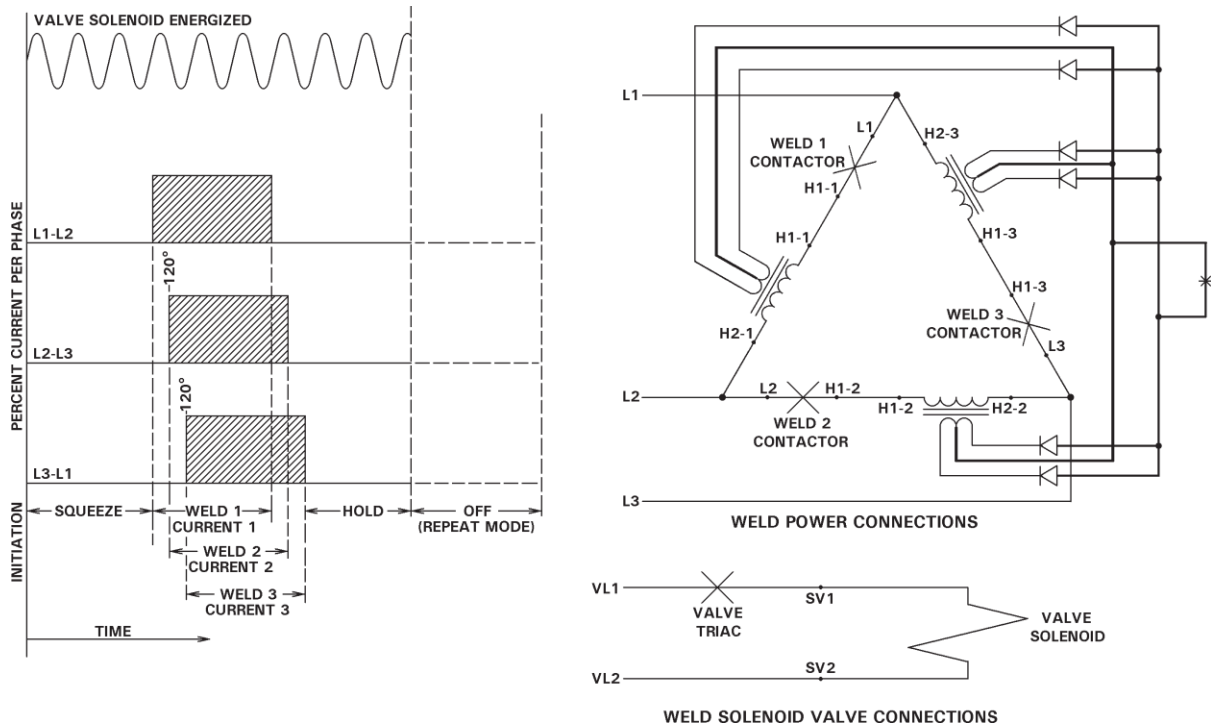
Inverters, generally, reduce primary demand, provide greater productivity (shorter weld times), reduce transformer size, provide balanced loads and usually reduced input wire size due to the lower primary current demand. These may be an asset for some resistance welding operations. Weld area cosmetics are also improved.

CONTROLS FOR SINGLE PHASE AND THREE PHASE DC MACHINES

Controls for machines which provide direct current secondary circuits are manufactured for both single phase and three phase operations.

The same control used for single phase AC machines is used for single phase DC machines. All functions and options are the same and are interchangeable. A solid state bridge rectifier circuit in the secondary circuit of the welding machine provides the DC output. Although a single

phase DC machine may cost up to 33% more than a single phase AC machine, power consumption is down about 40%. Losses in the secondary, due to inductance, are also greatly reduced in a single phase DC machine. Three phase DC machines are constructed with either a single core transformer with three primary windings or with three separate single phase transformers. In each case, the primary circuits of the transformer(s) can be connected in delta or a “Y” configuration to a solid state bridge circuit. Figure 47.



TYPICAL THREE PHASE DC TYPE CONTROL CONFIGURATION
Figure 47.

The weld control incorporates a single weld control system for initiating each of the three contactors in sequence across each phase of the three phase line. All primary switching is on the AC line. The DC power is provided in the secondary circuit of the welding machine. Both the control and machine have increased complexities over single phase systems. However, there is a saving of about 65% in power consumption, even though the machine and control costs may be 200% to 300% higher than a single phase AC system. The three phase DC systems operate at essentially unity power factor. There are no real inductive losses in the secondary of these systems. The set-up procedures for the control for a three phase DC system are the same as for a single phase AC or single phase DC system.

THREE PHASE FREQUENCY CONVERTER CONTROLS

Another type of three phase machine is the frequency converter. In the frequency converter machine, the frequency converter control is capable of converting the power source line frequency to a different and lower frequency. This is, essentially, a form of primary circuit rectification. The reduced frequency usually is 20 Hz or 12 Hz. At the lower frequency, the inductance of the secondary has been greatly reduced. The complexity of both the machine and control may be increased over a three phase DC machine. Control set-up procedures are also somewhat more complicated than for single phase controls or a three phase DC control. Besides power

consumption reduction, frequency converter type machines are often selected for welding aluminum. Because of the high current requirements for welding aluminum, the savings in power with the use of frequency converter machines is of real value. A physically smaller frequency converter machine can be used. The operating cost savings and convenience often offset the machine price differential.

CAPACITOR DISCHARGE CONTROLS

The capacitor discharge-type machine is also used in resistance welding. This is a form of single phase DC welding in which an AC voltage is rectified and used to charge a bank of capacitors. The capacitors are discharged through a single phase welding transformer, developing a high energy output pulse which is capable of delivering sufficient energy to the secondary of a welder to form a weld nugget in the workpiece. The capacitor discharge machines now in use are often used for smaller, bench-type machines for welding precious and semi-precious metals and micro welding of small parts. These machines are normally rated in watt-seconds rather than KVA. Both are similar energy ratings.

WELD MONITORS

Other aids to resistance welding are available in the form of weld monitors. A weld monitor can be used to track the performance of various parameters of the welding process once good weld parameters have been established. At this point, the monitor can be used to indicate variations from an established norm. Weld monitors vary from simple, single function devices which can be brought to a machine from time to time to check an established parameter, to monitors that can provide full-time read-out capabilities with complete Statistical Process Control (SPC) capabilities.

The use of monitors or the selection of the type of monitor to be used is based on the critical needs to maintain quality control on a given product. The results of the destructive “pull test” are still the only way to assure weld quality. This is also the basis for establishing the parameters for monitoring. In many cases, the use of a regular “pull test” program is more than adequate. Even with the most sophisticated monitors, “pull tests” are needed to be assured that both monitor and process are tracking. Modest changes in set-up parameters may cause only slight variations in weld nugget strength. Figure 48.

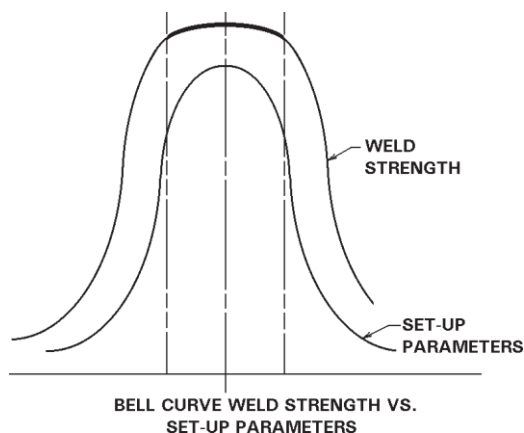


Figure 48.

Automatic feedback systems are also available, but have not always been accepted as a good economic solution to weld quality maintenance due to their greater complexity and inability to “monitor” a significant number of weld parameters.

Force gauges are also very useful for set-up and monitoring weld force at the electrodes.

Weld monitors and force gauges are very cost effective devices for use in establishing and maintaining good weld quality.

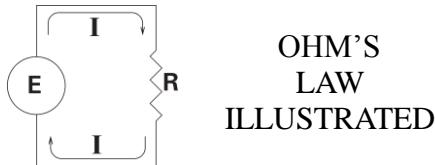
BASIC LAWS OF PHYSICS EFFECTING RESISTANCE WELDING

Mentioned earlier in this document, the principle of resistance welding is based on Ohm's Law. The R in resistance welding is the R in Ohm's Law. Ohm's Law is the reason why resistance welding works. Unfortunately, Ohm's Law is almost always the reason why resistance welding does not work. When resistance welding doesn't work, Ohm's Law is probably being violated. It is easy to do, as will be explained in the following discussions.

There are other laws of physics which may also affect resistance welding: Joule's Law, Kirchoff's Law, the Peltier Effect and Inductance. These five laws are listed below and will be the basis for our subsequent discussions.

I. OHM'S LAW: The relationship of Voltage, Current and Resistance in an electrical circuit.

$$E = IR \text{ or } I = E/R. \text{ Total Power: } P = I^2R \text{ or } P = EI$$



E is voltage, I is current, R is resistance.

Formulated by Georg Simon Ohm (1787-1854) in 1827, recognized in 1841. Georg Simon Ohm was a German physicist and mathematician.

II. JOULE'S LAW: The relationship of the heat energy produced when a current of 1 ampere flows through a resistance of 1 OHM for 1 second.

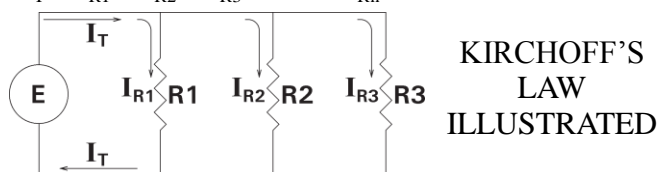
$$H = I^2RT \text{ (Joules), this may also be expressed as } H = EIT \text{ (Watt-Seconds)}$$

This Law was formulated by James Prescott Joule (1818-1889) in about 1845. Joule was an English physicist.

There is a direct relationship between Ohm's Law and Joule's Law.

III. KIRCHOFF'S LAW: The Law of Distributive Networks (current). The magnitude of the current in a circuit is the sum of the currents in the respective branches of the circuit.

$$I_T = I_{R1} + I_{R2} + I_{R3} + \dots + I_{Rn}$$



I_T is total current. $I_{R1} \dots I_{Rn}$ is current in branch circuits.

Beware of shunt currents, see Page 52. The monitored current may be constant, but the weld current R3 can vary with changes in R1 and R2.

Formulated by Gustav Robert Kirchoff (1824-1887) about 1850. Gustav Robert Kirchoff was a German physicist.

IV. PELTIER EFFECT: The Inverse Thermal / Electric effect. The application of an electric current to two dissimilar metals may have a heating or cooling effect according to the direction of current flow. The Peltier Effect applies principally to the welding of precious metals.

Formulated by Jean Charle Peltier (1785-1845) in 1834. Jean Charle Peltier was a French physicist.

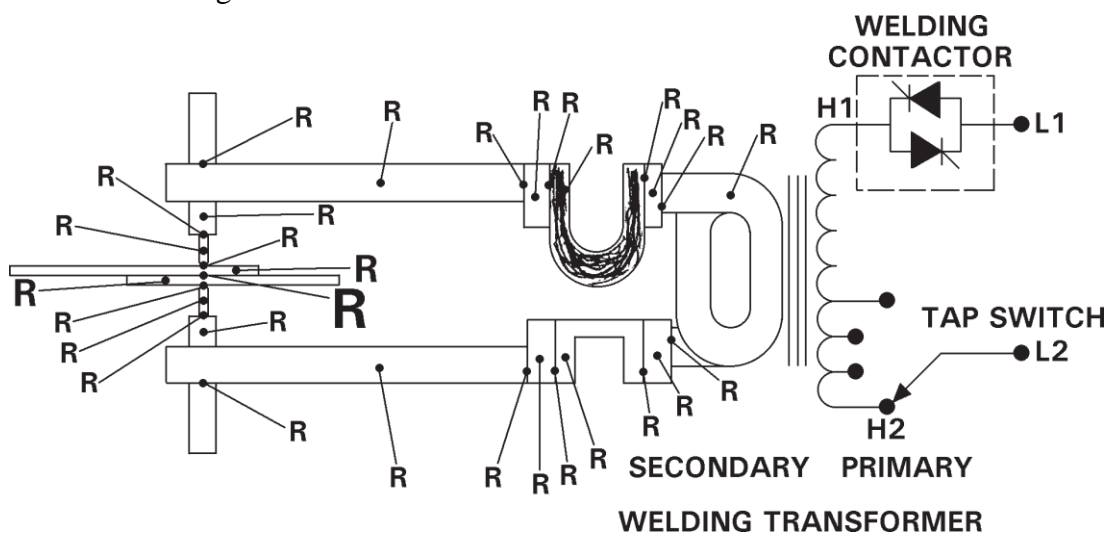
V. INDUCTANCE: The property of an electric circuit by virtue of which an alternating current induces an electromotive force in that circuit and/or in a neighboring circuit. Also, the property of an electric circuit by which it lags in receiving, in full measure, the full force of a current.

The result is a poor power factor for resistance welding machines.

OHM'S LAW/JOULE'S LAW

The resistance welding control is actually only a small part of a welding machine. Most of the machine is mechanical. The remainder is the electrical system which consists of the primary circuit, the control, the welding transformer and the welding machine secondary circuit. The control remains, basically, only the switch to close the primary power circuit to the welding transformer.

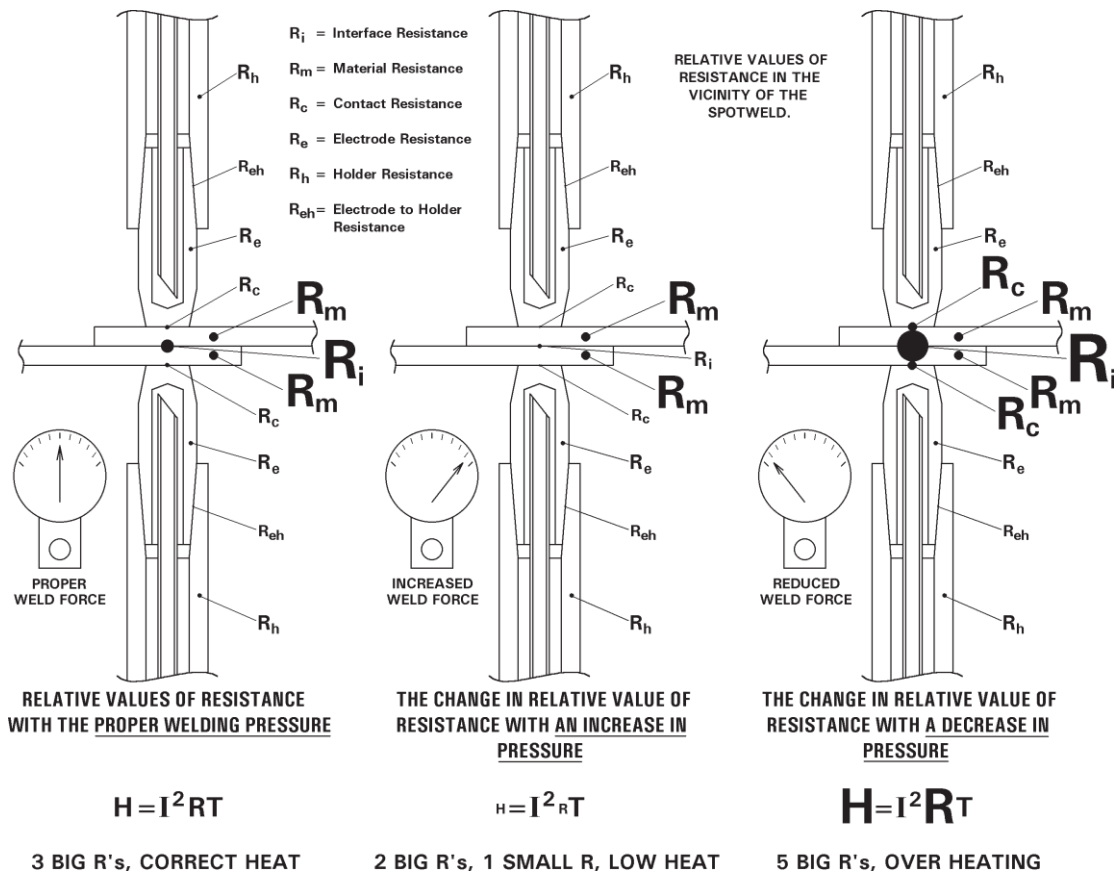
Figure 49 diagrammatically demonstrates that the secondary of the welder is a series of resistances in two paths from the welding transformer pads to the interface between the two pieces of metal to be welded. The sum of the resistances in each path must be equal for the weld nugget to form at the interface between two pieces of metal to be welded. The largest R is at the interface of the materials to be welded and the next largest R is the material. All other R s should be very small.



DIAGRAMMATIC REPRESENTATION OF THE RESISTANCES IN THE SECONDARY OF A ROCKER ARM RESISTANCE WELDING MACHINE

Figure 49.

The illustrations in Figure 50 look more closely at the resistance in the area of the electrodes and the work pieces. The relative resistance values are diagrammatically indicated by the size of the circular areas in the illustration and the size of the letters “R”. The first illustration demonstrates the resistance relationship of a weld made with proper welding pressure, assuming a correct selection of time, current and electrode size and shape. The resistance at the interface between the two pieces to be welded is the largest value in the system. Both the interface resistance and the resistance of the workpiece are many times greater than the sum of all the other resistances in the secondary of the welder.



CHANGES IN RELATIVE RESISTANCE AND HEAT ENERGY DUE TO PRESSURE CHANGE
 As R changes, so does H
 Figure 50.

The effect of Ohm's Law and Joule's Law can take many forms. Changes in pressure can cause a rather dramatic change in the interface resistance between the electrodes and the work pieces. The center illustration in Figure 50 demonstrates that when pressure is increased, above recommended welding pressure, the interface resistance decreases and the total energy to the weld will decrease for the same transformer tap switch setting, control weld time and percent current setting. The energy into the weld is a product or a function of the current squared (I^2), the resistance (R) and time (T). If R is smaller, the product of the current squared, time and the resistance will also be smaller. The result of too much pressure will be underwelding or no weld at all.

The opposite condition occurs when insufficient welding pressure is applied, but with much more dramatic, and possibly more damaging results. The third illustration demonstrates the relative resistances when pressure is decreased below recommended welding pressure. In this case, not only does the interface resistance of the two workpieces increase, the resistance between

the electrodes and the surface of the workpieces will also increase. The product of I^2RT may increase sufficiently to cause severe metal expulsion at the surface of the material to be welded as well as at the interface. The workpieces can be damaged, the electrodes (or fixture) can be damaged and a personnel hazard may be created by the resulting metal expulsion.

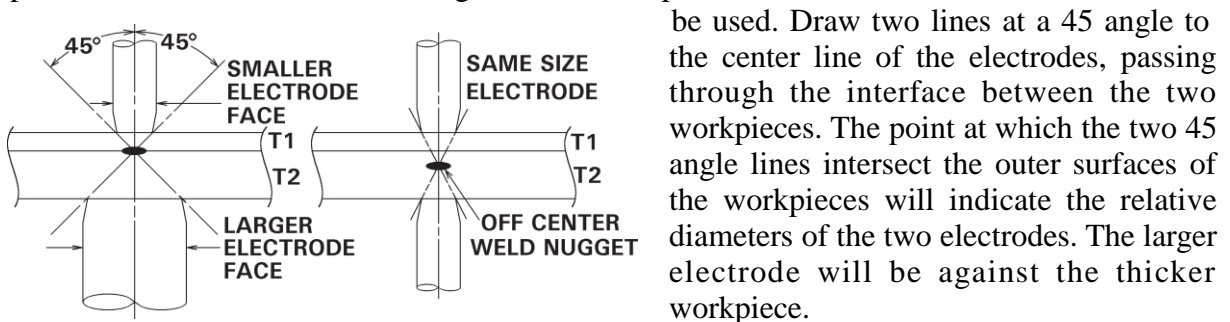
Another effect of Ohm's Law which can occur in the secondary circuit of the welding machine is electrical imbalance. If the sum of all of the resistances in each path from the transformer to the work are not equal, the result of the current in the secondary will be an attempt to form a weld nugget other than at the interface between the two work pieces. With current flow, the weld nugget will attempt to be formed at the point where the greatest heat energy is dissipated in the secondary. This is the point of greatest resistance, hence the point of the greatest voltage drop in the secondary. This point may not be at the interface of the workpieces. A constant current control will not overcome this problem. Even though the current in the secondary is constant, the weld nugget will attempt to form at the point where the greatest amount of heat is generated.

An imbalance in the secondary can also be caused by electrical differences in the size, shape or length of the major conducting members of the secondary circuit. For example, the length of the arms of a rocker arm machine, the diameter and length of dry jumpers used in the welding secondary circuit, improperly fitted parts in the secondary circuit, welding dissimilar thicknesses of material, welding dissimilar metals, using electrodes with dissimilar alloys or dissimilar size and shape can all contribute to an unbalanced condition in the secondary circuit. Maintaining the size, shape and length of the secondary is usually easily accomplished, and most machines are designed with an electrically balanced secondary circuit even when the mechanical arrangement appears to be unbalanced. Welding controls cannot overcome electrical imbalance in the secondary of the welding machine.

The welding of dissimilar thicknesses of material is not uncommon, and can unbalance the secondary circuit. Means to balance the circuit are readily available. A change in the size or shape of the electrodes or a change in material of one electrode can very often bring the secondary back into balance, placing the weld nugget at the interface between the two pieces to be welded. Figure 51.

Figure 51 represents the problems and solutions to the welding of dissimilar thicknesses of material. A basic "rule of thumb" to determine the size of the face of the electrodes to be used to weld dissimilar thicknesses of material is quite simple and is illustrated in Figure 51. If similar sized electrodes are used, the weld nugget will not form at the interface of the two materials.

To use this "rule of thumb," draw a sketch, to scale, of the two workpieces in a horizontal position. Draw a vertical line through the two workpieces, at the centerline of the electrodes to

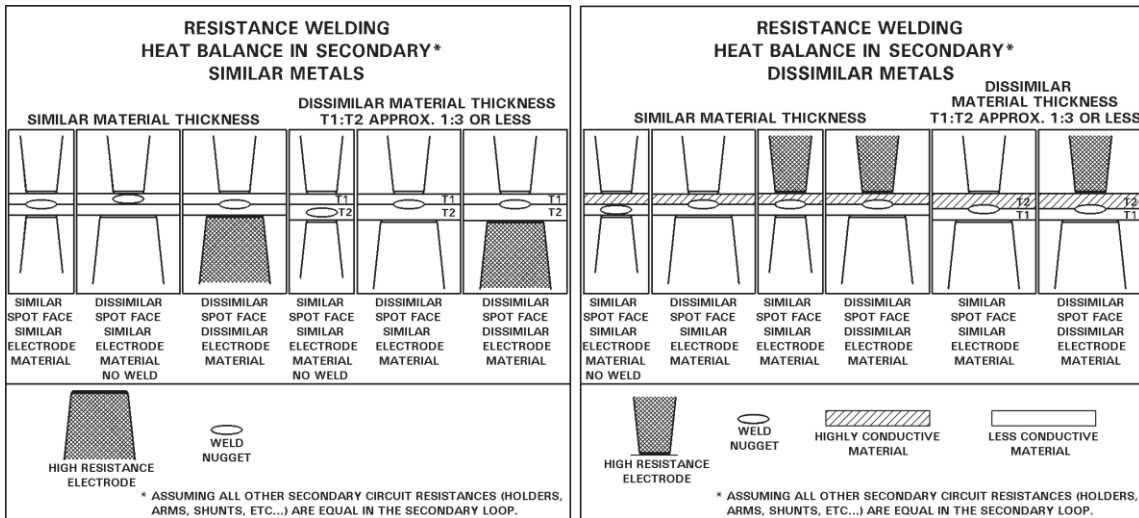


ELECTRODE SIZING FOR DISSIMILAR THICKNESSES

Figure 51.

This “rule of thumb” will work well where the ratio of the thin to thick material, $T1/T2$, does not exceed $1/3$. For cross-wire welding, which is a form of projection welding, balance is not a consideration. See Figure 41, Page 37. For series welding, larger ratios are acceptable. Changing the electrode material of one electrode can also move the weld nugget. Placing an electrode of higher resistance (lower conductivity) against the thicker workpiece and an electrode of lower resistance (high conductivity) against the thinner piece will move the weld nugget toward the interface of the two workpieces. For example, a Class 2 alloy electrode has a conductivity approximately 80% greater than Class 3 alloy electrode.

Mismatching electrode face diameter and materials can also cause an imbalance when welding like thicknesses of material. Electrodes should be properly stocked so that alloys and sizes cannot be mixed inadvertently. Electrodes should always be changed as a pair so that the proper diameter to the work can be maintained. Figure 52 is a representation of the variations in electrode selection for welding dissimilar thickness of materials as well as dissimilar materials.



SECONDARY HEAT BALANCE VS. ELECTRODE SELECTION

Figure 52.

Electrodes should be machined to shape, not filed. The problem of faulty welds due to improper selection and maintenance of electrodes so often results in control-like fault symptoms that it is well to mention the matter one more time.

The size and shape of the electrode also has a relationship to the welding current requirements. An electrode too small may “produce” a hot weld, where an electrode too large may “produce” a cold weld. Some adjustment in the control setting of percent current or timing may seem to alleviate this problem momentarily, but proper electrode selection is the correct answer to maintaining good weld quality. See Figure 55, Page 50.

Improper alignment of the electrodes will also adversely effect weld quality. Misaligned electrodes tend to “form” the workpieces as they contact the material to be welded, under force. Further, the heat generated raises the temperature of the metal to near the melting point. The effect of welding pressure against the misaligned, heated material will cause a malformation of the parts near the weld area. Electrode life will also be reduced. Figure 53.

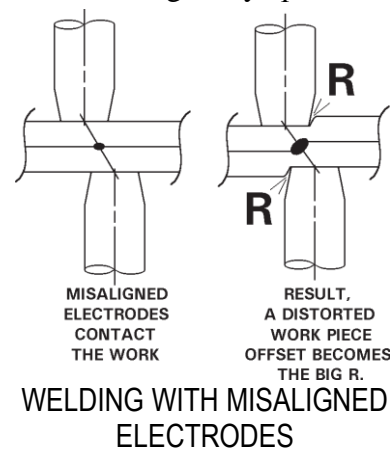
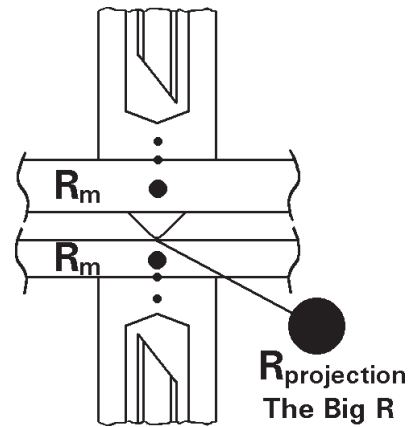


Figure 53.

There are instances where the welding of thick to thin materials cannot be conveniently solved by selection of electrode face size or material. In these instances, projection welding may be used to cause Ohm's Law to help form a proper weld nugget. Figure 54. Since a weld nugget will form at the point of greatest heat energy dissipation in the secondary circuit, a point contact of a projection deliberately establishes the point of maximum resistance in the secondary circuit, between the workpieces. Two large, flat-faced electrodes will provide the proper current conduction to the work. Welding electrode face diameter is not critical in projection welding.



RELATIVE RESISTANCE,
PROJECTION WELD

Figure 54.

The electrodes must be maintained flat and parallel.

Please note that the projection should be formed in the thicker workpiece to prevent collapse of the projection due to the weld force.

When it is necessary to place welds closer together than recommended in the welding tables, projection welding can provide the solution. Please remember each projection weld is a form of spot weld and requires essentially the same current and force as each individual spot weld. Refer back to Page 27.

Many welding problems are associated with overall machine set-up and the process, over which the weld control can provide little or no correction. The material to be welded (always start with the material) must be the correct material for the job. Material substitution involving changes in metallurgy, chemistry, tensile strength, carbon content, thickness, etc. may dramatically change the welding condition. In many instances these changes cannot be completely compensated for by merely changing control settings. Other machine set-up changes may be required.

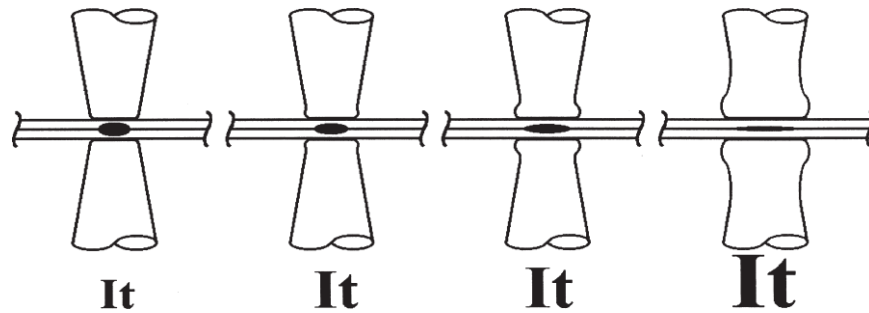
The surface condition of the material to be welded can also adversely affect weld quality. In most cases the weld control cannot compensate for dirt, rust, scale or paint on the surfaces of the material. Material should be clean and free of excessive oil or drawing compounds. Light mill oil will not adversely affect weld quality.

Electrode condition, type, shape, or material can also alter the weld parameters to the extent that changes in the weld control settings cannot fully overcome the weld problem created by the condition of the electrodes.

The size and shape of the face of the electrode is related to current density. It is current density that must be maintained constant in order to make welds of consistent quality. Electrode wear contributes dramatically to current density. An increase in electrode diameter of about 25% can reduce the current density by about 40%. Even though the control is maintaining the current constant, the weld nugget strength and size will be reduced. Figure 55 graphically demonstrates the result of electrode "mushrooming" on current density. The result is weld quality degradation.

	$\frac{1}{4}D$	$\frac{5}{16}D$	$\frac{3}{8}D$	$\frac{1}{2}D$
Electrode Face Diameter	.049	.076	.110	.196
Approximate Area of the Electrode Face	Square Inches	Square Inches	Square Inches	Square Inches
% of Measured Current Per Unit Area	100%	63%	44%	25%
Approximate Current Density at 12,000 Amps	245,000 Amperes Per Square Inch	155,800 Amperes Per Square Inch	109,100 Amperes Per Square Inch	61,200 Amperes Per Square Inch

A Stepper Can Change % Current and Time to Compensate for area change.



CURRENT DENSITY EXPLAINED

Figure 55.

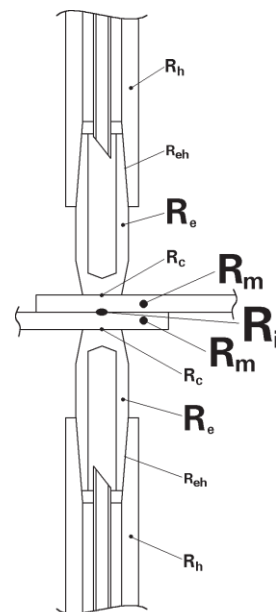
Even though the current remains constant, the current density reduces, reducing the weld quality. Steppers can be used to overcome the increase in electrode surface area to help maintain the same current per square inch of electrode face.

Welding electrode force must be correct for the material, material thickness and material hardness selected. Again, weld control adjustments have only a limited range in which to correct for improper weld pressure settings.

Proper electrode cooling is also important. Again, Ohm's Law and Joule's Law apply. If the electrodes are not sufficiently cooled during the welding process, the heat build-up in the electrodes will increase the resistance of the electrode. Eventually, the resistance of the electrode becomes equal to or greater than that of the workpieces. When this occurs, the voltage drop across the electrode consumes as much or more energy than is required to make a weld between the workpieces, resulting in no weld nugget being formed. Proper cooling of the electrodes and holders is essential. Figure 56. Refer back to Figure 49, Page 45.

To reiterate, the total energy into the weld is the product of the current, the resistance of the material, the material interface resistance, and the weld time ($H = I^2RT$). A weld control itself provides only two adjustable

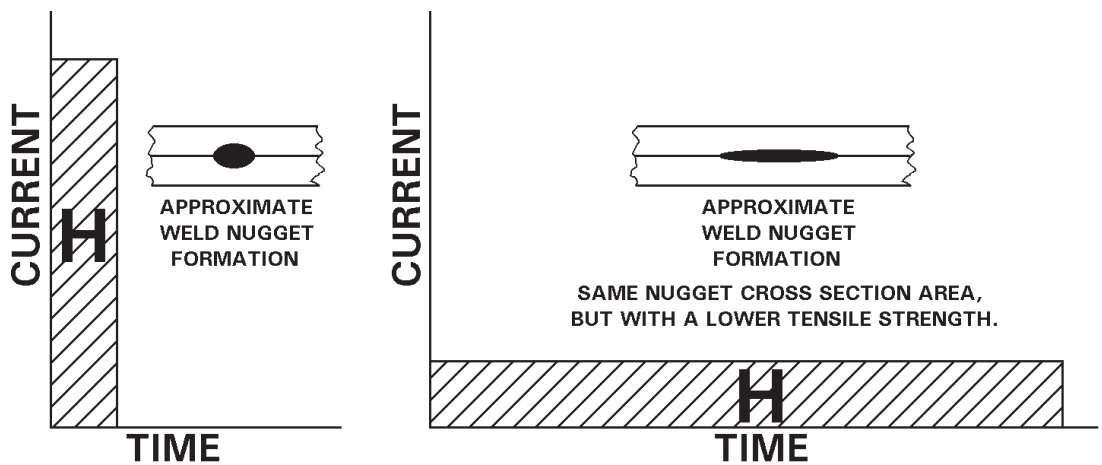
TOTAL HEAT IS TOTAL HEAT



$E = IR/H = I^2RT$
OHM'S LAW/
JOULES LAW
Figure 56.

parameters for controlling the energy to the weld. Assuming a correct transformer tap selection, the two variable control parameters are percent current (I) and weld time (T). The cold resistance (R) of the material and interface is assumed to be a constant for these calculations. When (R) varies, (H) varies, and (R) is the greater variable. Pressure control systems can offer some control over (R).

In almost every instance it is better to adjust the percent current than the time. The current is a squared function, so a small change in the percent current results in a larger increase or decrease in the total power, or energy, into the weld. Increasing time has a lesser effect on the total power and may introduce another source of energy loss. As the weld time is increased, the thermal considerations of the system come into play. The workpieces are thermal conductors and will begin to conduct heat energy away from the weld area during the longer weld time. The water cooled electrodes will also become more efficient in conducting heat away from the weld as time is extended. Figure 57. The amount of heat energy into the weld to attain the same size weld nugget is greater due to the increased heat dissipation through the electrodes and the workpiece.



Total energy into the weld is greater due to thermal losses

TOTAL ENERGY INTO THE WELD NUGGET I^2T
 ASSUMING A CONSTANT R AND THERMAL LOSSES THROUGH THE MATERIAL

Figure 57.

Use the LOWEST Transformer Tap,
 At the HIGHEST Percent Current,
 For the SHORTEST Time.
 This will help make the best weld consistently.

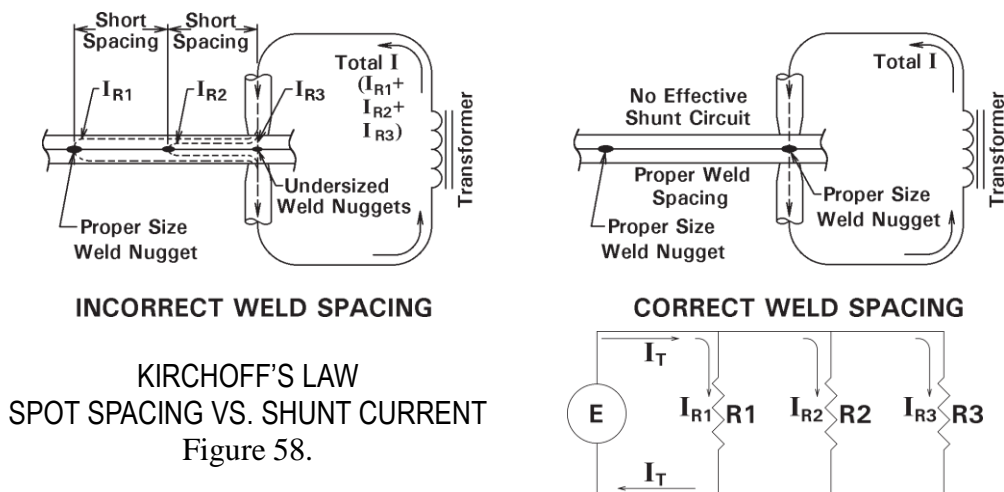
KIRCHOFF'S LAW

Kirchoff's Law of Distributive Networks can also work against making a proper weld when shunt current paths are allowed to exist in the secondary circuit of the welder. The workpieces themselves may even be a part of a shunt path. When an electrode shank or an electrode holder touches the workpiece at the same time that the face of the electrode is in contact with the workpiece, a second parallel path is provided for the current to travel through the secondary circuit. This second path decreases the current available for forming the weld nugget. The total current remains the same, but part of the current was "shunted" through a path that did not

contribute to providing sufficient energy to form the weld nugget. The total current is the sum of the current in the path to form the weld nugget AND the shunt paths. Figure 58.

When designing special tooling or fixturing, be aware that shunt paths may be unintentionally built into fixtures.

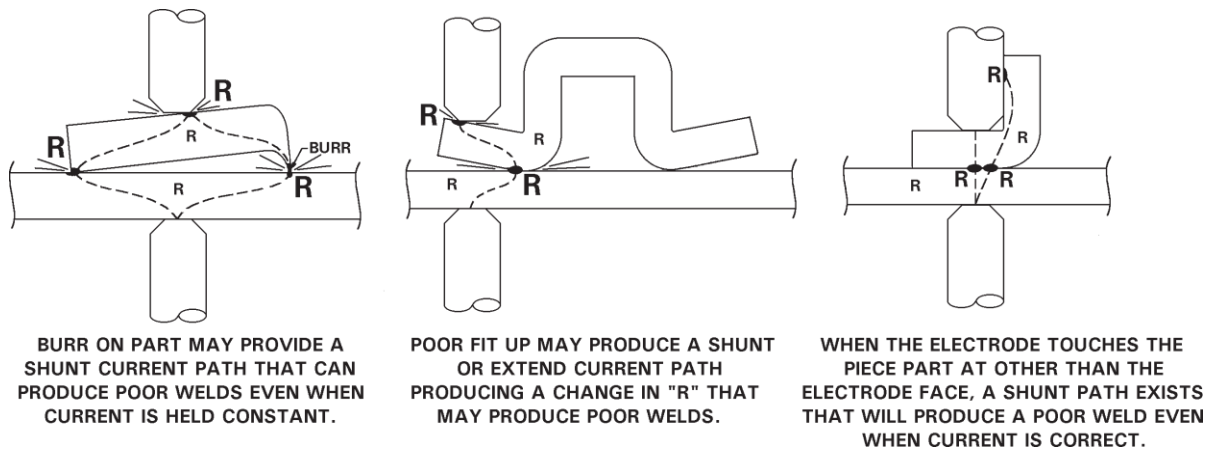
Another common form of shunting results from weld spacing that is too short for the material thickness being welded. The American Welding Society Recommended Practices for Resistance Welding, the RWMA Manual (see References, Page 62) and this discussion includes tables providing minimum weld spacing requirements for various thicknesses of material (see Figure 60). After a weld is made, a lower resistance path has been completed between the two workpieces. If an attempt is made to place the next weld close enough to the first weld that the total resistance of the material and the formed weld nugget is less than the resistance through the interface at the new weld location, some current will shunt through the previous weld nugget. The result is that the next and subsequent welds, at a similar spacing, will be of lesser quality and may be so poor as to not pass a structural strength test. Figure 58.



For seam welding, where the weld spacing is deliberately close, the weld current is increased to overcome the shunting effects of the close weld nuggets. This high current would be damaging to the wheels and workpieces as the wheels come up over the edge of the work piece. Stepping up currents, over the first few welds or Upslope control can overcome this problem.

If the spacing of spot weld nuggets is required to be closer than that recommended by welding standards, projection welding is again a solution for this problem. In this case, Kirchoff's Law can be used to our advantage. Fabricating two or more projections into a part, on very close centers, provides parallel current paths through the workpieces. The projections provide point contacts between the workpieces for the only paths for the welding current. Again, flat electrodes are used in projection welding.

Each projection is, of course, a separate weld. The current and pressure requirements for each weld will increase by the number of projections. Two projections require approximately twice the current and twice the pressure of a single weld. Also for the current paths to be equal, the projections must be the same size and shape and the electrodes must be flat and parallel with the work surfaces. The resistances at the point contact of the projections to the mating workpiece must be the same. If only one projection is initially making contact between the two workpieces, the initial current density will be doubled, possibly destroying the projection, resulting in poor weld quality. See Figure 26, Page 27, Projection Welding with Pulsation. See also Page 49.



PARALLEL WELD PATH PROBLEMS

Figure 59.

Other sources of adverse parallel weld paths may be large burrs or poor part fit-up. A large burr touching the mating piece near where the weld is to be made may provide enough of a shunt current path to result in poor weld quality. Part fit-up where a portion of the workpieces are touching near the weld area can also provide a shunt path that can lead to a poor weld being formed. Figure 59.

Another source of shunting in the secondary of a welding machine is a build-up of weld flash on the pads of the secondary of the welding transformer. Some current will shunt across the flash on the pads, resulting in less current at the weld interface. Constant current may maintain the current in the secondary, but not necessarily in the weld nugget area under these circumstances.

PELTIER EFFECT

The Peltier Effect is associated with the welding of dissimilar metals where the conductivity of the one metal relative to the other create differing thermal characteristics. The Peltier Effect is essentially an inverse thermal-electric effect. This is a concern where weld times of $\frac{1}{2}$ cycle to two or three cycles are used. Reversing the polarity of the first half cycle of weld is usually the accepted method of overcoming this problem. Since the materials involved are usually precious or semi-precious metals welded on smaller bench welding machines, the manufacturers of these controls often provide a polarity reverse switch on the front panel to accommodate this type of change. Reversing the polarity can move the weld nugget to the workpiece interface.

INDUCTANCE

Inductance has been discussed quite fully above as it relates to the power factor of the machine and the association of the phase shift current adjustment of the welding control. The size and shape of the secondary loop, the total amount of magnetic material in the secondary and the ability of the operator or control circuitry to properly adjust the power factor setting of the control are all factors in operating a welding machine efficiently. See Pages 20-23.

SETTING UP THE WELDING MACHINE AND CONTROL

Recommended practices for single impulse spot welding of low carbon steel, as prepared by The American Welding Society Resistance Welding Committee (AWS) are given in Table 1.1. This represents the composite experience and recommendations of some of the largest operators in the country. Schedule Tables for other processes and materials are also published by the Resistance Welding Manufacturing Alliance and the American Welding Society.

It must be remembered that low carbon steel may be satisfactorily welded over wide ranges of time, current, and pressure, and too low a value of one of these variables may, in part, be compensated for by the others. For instance, if the machine welding current is not great enough, this deficiency may be offset by an increase in "weld time" or decrease in force applied.

A given set of welding conditions or schedule that produces the best results for one operator may not be suitable to another. Therefore, recommended practice should be considered as a starting point from which any operator may make adjustments to suit his particular requirements.


An operators's first requirement may be maximum tensile-shear strength; whereas, another operator's first requirement may be a minimum of surface indentation. Both of these requirements cannot be obtained from the same settings.

The table in Figure 60 will usually provide a good schedule to follow. If for some reason this schedule or similar schedule cannot be followed, contact your welding machine manufacturer or refer to RWMA or AWS Standards for Resistance Welding. These tables are a good starting point. Heat (H) is the constant. Variations in current (I) or time (T), depending upon the material and welding pressure used, can still produce quality welds. For good set-up, it is suggested to use a current meter and a force gauge whenever possible. Also see Recommended Practices on

Page 36.

$$H = I^2RT$$

AWS Table 1.1-Spot Welding Low-Carbon Steel

1 THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE NOTES 1, 2, 3, AND 4 BELOW)	2 ELECTRODE DIAMETER AND SHAPE (SEE NOTE 5 BELOW)		3 NET ELECTRODE FORCE L.B.	4 WELD TIME (SINGLE IMPULSE) CYCLES (60 PER SEC.)	5 WELDING CURRENT (APPROX.) AMPS	6 MINIMUM CONTACTING OVERLAP 	7 MINIMUM WELD SPACING (SEE NOTE 6 BELOW) ϕ TO ϕ	8 DIAMETER OF FUSED ZONE IN., APPROX.	9 MINIMUM SHEAR STRENGTH		10 THICKNESS "T" OF THINNEST OUTSIDE PIECE (SEE NOTES 1, 2, 3, AND 4 BELOW)
	D. IN., MIN.	d. IN., MAX.							L.B.		
									ULTIMATE TENSILE STRENGTH BELOW 70000 PSI	TENSILE STRENGTH 70000 PSI AND ABOVE	
0.010	3/8	1/8	200	4	4000	3/8	1/4	0.10	130	180	0.010
0.021	3/8	3/16	300	6	6500	7/16	3/8	0.13	320	440	0.021
0.031	3/8	3/16	400	8	8000	7/16	1/2	0.16	570	800	0.031
0.040	1/2	1/4	500	10	9500	1/2	3/4	0.19	920	1200	0.040
0.050	1/2	1/4	650	12	10500	9/16	7/8	0.22	1350	—	0.050
0.062	1/2	1/4	800	14	12000	5/8	1	0.25	1850	—	0.062
0.078	5/8	5/16	1100	17	14000	11/16	1-1/4	0.29	2700	—	0.078
0.094	5/8	5/16	1300	20	15500	3/4	1-1/2	0.31	3450	—	0.094
0.109	5/8	3/8	1600	23	17500	13/16	1-5/8	0.32	4150	—	0.109
0.125	7/8	3/8	1800	26	19000	7/8	1-3/4	0.33	5000	—	0.125

NOTES :

1. TYPE OF STEEL - SAE 1010.
2. MATERIAL SHOULD BE FREE FROM SCALE, OXIDES, PAINT, GREASE AND OIL.
3. WELDING CONDITIONS DETERMINED BY THICKNESS OF THINNEST OUTSIDE PIECE "T".
4. DATA FOR TOTAL THICKNESS OF PILE-UP NOT EXCEEDING 4 "T". MAXIMUM RATIO BETWEEN TWO THICKNESSES 3 TO 1.
5. ELECTRODE MATERIAL, CLASS 2
MINIMUM CONDUCTIVITY - 75% OF COPPER
MINIMUM HARDNESS - 75 ROCKWELL "B"
6. MINIMUM WELD SPACING IS THAT SPACING FOR TWO PIECES FOR WHICH NO SPECIAL PRECAUTIONS NEED BE TAKEN TO COMPENSATE FOR SHUNTED CURRENT EFFECT OF ADJACENT WELDS. FOR THREE PIECES INCREASE SPACING 30 PER CENT.

OPTIMUM CONDITIONS-SCHEDULES FOR SPOT WELDING LOW CARBON STEEL-SAE 1010
Figure 60.

Column 1 specifies the thickness of the material to be welded. Note that this value is for the thinner of two (or more) sheets to be welded together. This also means that if no marking is allowed, a flat electrode should be against the thicker material. The smaller tip or electrode must be against the thinner material in order to balance the secondary current to assure that the weld nugget forms at the interface.

Column 2 is the minimum recommended size of the electrode to carry the welding current without undue voltage drop, wear or rapid change of electrode contact area.

Column 3 gives the maximum size of the contact face of the electrode (small “d”). Notice that the angle beyond the contact face is small (20°). A small angle will provide a longer electrode life. Enlargement of the contact area of the face of the electrode to the work piece is called “mushrooming.” Dimension (d) is very important. If (d) becomes too large, weak welds will result unless the weld current is increased accordingly. Should this face, (d), be too small, electrode force and current would have to be lowered, resulting in a too-small spot. The diameter of the weld nugget can be reasonably measured by measuring the diameter of the marking on the part. A destructive pull test is the correct method to determine the weld nugget diameter. The figure over column 3 is used where best appearance is desired. This shape of electrode must be turned on a lathe. Electrode life can be extended by the use of proper tip dressing tools. All electrode dressing should be done on a lathe or collet chucker. The use of files should be avoided whenever possible.

Column 4 “Weld Force” specifies actual electrode force. Here the gauge reading must be translated into electrode force. Refer to electrode force formula on Page 14.

Column 5 “Weld Time” is the length of time weld current flows, in cycles of the line frequency of the power source, and can be set to these values on the weld time switch on the weld control panel.

Column 6 “Welding Current” is the last control setting to make and check out. This setting, assuming all preceding adjustments are correct, will determine the size of the spot. It is not necessary to know the actual current in amps needed to make a weld. If the spot diameter and strength are correct, the current is correct (see column 9). A pull test, to check the diameter, should be made from time to time. An increase in the percent current adjustment will overcome some electrode wear. Re-dress electrodes as required, and return the percent current adjustment to the original set-up setting after electrode dressing or after a change of electrodes.

Column 7 specifies the minimum overlap of the parts for best quality welds. The same overlap must be used for test welds, especially for shear tests. A weld too close to the edge of the material may not be properly contained. Metal expulsion and poor weld quality will result.

Column 8 sets up the minimum spot spacing. If two spots are placed any closer together for a given material thickness, there will be undue shunting of current through the previously made spot(s) (see Figure 58). The subsequent spots will be smaller in size than the first weld and may be beyond safe limits for the subsequent welds. Test strips should be made at the same spacing as would be made on the final assembly workpieces.

Column 9 is the diameter of the fused zone. This can be checked two ways. One, after the making a spot weld, peel the test strip and measure the nugget size; two, place two test strips in “V” formation and spot weld at the bottom. Then twist the single spot in shear and measure the diameter of the fused zone. This is the test referred to in the notes on column 6 above.

Column 10 specifies the minimum shear strength of a single spot weld using test strips at least as wide as specified in column 7.

Note: "Hold Time" must not be set too short. To do so may result in cracked or damaged welds and bad surface discoloration. Longer hold times will usually do no harm except to take a little longer for the over-all weld sequence. Excess hold time may, however, produce "chill" cracks in the weld nugget of some materials. Hold time may vary from about 6 cycles to 10 cycles for most materials up to 14 ga. mild steel.

For Complete Welding Schedules see RWMA Manual (See References, Page 62), Chapters and Pages from the manual are listed below for various materials to be welded:

Materials:	Mild Steel	Chapter and Page:	7-14/15
	HSLA Steel		8-13
	High Carbon Steel		8-11
	Stainless Steel		9-9/10/11
	Coated and Plated Steel		Chapter 10
	Aluminum		11-14/22/23
	Nickel and Nickel-Based Alloys		14-4/5/7/9
	Copper and Copper-Based Alloys		13-10
	Magnesium and Magnesium Alloys		12-6/7/8
	Refractory and Miscellaneous Metals		Chapter 15

GENERAL OPERATING INSTRUCTIONS

1. Be sure all electrical connections are properly made and that all fittings are securely tightened. Loose electrical connections can cause faulty or erratic operation of the control and welding machine.
2. If air operated machine, turn on air to machine. Set machine manufacturer's recommended air pressure, or calculate the correct line pressure for the force required for the cylinder diameter of the welding machine. See Page 14.
3. Turn on water. Be sure water is flowing freely in drain. (On closed systems check flow gauge for water flow to assure that water is flowing properly).
4. Place WELD/NO WELD Switch on control (or external Weld/No Weld Switch) in the NO WELD position.
5. Place REPEAT/NON-REPEAT Switch on control in the NON-REPEAT position.
6. Turn on power. Be sure welding machine head or upper arm is fully retracted before turning on Power. A power "ON" light is installed on most welding controls. The power "ON" light should be lit.
7. Set Timer Functions and transformer tap switch as recommended by machine manufacturer or RWMA Standards for work to be performed. Place work in machine fixture or between electrodes.
8. Initiate control. On installations with two stage pilot, depress first stage only. Welding machine head or arms will close. Control will not sequence. Be sure welding electrodes have closed together and are properly aligned. Depress pilot to second stage, control will sequence, but will not weld, and head or arms will retract. On single stage operation, closure of the pilot switch will sequence machine. On foot operated machines only, a switch on the mechanical linkage of the machine will initiate Weld Time.

KEEP HANDS, ARMS, OTHER PORTIONS OF THE BODY, CLOTHING AND TOOLS AWAY FROM THE MOVING PARTS OF THE MACHINE.

9. Place Weld/No Weld switch in “Weld” position. Machine is ready to weld.
10. If no standards have been set, it is recommended to use a short Weld Time for initial welding. Weld Time can be increased; welding machine tap switch setting can be increased and Percent Current Setting can be adjusted for best weld. The most efficient use of the control and welding machine will generally be made at the lowest welding transformer tap, the highest percent current setting and the shortest weld time.
11. Set Timer Functions for initial machine start-up approximately as follows:
 - Set Squeeze to 30 to 60 cycles.
 - Set Weld to 2 to 3 cycles.
 - Set Hold to 10 or 15 cycles.
 - Set Off to 50 or 60 cycles (for repeat operation).
 - Set Percent Current to 70% to 80%.
12. Set Welding machine transformer tap to LOW or the lowest tap switch position. Repeat steps 8 and 9 as may be required to form a proper weld by making changes as required for control setting and transformer tap setting.
13. On Repeat operations, place REPEAT/NON-REPEAT Switch in REPEAT position. As long as the pilot remains closed, the control will continue to sequence and re-initiate the machine automatically.

A REVIEW OF RULES FOR MAKING GOOD WELDS

Refer to Figure 61 and Figure 62 at the end of the manual

Use the LOWEST Transformer Tap,

At the HIGHEST Percent Current,

For the SHORTEST Time.

This will help make the best weld consistently.

1. Squeeze Time too short can result in metal expulsion, burned electrodes, bad welds, marked work, damage to the contactor and a personnel hazard.
2. Weld Time too long will shorten the life of the electrodes, cause excessive indentation and cause internal cracks in the weld nugget which can result in weld failures. Too long a weld time may also destroy the stainless properties of stainless steel.
3. Weld quality cannot be judged by surface appearance only. Destructive testing is the only positive means of establishing weld quality against standards for strength of the weld and weld nugget size, published for the material being welded. Even where non-destructive testing procedures are used in production, a destructive test sample is required to establish the weld parameters that must be met by the non-destructive test procedure. Periodic destructive tests must be made to be assured that the non-destructive test procedure is truly helping to maintain weld quality. Use the pull test.

4. Weld Time too short will result in low weld strength, assuming all other factors are normal.
5. Hold Time too short can result in surface expulsion, electrodes sticking, internal cracks in weld nugget, and sometimes even cracks in parent metal. Follow the tables for minimum time.
6. Weld pressure too low can result in expulsion of metal and a personnel hazard, electrode damage (sticking), short electrode life, internal cracks in weld nugget, and sometimes excessive indentation.
7. Weld pressure too high can result in low or variable weld strength, excessive weld current requirements, mushrooming of electrodes, and excessive indentation. Possibly no weld at all.
8. With all other settings correct, adjust weld current to meet weld quality standards.
9. Electrode contact face too small will result in too small a weld, eventually excessive electrode mushrooming, and excessive indentation. Possibly no weld at all.
10. Electrode contact area too large will result in too large a weld (assuming current is set accordingly), internal cracks, or possibly no weld at all.
11. Electrodes misaligned or mismatched will result in expulsion and displaced weld nugget, accelerated electrode wear, deformed parts and possible personnel hazard.
12. Insufficient cooling will result in mushroomed and short life of electrodes, cracks on the surface of the electrodes and excessive material indentation, in some cases. It is very important that the water that is cooling the electrodes flows in through the water quill in the holder and back out the outside of the quill. Also, the angled water quill must be bottomed gently against the inside of the electrode cavity every time an electrode is replaced.
13. Dirty material - Dirt on the surface of the material will shorten electrode life and mark and burn the work surface. Poor weld quality may also result.
14. Excessive electrode approach speed will accelerate electrode wear and damage equipment. On projection welding, it can damage the projection, resulting in poor weld quality. Speed control valves can adjust the speed of the electrode approach.
15. Don't make a weld over the same spot to try to cover up for a bad weld. To do so effectively, the work must cool and then be hit with a much higher current. If a weld cannot be made with one hit, either the set-up of the machine is incorrect or the machine is not of sufficient size to make the weld. Pulsation welding (weld and cool) can be used to weld heavier material to effectively extend the weld capability of a machine.
16. Do not use the welder as a forming press. If parts do not fit correctly, correct the part form or shape before welding. A welding machine is not a forming press. The machine, electrode holders or fixturing can be severely damaged.

CONCLUSIONS

Good welder maintenance is always important. If the welding machine is not capable of welding properly, no control function can overcome the deficiencies. Proper care of the secondary of the machine, the electrodes and pressure system are often more important to good weld quality than the selection or set-up of the control.

Resistance welding is one of the simplest, lowest cost, surest means of metal joining. An understanding of the resistance welding process is basic to making good welds. The machines, controls and fixtures are only the tools necessary to help make the weld. The process is doing the real work.

**ONE MORE TIME
H=I²RT, JOULE'S LAW
IT WORKS!**

UNIVERSAL WELD SCHEDULE

JOB DESCRIPTION-----
PART NUMBER-----**JOB ORDER NO.**_____

MATERIAL: SPEC. _____ TENSILE STRENGTH ----- KVA -----
 WELDING MACHINE NO. _____ SURFACE PREPARATION -----
 THICKNESS (THINNEST PIECE) -----

DESCRIPTION OF WELD:

TENSILE STRENGTH ----- AIR GAUGE PRESS (PSI) -----
 PEEL TEST BUTTON DIAMETER ----- TRANSFORMER TAP -----
 GENERAL APPEARANCE ----- WELD FORCE (LBS) -----
 DIMENSIONAL CHECK ----- SECONDARY CURRENT (AMPS) -----
 SECONDARY DEPTH (IN) _____ HEIGHT **(IN)**-----
 SECONDARY VOLTAGE (V RMS) -----

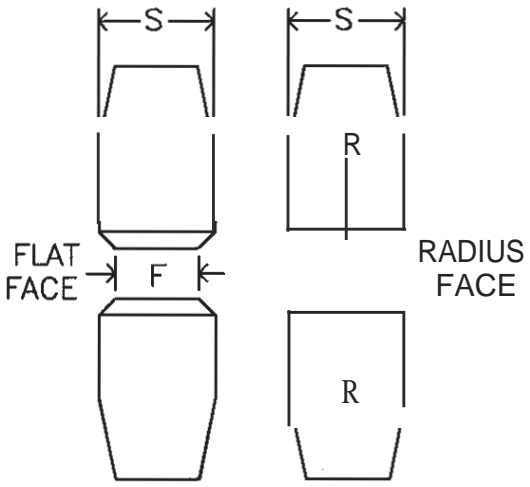
ELECTRODES: UPPER: LOWER:

MATERIAL CLASS _____
 SHANK SIZE (S) _____
 FACE SIZE (F) _____
 RADIUS {R} _____

WELD CONTROL DATA:

SPOT / SEAM / PULSATION-----
 SQUEEZE COUNT -----
 PREHEAT COUNT -----
 PREHEAT CURRENT -----
 UPSLOPE **COUNT**-----
 SLOPE BOTIOM **CURRENT**-----
 WELD **COUNT**-----
 WELD PERCENT **CURRENT**-----
IMPULSES-----
 COOL -----
 QUENCH COUNT _____
 TEMPER COUNT _____
 HOLD COUNT _____
 TEMPER CURRENT _____
 POST HEAT **COUNT**-----
 POST HEAT **CURRENT**-----
 NON REPEAT OR REPEAT _____ OFF
 COUNT _____
 INTERMITTENT OR **CONTINUOUS**-----

REDRESS ELECTRODES
 AFTER WELDS.



COMMENTS -----

 ORIGINATOR _____ DATE _____

UNIVERSAL WELD SCHEDULE WORKSHEET
 Figure 61.

REFERENCES

To order:

RWMA Resistance Welding Manual
RWMA Bulletin #1 - Precautionary Labeling of Resistance Welding Machines
RWMA Bulletin #5 - Resistance Welding Control Standards
RWMA Bulletin #14 - Maintenance Manual for Resistance Welding Machines
RWMA Bulletin #16 - Resistance Welding Equipment Standards

For the above and other RWMA Publications:

Contact - Resistance Welding Manufacturing Alliance
8669 NW 36 Street #130
Miami, FL 33166
(305) 443-9353 - FAX: (305) 443-5951
www.rwma.org

To order:

AWS Recommended Practices for Resistance Welding - C1.1 2000

Contact - American Welding Society
8669 NW 36 Street #130
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800-443-9353
305-443-9353
www.aws.org