Application Note 4

DC Resistance Spot Welding Process Variables

This application note provides an overview and explanation of some of the most commonly used terminology applied when describing the many process variables found in DC resistance spot welding. The aim of this note is to help the reader better understand some of the principles in DC resistance welding as well as those principles associated with weld process monitoring.

DC resistance spot welding uses the electrical resistance found in electrically conductive materials as a convenient heater that is capable of reaching temperatures that allow the materials to melt and weld together. In order to generate heat from the material resistance's, a pulse of electrical current is applied.

From Ohms Law :

Voltage = Current x Resistance $(V = I \times R)$
Power = Current x Voltage and hence Power also equals Current x Current x Resistance $(P = I^2R)$

Energy is Power x Time = $V \times I \times t = I^2 \times R \times t$

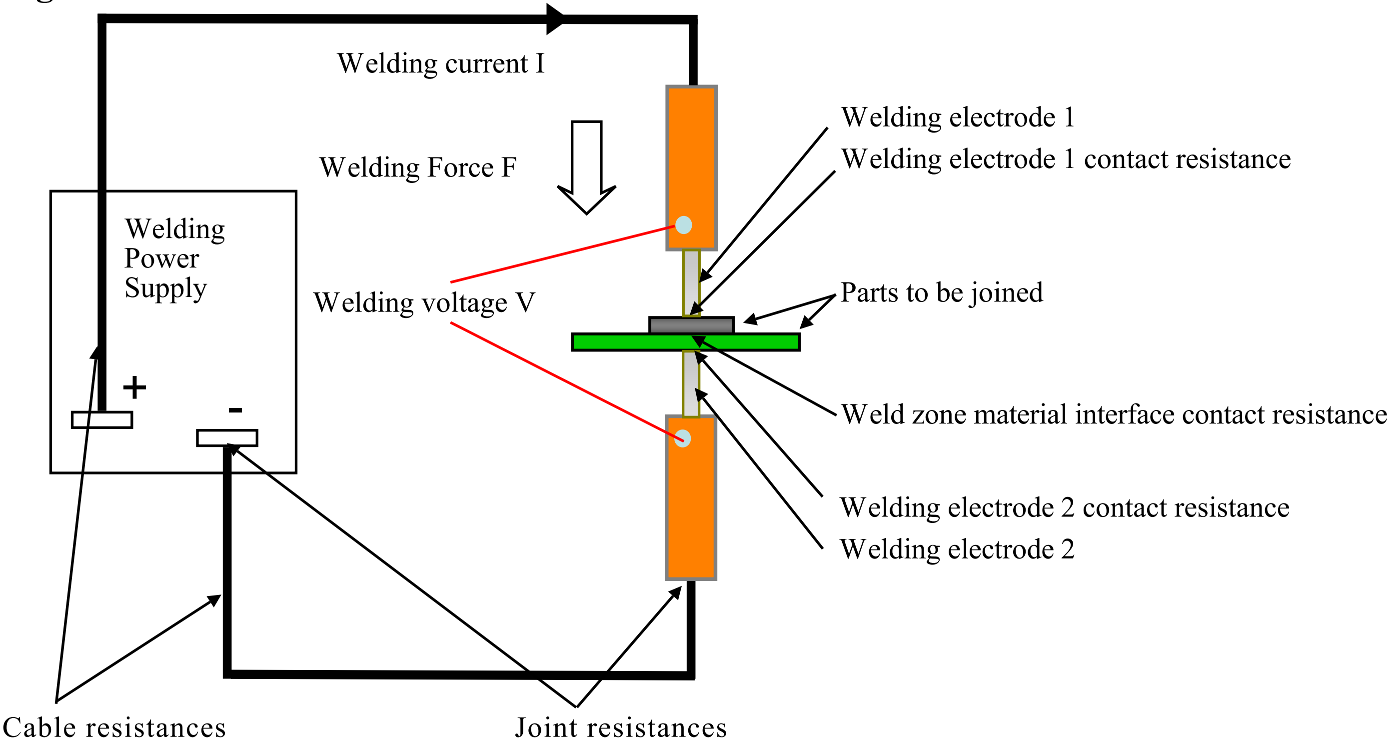
and **Energy density** is the Energy divided by the volumetric mass to which the energy is applied.

Given these simple equations and rules, we can see that the heating effect relies on both resistance and current and that the relationship with current is a squared law. If current is doubled, the energy increases by four fold.

Basic opposed DC resistance spot welding scenario

Fig 1 depicts a typical opposed weld scenario and highlights the various resistance sources in the circuit

Fig 1



DC Resistance Spot Welding Process Variables

Circuit Resistances

In order to create a stable process, the overall circuit resistances should be made as repeatable as possible. Cable resistances and joint resistances are unavoidable, but should normally be minimised by ensuring the connections are clean and tight. In some cases, such as with capacitive discharge welding, it can be advantageous to increase the cabling resistance by using smaller longer cables, which in turn helps to lower aggressive rates of rise of current.

Weldment : Focusing on the points between the two electrodes, the weldment is that part of the circuit that effectively acts as the primary heater and melting area for the weld. From Fig 1, we can see the various material interface resistances that will contribute to the heating effect when current is passed. The materials themselves will also have an electrical resistance.

As current is passed, the materials heat and their resistances will start to increase further increasing the heating effect. As melting starts to occur, the materials begin to combine increasing the overall material contact volume, decreasing the **energy density** and spreading the **weld energy** further, thereby heating more material.

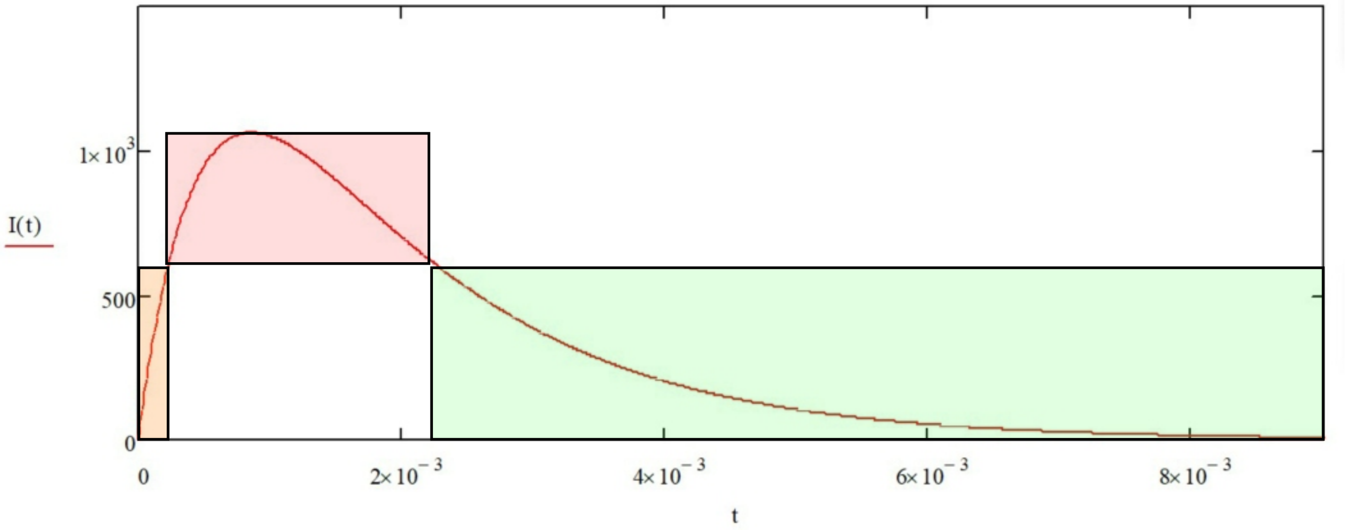
Static weld resistance : This is the effective weldment circuit resistance just prior to welding. Ordinarily, the welding engineer will aim to make the Static weld resistance as repeatable as possible from weld to weld as this is a good indication that the materials and electrodes are remaining consistent.

Dynamic weld resistance : This is the varying weldment circuit resistance exhibited as current is passed and the materials begin to combine as a weld.

The welding process

Reviewing and monitoring the weld energy and the circuit parameters is helpful in optimising the welding condition. It is important to bear in mind that the peak current flowing will determine the peak power and hence the peak heat. The current and power peaks therefore determine the majority of the welding capability and hence much depends upon the type of material being welded.

For conductive materials, higher current peaks will naturally be required, whereas with higher resistance materials, lower current levels result in more melt capability. Thus 3 stages occur, warming, melting & cooling.



DC Resistance Spot Welding Process Variables

Welding Forces

Referring to Fig 1, we can see that the materials to be joined a forced together by the welding force applied by the weld head. As is the case with any electrical contact joint, the higher to weld force applied, then the lower the contact resistance.

Achieving the optimal **welding force** is usually a matter of trial and error through welding trials. If there is too little force, then the subsequent higher resistance at the electrode to material interfaces can cause excessive instantaneous heating at the electrode which can lead to sparks and material damage. Conversely if the weld force is excessively high, this may reduce the overall weldment resistance to such an extent as to require significantly more current by which to make a weld. Excessive **welding force** can also lead to premature mechanical electrode wear and undesirable material deformations, hence an optimal balance of welding force must be found.

Weld head follow up : Spot welding usually takes a matter of milliseconds. During this time, relatively high currents are passed through the electrodes, material is heated to melting point, combined and then cooled. As the parts weld and combine, the gap between the electrodes will decrease as the materials collapse together during the dynamics of the weld process and it is vital that the electrodes remain in good contact throughout.

From Newton's Law : **Force = Mass x Acceleration**, we can see that the mass of the electrode holders along with their ability to move quickly and freely will be a determining factor in whether or not good contact is maintained throughout the welding process. It follows that with more **welding force** applied, there will be more spring energy available to accelerate the electrode holder as the weld begins to collapse, thereby helping the welding head **"follow up".**

Fig 2 - Offset electrode holders

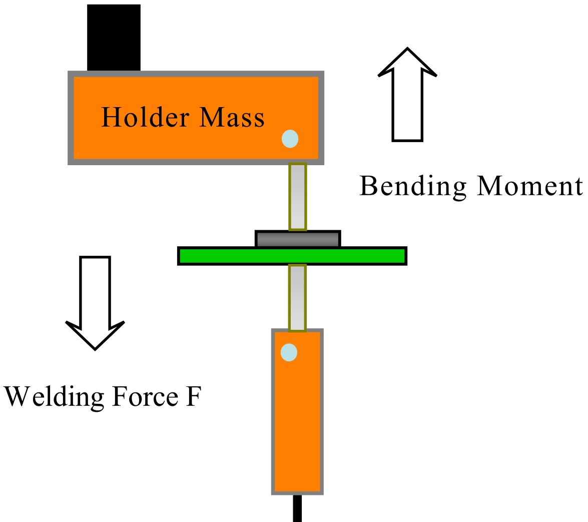
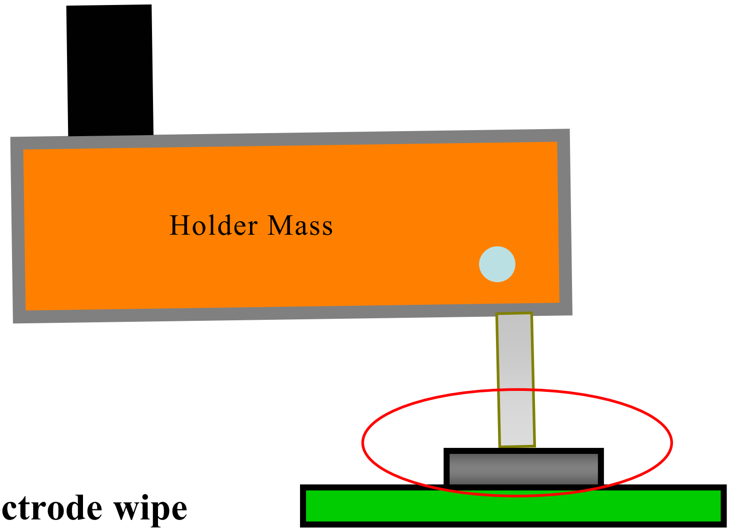


Fig 3 - Electrode holder compliance

Magnified view



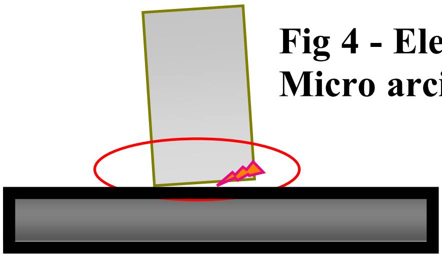


Fig 4 - Electrode wipe
Micro arcing

DC Resistance Spot Welding Process Variables

Welding Forces

Figures 2 & 3 highlight the mechanical effects created by the welding force. Firstly, **Fig 2** contrasts an offset electrode holder (top) against an in-line electrode holder (bottom). In this diagram we can see that there is a **bending moment** associated with the electrode holder and electrode being offset from the axis of applied force. **Fig 3** shows a magnified version looking at the electrode interface with the material as a result of the bending moment. Here we can see that the electrode contact area is no longer fully in contact since it has has been bent away from the product by the applied force.

In such a scenario, as welding current is applied and materials start to collapse, the electrode contact area will effectively cause **electrode wipe** against the product while current is passed. This will lead to excessive electrode wear and inconsistency from weld to weld.

Weld head follow up : Spot welding usually takes place in a matter of milliseconds. During this time, relatively high currents are passed through the electrodes, material is heated to melting point, combined and then cooled. As the parts weld and combine, the gap between the electrodes will decrease as the materials collapse together during the dynamics of the weld process and it is vital that the electrodes remain in good contact throughout.

From Newton's Law : **Force = Mass x Acceleration**, we can see that the mass of the electrode holders along with their ability to move quickly and freely will be a determining factor in whether or not good contact is maintained throughout the welding process. It follows that with more **welding force** applied, there will be more spring energy available to accelerate the electrode holder as the weld begins to collapse, thereby helping the welding head **"follow up".**

Wherever possible and practical, in-line electrode holders should be used to remove these bending moment effects, thereby reducing stresses not only on the parts, electrodes and holders but also on the weld head itself. Where electrode holders are adjustable, then the electrode should be positioned as close as possible to the axis of force applied by the head in order to keep stresses to a minimum and to avoid **electrode wipe**.

Weld head Head compliance is a further term used to describe the effectiveness of the weld head and electrodes in remaining in good contact with the parts during welding. A stiff, poorly maintained weld head operating with a low force may well struggle to keep the electrodes in good contact during the weld collapse. The likely result will be variable welding and sparking or **micro arcing** at the electrode surfaces, again decreasing the longevity of the electrodes.

Micro arcing : **Fig 4** shows an exaggerated situation. Electrode tip wear occurs through both mechanical work and electrical wear. Where high currents are passed, there is a tendency for micro arcs to develop on a microscopic level at the electrode surface, which ultimately cause surface degradation. This happens as a result of the contact area being unable to fully sustain the energy density at the microscopic peaks and troughs along the electrode surface.

As current is increased, so is energy density, hence higher currents tend to lead to more micro arcing and faster electrical degradation of the electrode tip. To counter these effects, welding force is often increased, forcing the contact points tighter together, but again, a balance must be found, since increasing the welding force, can also decreases the resistance and hence decreases the heat energy for any given current level. Increasing the force can also increase the electrode holder bending moment and potential for electrode wipe, so these aspects should be considered carefully.

DC Resistance Spot Welding Process Variables

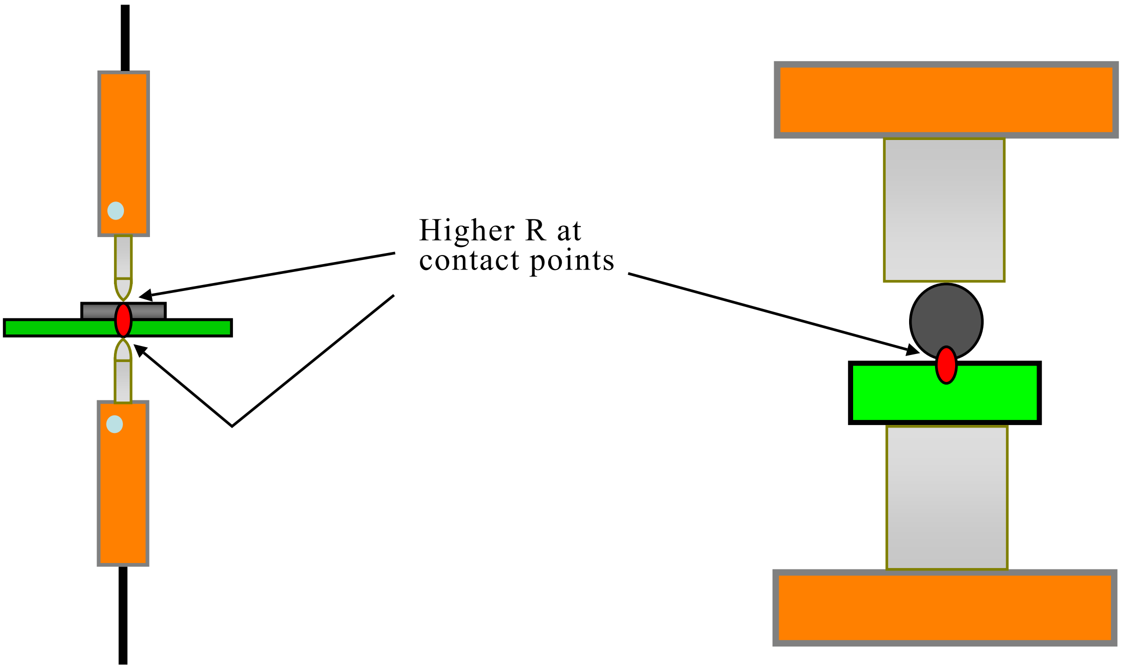
Electrodes

The material makeup and dimensional choice of welding electrodes plays a fundamental part in determining the reliability, longevity and stability of any particular DC resistance spot welding application.

In most cases there will be a multitude of potential electrode solutions that will actually create a welded joint, but usually after careful welding trials, this apparent choice should narrow considerably.

In order to select the appropriate electrode combination, it is important to understand the basic choices that are available and how the options ultimately effect the welding process in the longer term.

Fig 1 : Using electrode shapes **Fig 2 : Using product shapes**



Ideally, electrodes will be shaped such that production, maintenance and redressing is as simple as possible and this usually means that the electrodes should be circular with a flat contact face.

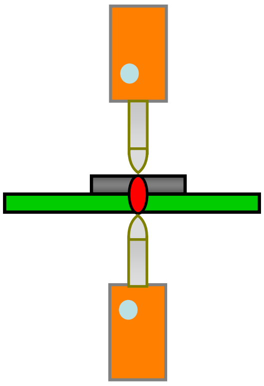
Wherever possible, it is best to try to exploit the natural shape of the products to be welded so that they themselves define the weldment setup. Fig 1 shows an example where the electrodes are machined in order to define the weld points whereas Fig 2 shows a cross wire weld where the components themselves define the weldment points. It should be clear that electrode maintenance of a circular flat ended electrode will be much easier than with a machined domed point electrode that will inevitably wear over time.

Electrode Materials and heat balance

Electrode materials vary considerably in terms of cost, functionality and maintenance. Having considered the mechanical **fit-up** of the parts i.e. the contact points at which the weld will be made, as per Fig 1 & Fig 2 above, the welding engineer should then consider the material types involved in terms of relative electrical resistance. As a common rule of thumb, conductive material welding can often be improved through the use of more resistive electrodes whereas when parts are naturally resistive, conductive electrodes generally improve the situation.

DC Resistance Spot Welding Process Variables

Electrode Materials and heat balance

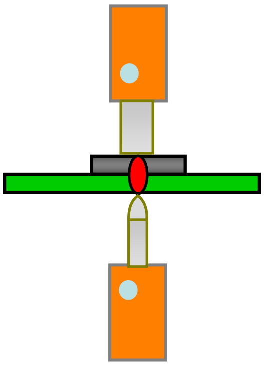


If we consider Fig 1, the aim is to generate an even weldment within the grey and green materials between the two electrodes.

If we assume that the upper grey material is highly resistive and that the lower green material is highly conductive, then if both welding electrodes are identical and the material thickness is the same for both upper and lower components, it is logical that much more melting will occur in the upper resistive material and this the energy density and heat balance is biased into the upper material.

It is therefore likely that the upper material will melt excessively with possibly no melt from the conductive material. In order to help balance the weld heat across the joint, in such a scenario the welding engineer might choose to counter these effects by using different electrode materials.

By making the top electrode more conductive and by making the lower electrode more resistive, there will be proportionally less heat generated at the top electrode interface and more heat generated at the lower electrode interface. This therefore helps to balance and focus the heat energy and density toward the material interfaces required to be welded.



Further heat balancing methods might be enacted by changing the electrode profiles. For example, if the lower material is more conductive, then a broader flat electrode on the upper more resistive material would also help to balance and focus the weld heat as shown right. In this case, the domed lower electrode provides a much higher point of initial contact resistance while the upper electrode simply dissipates the heat energy.

Common conductive electrode materials are generally alloys of Copper such as Copper Chrome Zirconium and Glidcop®. These allows are harder than copper alone and therefore are designed to last much longer.

Common resistive electrode materials include Molybdenum and Tungsten. Molybdenum is a softer, lower cost alternative to Tungsten and is ideal when developing a welding trial. Tungsten electrodes are of course much harder and therefore more expensive to machine.

In all cases, there will be trade-offs as to which materials provide the most economic and effective solutions.

Weld displacement

In highly monitored quality manufacturing environments, weld heads are sometimes fitted with displacement transducers. These devices actually measure the physical amount of weld collapse from weld to weld, thereby verifying a proper weld has taken place and that it has collapsed to within certain limits.

Electrical weld monitoring provides a means to verify that a certain amount of energy has reached the weldment but of course, cannot physically prove that the weld has collapsed to within a certain displacement range.

Weld displacement monitoring is therefore a relatively expensive quality control addition.