THE PROCESS OF SPOT WELDING

&

THE FACTORS WHICH INFLUENCE QUALITY

An Electrastart Ltd Application Note

Auckland New Zealand

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Introduction

What is “Spot Welding”?

Resistance spot welding is a process in which sheet metals are joined by the passage of a high electrical current through them, via a pair of damping electrodes. This high current creates a very high temperature in the metal, under the clamping electrodes. The metals melt and fuse together, with a nugget formed between the electrodes. Think of a continuous column of the combined metals, from the outside surface of one piece, to the outside surface of the other, and, when properly formed has the same strength as the originating metals.

While the basic principle of resistance spot welding is quite simple, the achievement of good quality, consistent, welds require consideration of a number of factors, all of which affect spot weld quality.

It is important to also recognise that spot welding is a dynamic process in which the work environment between the electrode is changing, even when careful control of the various factors is maintained. These factors consist of the electrical and mechanical aspects of the process. In particular, the electrodes change over time, both mechanically and chemically, such that no spot weld is identical to the one created before it, or to the one created after it. However, a small amount of variation will not affect quality.

The important point is to understand the process of spot welding and know when the variations have reached the stage when they are about to affect quality.

How Important is the Quality of Spot Welds?

Spot welding is often the primary method of attachment used in the manufacture of a wide range of everyday items, including motor vehicles. It takes little variation of some of the factors influencing spot welds to move from consistent high-quality welds to welds which fail.

In over 40 years Electrastart Ltd (and its predecessor Electro Control Services Ltd) has been in the business of consulting on spot welding applications, we have seen a number of instances of large quantities of manufactured items returned to the manufacturer, by the customer, because a few of the entire batch had spot welds which failed. In a couple of cases, large export orders were at stake.

In the modern world, in which product quality is demanded, no excuse is accepted for assembly failures as basic as poor spot welds. As stated above, the spot-welding environment changes constantly, and if rigorous monitoring is not continually carried out, there is the real risk of a few failed, undetected welds causing the cancellation of orders and the loss of reputation

However, there are now products available which dramatically improve the manufacturer's ability to achieve high quality, consistent spot welds.

Controllers provide standardisation of the electrical factors leading to good spot welds.

Weld Monitors (or "weld checkers”) provide real time monitoring of all aspects, both electrical and mechanical, of spot welding to alert the operator before failed welds occur. Monitors indicate the need for remedial maintenance of the equipment and the placement of additional welds if necessary. However proper choice of the monitor is essential if optimum results are to be achieved. The necessary considerations are discussed later in this note.

Factors Influencing Spot Weld Quality

There are a number of factors which affect the quality of a spot weld. These can be broadly divided into two categories - mechanical and electrical.

Mechanical Factors:

Squeeze Pressure - This is an important factor in proper nugget formation

Tip Shape - The electrode surface shape. Is it correctly sized for the material thickness being welded?

Tip Condition - Are they flat and clean? Is there alloyed material on the tips?

Material Surface Conditions - Is there oil or rust on the surface? Is it galvanised or has an alloy coating?

Material Thickness - Is it consistent?

Material Conductivity - Is the material composition consistent? This is normally not a factor with standard materials but may need to be considered if attempting to weld unusual materials.

Electrical Factors:

Power Level - Is the amount of power going into the weld appropriate for the job?

Weld Duration - How long is power being applied? Is it too short or too long?

Squeeze Pressure

Squeeze pressure is the force exerted by the electrodes to hold the two pieces of metal together. It is an important factor in the creation of the weld nugget that forms between the work. Variation in squeeze pressure causes inconsistency in nugget formation, expulsion of molten metal during welding and visible burning of the surrounding surface.

Spring controlled, mechanically operated, spot welders are particularly susceptible to squeeze pressure variation.

It can also occur with pneumatically controlled welders when solenoids, regulators and air lines require attention.

Electrodes and their Role in the Process

Electrodes must possess high electrical conductivity to minimise electrode heating, and high thermal conductivity to dissipate heat from the contact area between the electrode tip and the workpiece. Electrodes should also exhibit high hot strength to resist deformation caused by the application of high squeeze pressure. Ideally, limited or no alloying reaction should occur between electrode and sheet metal. However, this alloying reaction occurs readily when spot welding galvanised material, requiring more regular electrode maintenance.

The usage of metallic coated steels (e.g., Electrogalv and dip galvanised steel) increases the rate of electrode deterioration. The increased welding currents and times required to weld metallic coated steels cause the metallic coating to alloy with the electrodes. The use of accurate controllers can reduce this effect by optimising the weld current and time to the absolute minimum necessary. For these reasons good quality spot welding electrodes are manufactured from a Zirconium- Chromium-Copper alloy (UNS-C18150) commonly known as J47Z. This material has virtually the electrical and thermal conductivity of pure Copper but is much harder. It will retain its hardness to at least 500°C.

A key element in the production of a strong spot weld is the size of the created “weld nugget”. This is the area of the work in contact with the electrode and shows the effect of melting the material to create the weld nugget.

> As a rule of thumb, the diameter of the weld nugget should be about the same as the combined thicknesses of the material being welded.

Over time the tips flatten and the voltage across the weld decreases - a larger surface area over which the weld energy is distributed, creating a weaker weld.

Therefore, it can be seen that maintenance of electrode tip condition and shape is a critical factor in spot weld quality.

Material Variation

A common cause of faulty welds is material variation. Usually, it is variation in the condition of the surface. Modern metallurgical manufacturing techniques generally rule out the possibility of material composition variation.

Surface variation usually falls into two categories:

> Inconsistent preparation of the surfaces prior to welding - cleaning etc
>
> Even minute particles on one of the surfaces can have a significant impact on weld quality, by preventing full surface to surface contact of the materials to be spot welded together. Oil coatings are a common problem here.
>
> Variation in surface material - If the surface has an outer coating (e.g., galvanising or other plating) it may be of inconsistent thickness.

Control of Spot Weld Quality

The mechanical factors are controlled by good "housekeeping" - regular inspection and maintenance of electrodes, attention to quality control of raw materials and appropriate cleanliness of the work material. However, there is always some variation within material conditions and, as already mentioned, the electrode tips are constantly changing. These mechanical factors are not readily apparent, even to a trained eye, and the use of a spot weld monitor is essential if these constantly varying factors are not to jeopardise quality, while ensuring production throughput.

The electrical factors are best controlled by use of a good quality spot weld controller, which offers consistent timing and power control.

The Role of Spot Weld Controllers

The ideal spot weld, from an electrical perspective, is simply defined:

The maximum amount of power for the job is applied for the minimum amount of time for the job.

This approach provides good welds with the least distortion to the remainder of the material.

However, there should not be expulsion of material from the weld. This obviously weakens the weld. Showers of sparks might look impressive, but they also show that the operator or machine setter doesn't know what they are doing.

→ Appropriate power levels and weld times for a given material are listed in other applications notes available on this website

Uncontrolled spot welders (the old "Youngs" type) in which the fool pedal also directly operates the main power switch, are notoriously inconsistent in their welding performance. The duration of the weld is dependent on the operator and the full power of the welding machine is applied to the weld. Fitting a recognised controller provides consistent weld times independent of the operator and precise power adjustment.

The controller is required to provide adjustment and control of both the power level of the weld and the weld duration. The power level adjustment should provide control from very low levels of power to the full capability of the spot welder. This provides greatest flexibility and allows a single spot welder to carry out a wide range of work. The weld duration should be able to be controlled down to a single cycle of mains i.e. 0.02 seconds.

Weld Timing

In the past we had noted the use of mechanical timers as spot weld controllers, which often have a timing range up to 5 or 6 seconds. Most spot welds require power applied for less than half a second and for mechanical timers spanning 10 or more times this period, precise time control is beyond their capability. Mechanical timers use electro-mechanical relays for power switching, which also do not have precise timing control.

Weld timing is measured in the number of cycles of mains applied to the welding transformer, and so to the weld. When a single mains cycle is 20 thousandths of a second in duration – 0.02 seconds – it can be seen that not only is precise mains-synchronised timing required, but the typical welding times are extremely brief.

Modern solid-state controllers have timing ranges from 1 – 99 mains cycles (0.02 sec – 2 secs)

Constant Current Control

Some of the more sophisticated controllers provide a constant current feature, in which they measure the intensity of the weld at it is occurring and automatically adjust to keep it constant. This adds significantly to the cost of the controller and may not be required for the majority of spot weld applications. It also introduces factors into the issue of quality monitoring which need careful consideration - see the following section on spot weld monitors

Dealing With Surface Contamination

Some controllers make automatic allowances for surface variation, allowing the controller to burn away any contaminant, or melt galvanising, before detecting that a standardised weld environment has been achieved and beginning the timed weld. This feature is usually called either "thermic" or "compensation".

Pneumatically Controlled Spot Welders

The larger pneumatically controlled spot welders require the controller to provide all of the sequenced control functions, typical of this type of machine The pneumatic solenoid is energised to lower the upper electrode and achieve the required squeeze pressure before weld power is applied, usually using an air-pressure switch . At the end of the weld the electrodes remain closed for a precisely timed period to ensure the weld nugget cools under full squeeze pressure. The controller then releases the upper electrode to allow the work to be removed.

Mains Control

Some types of controllers do not precisely control the mains to the welding transformer. The weld time can vary from weld to weld by several cycles of mains, depending on the design of the controller. In many applications, a variation of one or two cycles of weld time is not usually a problem. However, if the weld requires only two or three cycles of mains, a variation of one cycle is obviously significant. All modern controllers provide precise and consistent control of the number of mains cycles applied to a weld

Older controllers featured electro-mechanical switching of the mains to the welding transformer. These mechanical contactor-controlled units cannot offer the precision of control that is standard with all solid-state controllers, and they cannot offer power control, being a crude on/off device. They also require regular expensive maintenance as their contacts burn out.

Installation of a solid-state contactor is an essential element in the choice of any spot welder and controller, particularly when considering second-hand machines.

Power Control (Commonly called "Heat")

Many older spot welders have a number (typically 6) of voltage selecting taps on the primary winding of the spot-welding transformer. This provides a coarse power adjustment. However, it is seldom able to provide the precision of power adjustment required.

A good controller also features power control in which the proportion of each mains cycle applied to the weld is also adjustable. Modern controllers provide full adjustment of "Heat", allowing the machine setter to precisely set the power level in the weld.

The power control provides precise adjustment of the power level from 100% (all of each mains cycle) down to very low levels (only a very small portion of each mains cycle).

Up Slope

This function ramps the power level up to the set level, rather than applying the set level right from the start of the weld. This has the effect of reducing expulsion of material from the weld, particularly when welding coated materials. However, this feature will only work successfully when correct squeeze pressure is applied.

Multi Pulse Welding

Many modern controllers offer the feature of creating a weld with a number of brief repeated welds. This is particularly useful when welding a number of thin layers at once. It allows the weld to develop through all the layers, creating one continuous weld nugget.

Repeat Welding

Often the welding process requires a number of evenly space welds along the work. The repeat function has an "Off" setting in which the time required to raise the electrode off the work, before bringing it down again to start another weld, may be set to allow for the work to be shifted to the next position. This means the operator can leave their foot pressed on the pedal, and just shift the work at the appropriate times. This allows for high productivity with the least operator fatigue.

Monitoring of Spot Welds - The "Weld Checker"

The spot weld monitor, or “Weld Checker" as it is more commonly known, operates by measuring the electrical energy going into the weld as it occurs, and compares the measured value to precise limits entered into the weld checker by the machine setter when setting up the spot welder. Welds which fail to meet acceptability are flagged by the weld checker as they occur. This allows remedial work to be done on the welder or electrodes. It removes the responsibility of detecting faulty welds from the operator to the weld checker device. However, if the weld checker is not the appropriate type for the job, then there is still the real possibility of faulty welds in a batch of product that has been signalled as being up to standard.

There are two types of spot weld monitor. The difference is in their measurement methods. One type measures weld current and the other measures weld voltage. The difference is more significant than it first might appear.

Current Measuring Spot Weld Checkers

This type is the most common and typically features a digital display which shows the current that was used to create the spot weld. It is scaled in “kiloamps” (thousands of amps). There is often a second digital display which shows the number of weld cycles in the last weld.

This type of checker is actually providing an indication the performance of the controller. How many Amps and for how long were those Amps applied. However, it is important to recognise that it is not actually checking on the impact of mechanical factors which affect weld quality.

Electro Control Services (the forerunner of Electrastart) was involved in investigating why a current measuring weld checker was indicating that the spot welds were OK when in fact a number of welds had failed. A large export shipment was at stake.

Examination of the equipment showed that the controller was a sophisticated unit which featured constant current control. This meant that the controller automatically adjusted its output to ensure the current in the weld remained constant. The current (or “heat”) was set up correctly for the material being welded, and the alarm settings on the weld checker were appropriate. The weld checker was faithfully indicating that the controller was doing what it was required to do. But welds were failing.

However, as in any spot weld process the electrode tips were gradually flattening and becoming wider. The result was that while the current flowing through the tip remained constant, it was passing through the increasing surface area of the tip and at a consequence the current density (amps per square millimetre) was reducing. It was producing a bigger but weaker weld nugget in the work.

It was this type of experience that led to the development of the voltage measuring weld checker.

Voltage Measuring Spot Weld Checkers

Electro Control Services had been aware that the current measuring spot weld monitor has a number of significant limitations. In particular it did not easily detect the effects of the various mechanical factors which impact on a spot weld.

Investigation showed that variation of the mechanical factors had an impact on the voltage developed across the work by the current flowing through the weld. For example, if the squeeze pressure was reduced, the voltage increased even if the current remained constant. Surface contaminants on the work metal had a similar effect.

Over time, the electrode surface area, in contact with the work, increases as the electrodes flatten and distort due to heating and pressure effects The result is to reduce the current density in the weld. This is especially obvious with the more sophisticated controllers employing constant current control. The current remains constant in the weld, but it is spread over a bigger area, thus reducing the energy per unit area of the work. The result is a weaker weld that is not necessarily apparent to visual examination. And of course, visual inspection of each weld is extremely time consuming.

The more common spot weld controllers do not feature constant current control. When there is a variation in one of the factors, leading to increased voltage across the work, there is often a corresponding decrease in current flow through the weld. While this may appear contradictory when viewed from Ohms Law (an increase in voltage means an increase in current), is important to realise that a spot-welding transformer has a drooping characteristic such that it delivers maximum current when it is short circuited - that is, no voltage across its output. So, it can be seen that a voltage measuring weld checker can also detect reduced welding current

As a result of this work a voltage measuring weld checker has been developed, which also integrates time with the voltage measurement. This last feature means that the weld checker also monitors the duration of the weld. We now have a spot weld monitoring system which detects the effect on a spot weld of every factor

The Electrastart weld checker displays readings in millivolt seconds and also contains alarming functions so that every weld is compared to pre-set limits This unit truly allows the skilled machine setter to leave relatively unskilled operators to carry out the repetitive spot welding, knowing that any faulty weld will be signalled as it occurs.

Voltage Measuring Weld Checker as a Diagnostic Tool

The voltage measuring weld checker also has a useful function as a diagnostic tool when investigating the reason for increasing weld checker alarms

A typical spot welder consists essentially of a big low voltage transformer connected to the welding electrodes by copper busbars or multilayer flexible copper straps These connections are made with bolted joints. Over time, the bolted joints can become loose (especially if the welder shakes when it welds), corroded by cooling water leaks, and the flexible transformer straps (consisting of many layers of thin copper sheet) can increase their electrical resistance as the individual layers work harden and crack. The end result is that more and more of the weld energy from the transformer is dissipated in these steadily worsening joints. Less of the weld energy is going into the weld.

Many spot welders employ cylindrical welding arms clamped into brass housings which are slotted to allow the use of bolts to provide the clamping force. Over time, oxides and other materials build up in the clamps and it is not unknown for the entire open circuit voltage of the welder - often only 3 or 4 volts - to be lost across this clamp. The final result is no power at all at the welding electrodes.

The causes of decreasing weld energy can be discovered by clipping the ECS weld checker input sensor clips on either side of a bolted or flexible joint and carrying out a regular a weld. The ECS weld checker will display the energy dissipated in the joint. Tightening, cleaning, or repairing this joint, to minimise the energy measured, will result in the energy previously being lost now being available for the spot weld - where it is required.