Application Note 2

Weld monitoring with single and double weld pulse applications

This application note sets out to explain the benefits and pitfalls in using double pulse welding. This note will look at the implications of using double pulse welding in Capacitive Discharge / CD micro welding applications, contrasting the differences as compared with a controlled, closed loop welding power supply.

In particular, this note will explain the benefits of monitoring real weld energy as compared with simply looking at current signals or energy outputs and how these measurements help determine weld process stability & quality.

In order to appreciate some of the technical detail presented, it is recommended that the reader familiarises themselves with the information provided in Application Note 1 - Weld Monitor Quality Control.

Generally speaking, Less is more… this note looks at why

Just because your micro welding power supply has a double pulse welding feature, that doesn't mean you need to use it. In fact, if you can reliably work with a single pulse weld, then it's usually best to do so.

Why ? Well as a general rule, the less weld heat energy you put through the tips of your electrodes, the longer they will last between redressing. You'll also put less strain on your power supply and less thermal stress on your product.

The general idea behind using a double pulse weld feature is to pre-condition the weldment setup prior to the actual welding, so that the electrodes and materials achieve a more stable and consistent starting resistance in readiness to accept a higher welding current.

Micro resistance spot welding relies upon using the inherent resistance at the material interfaces prior to and during the welding process by exploiting ohms law with the passage of electrical current. The heat energy generated at the weld comes from current x current x resistance x time, better known as **I^2R x time**.

As with all micro resistance welding applications, in order to achieve and maintain a stable process, it is desirable to try to stabilise the weldment resistance as far as possible, so that it appears and behaves in the same way for each and every weld. Fig 1 below shows the basic electrical arrangement.

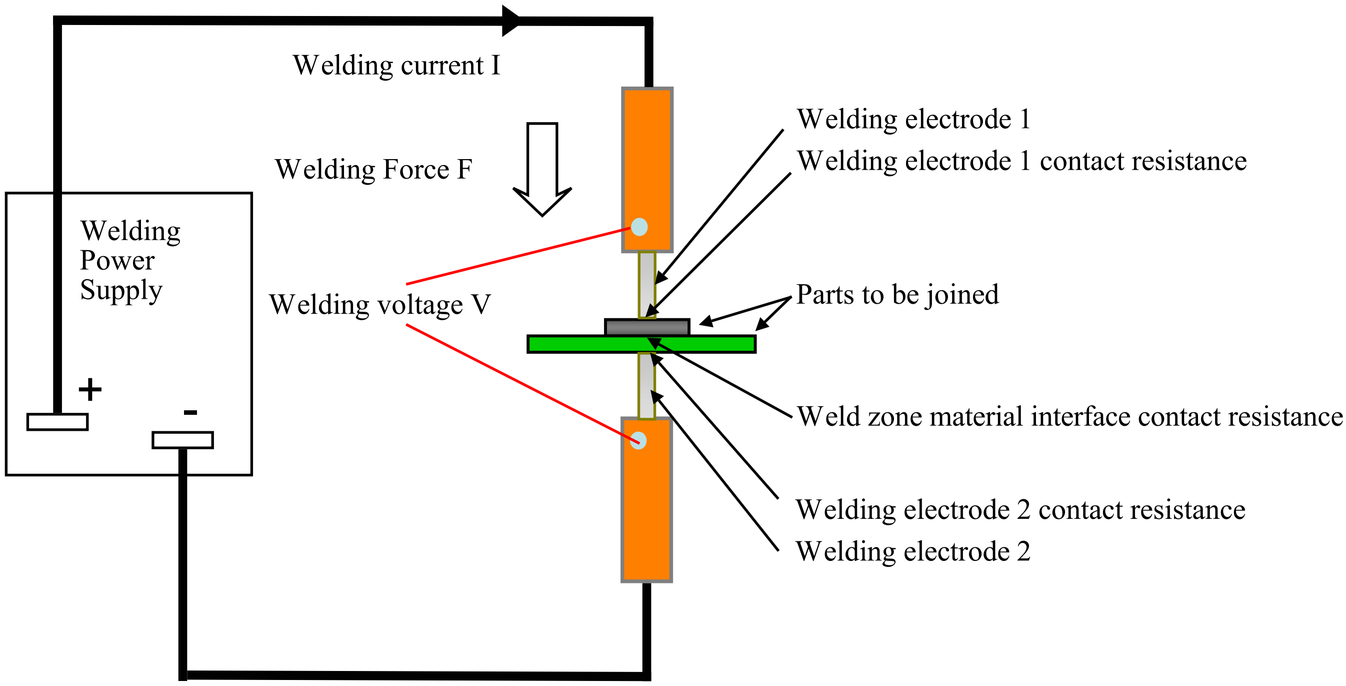

Fig 1 - Electrical conditions for resistance spot welding

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Fig 1 shows the basic parameters that should be considered when micro resistance spot welding processes are setup and monitored.

Welding Force F: More force squeezes parts together and helps keep the electrodes in good contact during the dynamic collapse of the materials. More force also decreases the contact resistance, thereby requiring more current to generate the same amount of heat. There is usually an optimum process balance for welding force.

Welding Current I: For controlled power supplies this is usually programmable in terms of time and amplitude, whereas for capacitor discharge applications, the current will vary depending upon the circuit impedance.

Welding Voltage V: This is the voltage appearing across the weld as a consequence of passing current through the weldment resistance. Note that the voltage at the weld is different to the voltage at the power supply due to losses in the circuit.

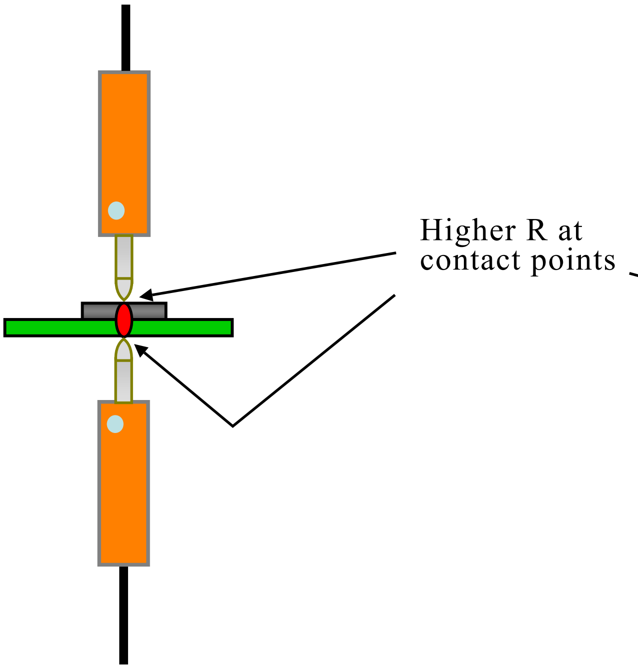
Contact resistance R: The electrical contact resistance at electrode and material interfaces.

Electrical Welding Power: From ohms law, this comes from V x I = Power = I^2R

Electrical Welding Energy: This is Power x Time, measure in Joules or W/S (same thing)

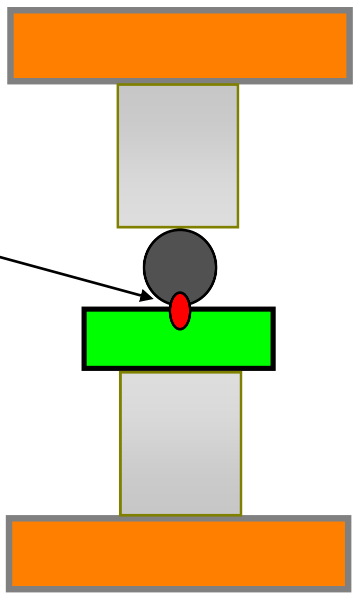
Electrical Welding Energy Density: This is the electrical welding energy dispersed across the geometrical aspects of the joint. Energy density will determine the temperatures at the joint and hence is directly related to the welding.

Fig 2 : Using electrode shapes



Welding flat surfaces, the electrode tip shape is used to define the contact resistance and focus the weld energy.

Fig 3 : Using product shapes



With cross wire welding and projection welding, the product shape is used to define the contact resistance and focus the weld energy.

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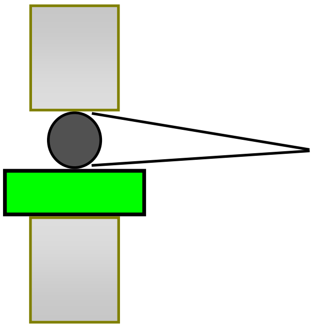
It is generally best to use natural or introduced product shapes as the key definitions for the weld resistance. This usually enables flat, easily machined electrodes to be used which can be larger and relatively robust compared with those that require shaping.

In considering the cross wire weld scenario, we can identify other areas of resistance and potential hot spots.

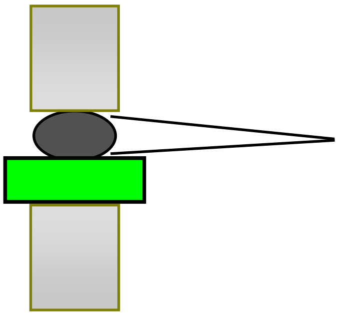
1



The initial tangential contact of the flat electrode to the wire circumference will have relatively higher resistance due to the small contact area compared with the contact area remaining once product deformation begins through welding.

Contaminants and oxides at these points will tend to increase this initial contact resistance, both at the electrode to wire point and the wire to wire point.

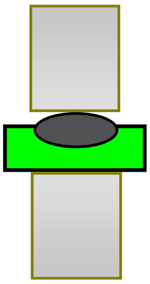
2



With double pulse welding, the idea is to pass a relatively small warming current through the parts, in order to burn off any oxides or contaminants.

This initial first pulse of energy may also be large enough to gently deform the parts in order to create a larger or more consistent contact area which is then able to sustain a much higher second pulse of current for welding.

3



Given that **Resistance** is a key element in generating the welding heat, in using a double pulse setup, it is advisable not to over cook things with the first pulse. This then leaves the second pulse with plenty of resistance to work with and hence, should require less current and therefore energy to make the weld.

Trying to minimise the energy at the weld is a sensible goal, since this will increase the electrode life and reduce potential thermal effects in the product created by conduction.

Material considerations

As a starting point, it is a good idea to know what materials you are working with and to determine their relative resistance values. Similarly, it is worth knowing if there are any plating materials used and what they might be.

In quality controlled and monitored welding environments, it is vital that the materials used in resistance welding processes remain the same once a welding schedule and process has been established.

There have been many occasions when an enthusiastic purchaser has purchased “the same” device from a different manufacturer. For example, a conventional 10K 0.5W resistor or a 1N4004 diode might be engineering specified as multi-source from multiple manufacturers and in terms of circuit performance, there’s no problem.

However, it is also likely that each manufacturer will have a slightly different manufacturing process, plating process and/or material content, so when the second source part is used in production welding, there is a problem or the welding schedule needs to be changed. Hence mixing multi source parts should be understood.

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Where to start

Before even thinking about a double pulse weld, it's not a bad idea to first try to make the weld with a single pulse. More often than not this is entirely possible. If you find that a single pulse weld is reliable and consistent, then you might as well save your energy and electrodes !

In order to make a start on your single pulse welding schedule, you will likely begin with a low welding energy and then gradually increase it. With servo controlled power supplies delivering programmable modes of operation, this is usually quite easy in terms of experimentation. Many such power supplies provide feedback measurements and graphs to help visualise what is going on electrically.

In order to make meaningful measurements, it is important that the voltage as well as the current is measured as close as possible to the electrode and weldment arrangement so that the real energy delivered to the weld can be established. With a controlled servo power supply, it is quite intuitive to increase or decrease the weld energy since these power supplies allow you to control a fixed output parameter such as current or power.

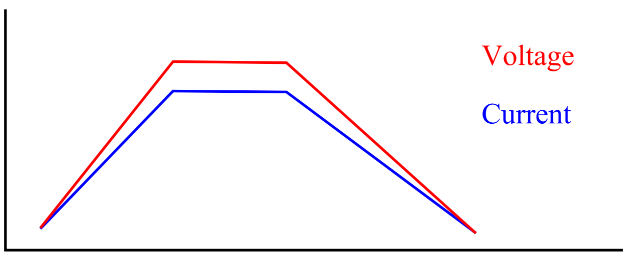
If you're using a capacitive discharge CD welder, then the result of changing the output energy is more difficult to measure and/or visualise since the weld energy developed at the weldment depends upon both the voltage and the current simultaneously, neither of which are under control.

With a CD welder, the voltage & current and therefore the energy developed at the weldment depends upon all the other electrical variables that are in the welding electrical loop. In actual fact, the power at the weld will depend upon the ratio of these various resistive elements, such as welding cables, weld head flexures, terminal lugs etc… compared against the value of the resistance at the weld. See Application Note 1 for more details.

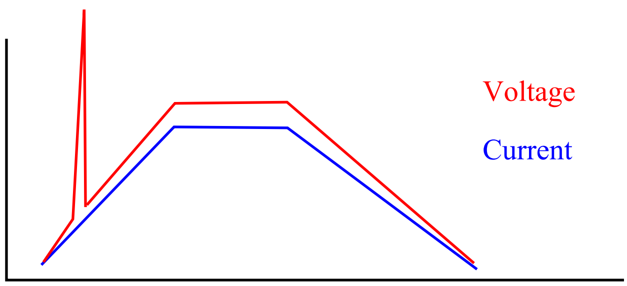
When setting up a weld, monitoring the actual energy at the weld by means of voltage and current measurements to derive weld energy provides an intuitive means by which to understand and visualise what is happening.

In all cases, be it a servo controlled or CD power supply, inherent circuit inductance dictates that once current starts to flow, it can take quite some time for it to change in amplitude. Conversely, voltage at the weld can change almost instantaneously, thus the actual power at the weld can change instantaneously for a fraction of a second as a result of a rapidly changing resistance, and this is what can lead to unwanted pops, bangs and sparks which can degrade both product and electrodes.

It is important to appreciate that the current waveform alone is not enough to see what is really happening since the current level cannot change very quickly. Thus a current waveform does provide an indicative means of visualising or monitoring the weld energy. In order to do this effectively you must look at both the voltage and the current signals and compute the total energy as real time values as shown below.



Voltage mimics the Current shape when contact resistance is constant - energy is contained

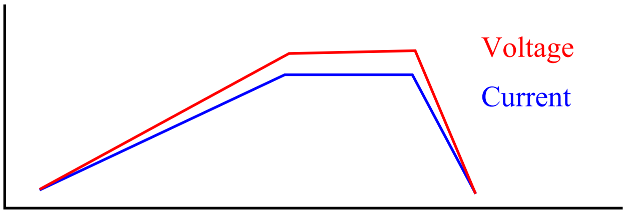


Sudden changes in resistance, cause voltage and thus energy spikes. Total weld energy increases, current stays the same !

Weld monitoring with single and double weld pulse applications

Controlling Weld Energy by controlling resistance

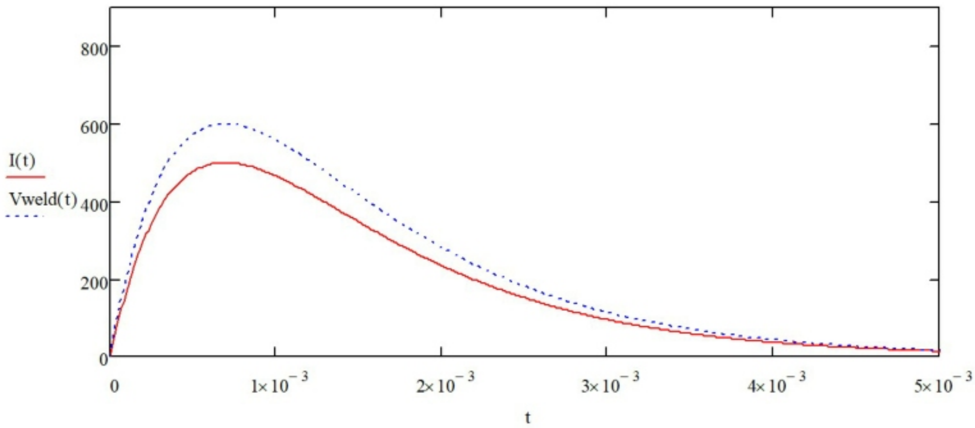
The more aggressive the rate of current rise is, then the greater the likelihood that high resistance hot spots will create unwanted power / energy spikes that can cause material expulsion. With a programmable controlled power supply, these effects might be mitigated by slowing down the current rise time, allowing more time for surface resistance and thermal effects to stabilise as the current increases.



Left : Programming a slower rise time to allow more time

With a CD welder there is little or no control over the rate of rise of current, so additional care and thought should be taken in deciding whether or not a double pulse weld might help your process.

If contact resistance points along with the dynamic weld resistance remain relatively constant, then consistent weld energy levels will be achieved because the voltage and current signals will remain in phase with each other, as shown below.



On the other hand, if weld contact resistance changes suddenly, then energy spikes can occur as with a programmable supply and these will be reflected as changes in the weld energy, as well as possible sparks and material expulsions ! Since the current waveform is not programmable, consideration needs to be given to mitigation methods that will help stabilise the weldment dynamic resistance.

As a first and simple consideration, it is useful to experiment with the **Welding force F**. Simply by bringing two opposed welding electrodes together without any product between, it is possible to start to estimate a useable welding force by measuring the electrical energy at the electrodes from a small fixed energy pulse and checking to see that the energy remains constant, despite small adjustments in the force.

What you should find is that when the force is very low, the electrodes may tend to stick slightly and that the energy levels will vary quite a lot. Note also that the current waveform may continue to look much the same, however the voltage will likely vary quite a bit. Here the contact resistance is highest and hence more heat.

As force is increased, you should find and expect that this energy variation decreases considerably to the point where there is little discernable change in energy across the electrodes per pulse. At this force level, we now know that the electrodes are making a consistent electrical contact with each other and thus the resistance is constant.

Weld monitoring with single and double weld pulse applications

Controlling Weld Energy by controlling resistance by controlling force

Having established an absolute minimum welding force, the process development should move to placing the components between the electrodes with a view to making a real weld by increasing the power to welding levels.

Capacitor discharge welders provide high currents for relatively low prices, whereas controlled power supplies tend to cost a lot more per ampere of output.

On the one hand, a servo controlled power supply offers the flexibility of being able to modify the waveform shape in order to combat contact resistance issues, but on the other hand, it may be limited in it's maximum current level when compared to a CD welder.

Knowing that resistance is needed to generate the heat and knowing that more welding Force reduces the resistance, the welding engineer must consider the balances involved.

For example, it may be possible to weld the same product at much lower forces and thus lower currents with a programmable supply but equally, if the product can stand it, higher currents at higher forces can do the same job and thus possibly, at a much lower price point.

This is especially relevant if those parts being welded are relatively conductive, which by definition, means they will require higher currents to weld them anyway.

Higher welding forces also have the positive effect of helping the electrodes maintain a good contact during the welding process. This in turn reduces the likelihood of micro arcing and can help extend electrode life.

Of course, if the welding force is increased too much, then the overall welding resistance might be reduced too much, preventing enough weld heat generation from I^2R . Excessive product deformation might also occur.

The welding engineer therefore needs to be thinking about the effect of Force on the weld resistance and how this might be used to the best welding advantage for any given scenario.

Energy at the weld will be defined by I^2R x time. This infers that if we can maximise the current and the resistance, we can also reduced the time that energy is injected.

Unlike a controlled power supply where the current level and it's time duration can be programmed, with capacitor discharge welding, we are starting with a capacitor energy level and then attempting to deliver that into the weldment via the cabling and weld head etc..
Our resultant weld energy waveform is therefore going to very much depend upon the dynamic weldment resistance, which in turn will determine the average current waveform and the overall pulse shape and duration.

The resistive dynamics of the weld will be reflected by the ENERGY at the weld, as a consequence of the voltage and current wave shapes combining in real time.

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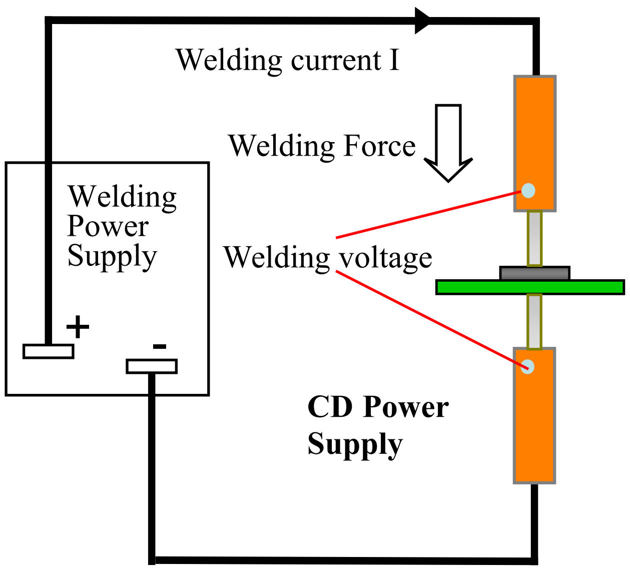
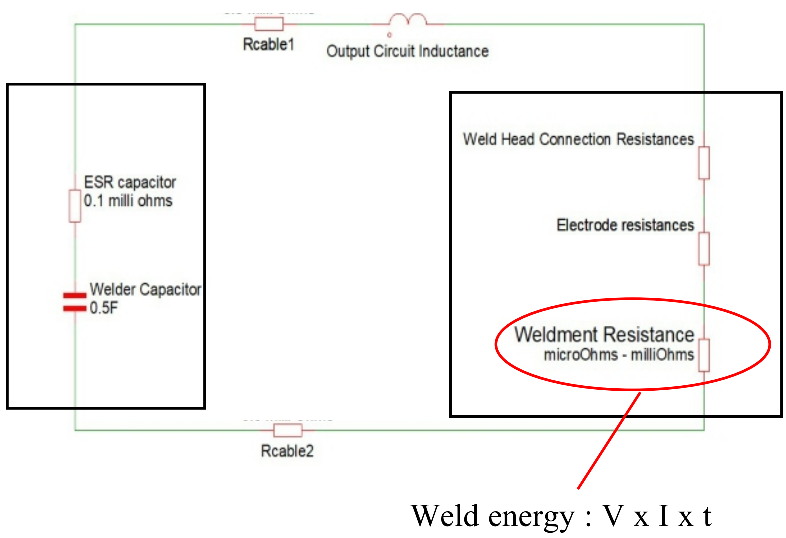
It stands to reason that with capacitor discharge welding, by monitoring the actual weld energy and it's stability and repeatability, we can get a good guide appreciation of how stable our welding process is, which in turn can help inform the welding setup and settings that are chosen.

Weld monitoring with single and double weld pulse applications

Controlling Weld Energy and stability by controlling resistance

Some examples :

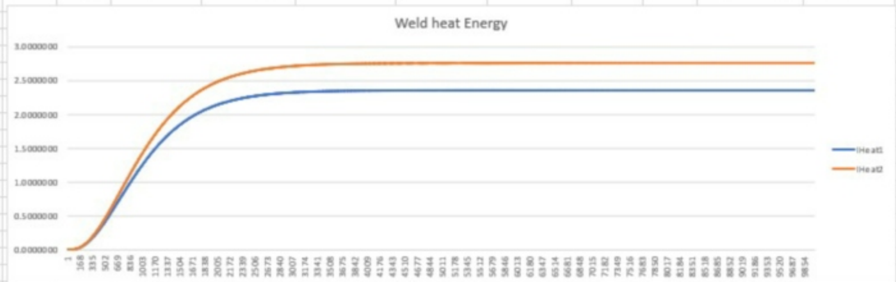


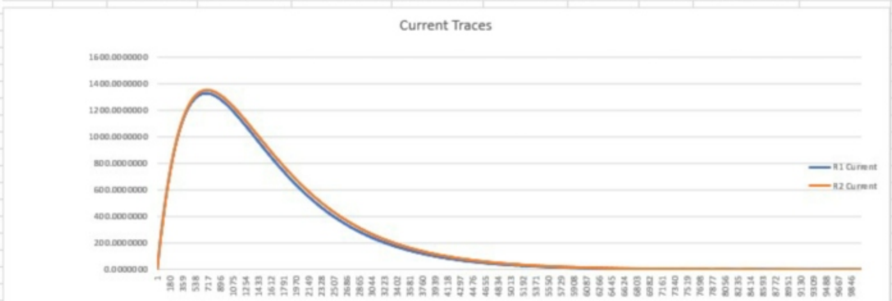


The figures above show a simple capacitive discharge welding setup with equivalent electrical circuit model. By modelling and understanding what is happening in terms of energy with different scenarios, an appreciation of welding process stability and it's relationship with energy can be gained.

Scenario 1 : Welding cables are 1milliohm and the weldment varies from 1milliohm to 1.1milliohm

	Inductance	Capacitance	Supply Volts	Total Cct R	Rcct	Rweld		Pk Current	Tot Weld Heat Energy
Condition1	0.0000020	0.5000000	10.6430000	0.0020000	0.001000	0.001		1330.375	2.360
Condition2	0.0000020	0.5000000	10.6430000	0.0021000	0.001000	0.0011		1354.429	2.764
Peak Current Change		1.78%						Output Energy1	28.31836225
% Heat Energy Change		14.62%						Output Energy2	28.31836225





As might be expected, a small change (1.78%) in peak current but the additional heat caused by the 0.1 milliohm change at the weldment, amounts to an 14.62% increase in weld energy (2.36J increasing to 2.764J).

Note the output energy is set at 28.3J and the peak current is 1330A.

Next step, let's see what happens if we deliberately increase our cable resistance.

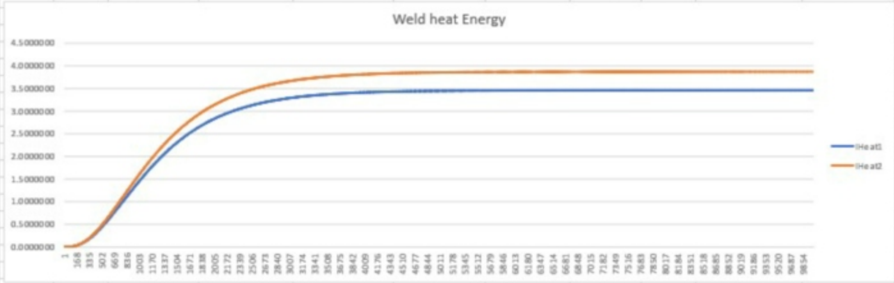
Weld monitoring with single and double weld pulse applications

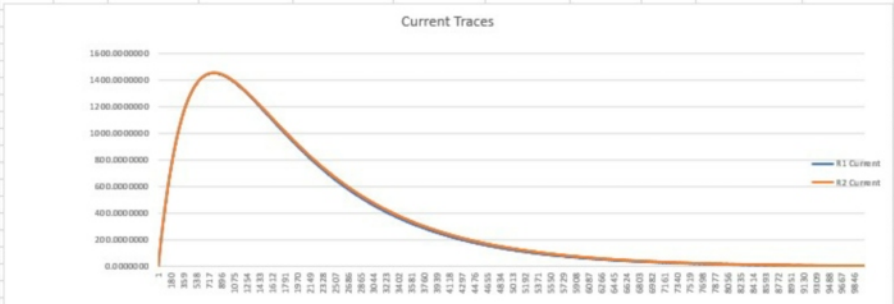
Controlling Weld Energy and stability by controlling resistance

Scenario 2 : Welding cables are now 2milliohm and the weldment varies from 1milliohm to 1.1milliohm

	Inductance	Capacitance	Supply Volts	Total Cct R	Rcct	Rweld	Pk Current	Tot Weld Heat Energy
Condition1	0.0000020	0.5000000	10.6430000	0.0030000	**0.002000**	**0.001**	1454.582	3.460
Condition2	0.0000020	0.5000000	10.6430000	0.0031000	**0.002000**	**0.0011**	1456.182	3.872

Peak Current Change	0.11%	Output Energy1	28.31836225
% Heat Energy Change	10.65%	Output Energy2	28.31836225





By increasing the cable resistance, the welding energy has actually gone up !

With 1 milliohm cables, it was 2.36J increasing to 2.764J with a 0.1 milliohm weld variation BUT with 2 milliohm cables for the same output energy, the weld energy is now 3.46J rising to 3.872J with a 0.1 milliohm weld change.

46% more energy at the weld !

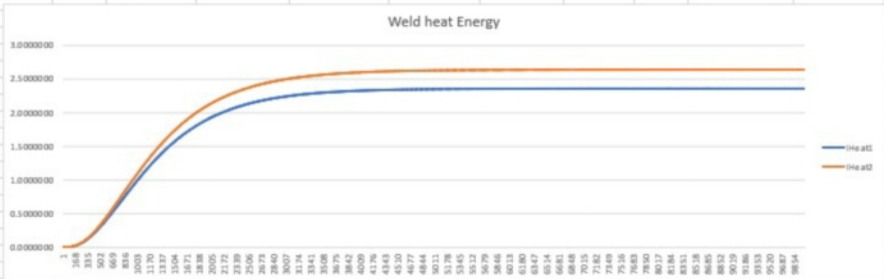
So, by making our welding cables longer and/or smaller in this example, we have made the weld hotter !

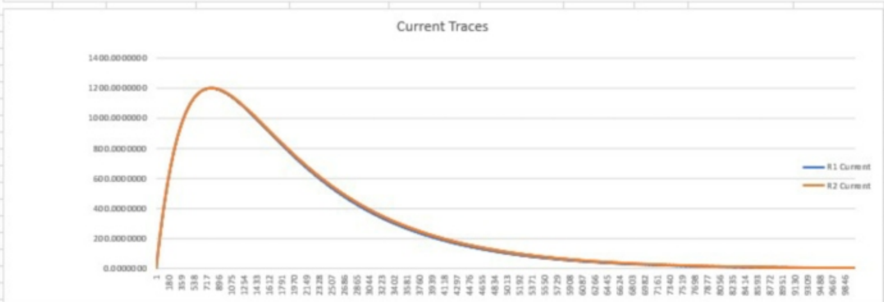
To get back to the same weld heat energy as for scenario 1, the welder output energy must be <u>DECREASED</u>.

Scenario 3 : Welding cables are 2milliohm and the weldment varies from 1milliohm to 1.1milliohm, output lowered

	Inductance	Capacitance	Supply Volts	Total Cct R	Rcct	Rweld	Pk Current	Tot Weld Heat Energy
Condition1	0.0000020	0.5000000	8.7900000	0.0030000	**0.002000**	**0.001**	1201.332	2.360
Condition2	0.0000020	0.5000000	8.7900000	0.0031000	**0.002000**	**0.0011**	1202.653	2.641

Peak Current Change	0.11%	Output Energy1	19.316025
% Heat Energy Change	10.65%	Output Energy2	19.316025





Reducing the output energy down from 28.3W/S to 19.3W/S, we get back to our original 2.36 J of weldment energy with a 1 milliohm weldment.

Note also, some of the other counter intuitive factors.

With 2 milliohm cables instead of 1 milliohm cables, a 0.1 milliohm change at the weldment represents an 8.96% change in weldment energy, instead of a 10.65% change !

Also, the peak current has reduced from 1330A to 1201 A which will help reduce the stress on the electrodes.

The process can be made more stable through understanding and monitoring the weldment ENERGY !
The process has a lower peak current through understanding and monitoring the weldment ENERGY !

Weld monitoring with single and double weld pulse applications

Explaining the effects of resistance and inductance

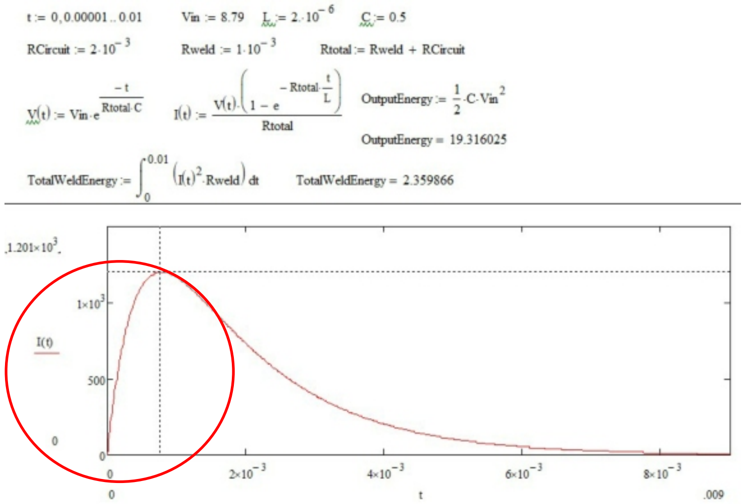
It will likely seem counter intuitive that by adding some resistance to the welding circuit, we can reduce currents while also increasing weld energy and process stability.

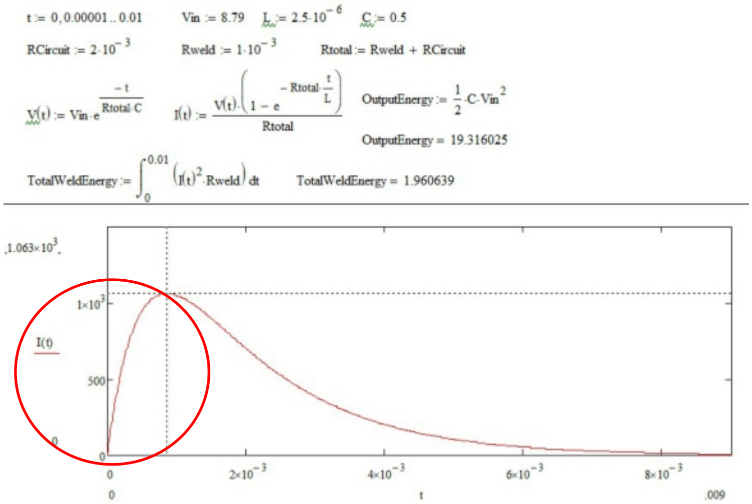
The explanation is quite simple - by monitoring the weld energy and comparing it to the output energy at the welder, we are looking at how energy is transferred from the CD welder to the weldment itself. Since we know energy is determine by the resistance, then we should expect some changes.

By increasing the cable resistance, the time constant of the circuit was modified, slowing down the current rise time and providing more energy release over a longer period into the weld.

Depending on weld cable lengths and layouts, we could also attempt to modify the circuit inductance. Keeping cables short and close together reduces inductance and resistance whereas increasing the lengths and keeping the cables far apart will increase both resistance and inductance.

The graphs below show how adding 0.5uH of inductance also slows the current rate down and modifies the peak current and total weld energy.

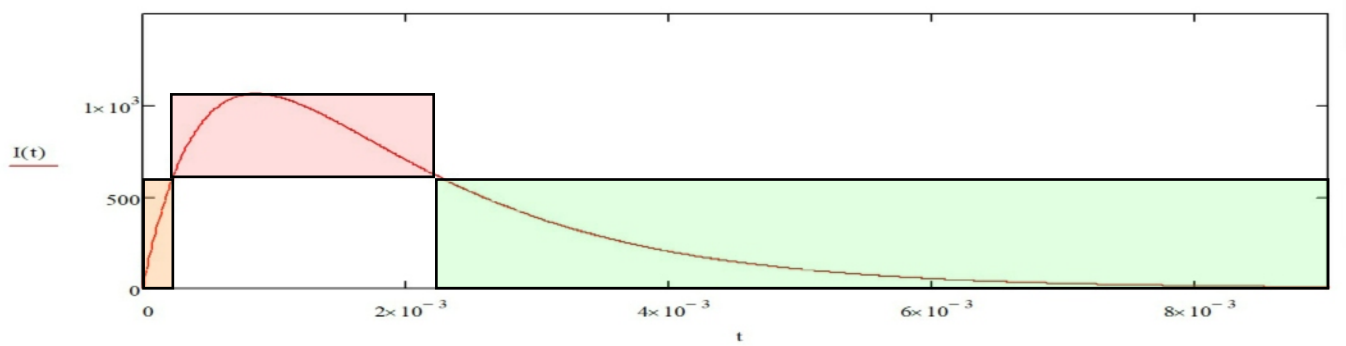




The welding process

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.



Weld monitoring with single and double weld pulse applications

Single or double pulse welding

In optimising conditions for a single pulse weld, there is a good chance this will suffice and will minimise the overall energy used.

As a secondary consideration, a double pulse welding scenario can be considered whereby the first pulse is used to pre-condition the parts to a more stable resistance. If too much energy is put in with a first pulse, then it is possible that some welding might take place, thereby reducing the material resistance interface.

This might have the undesired effect of significantly changing the ratio between the electrode contact resistance and the resistance between the parts being welded.

This then implies that with a high current second pulse, more heat would be developed at the electrode to component interface than would otherwise have been the case without the pre-conditioning pulse and hence electrode life may be degraded.

Again, careful consideration is required as to how much energy should be used in the first pulse. By monitoring the stability of the overall weld energy, it should be possible to quantify the benefits.

In some instances, operators may be tempted to over weld or double weld a joint - just to make sure !

This is similar to setting up a double pulse weld with both pulses at the same amplitude. In such a scenario and assuming a weld is made on the first pulse, it should now be clear that the second pulse will be significantly less effective in terms of adding anything to the weld.

Why ? Because the first weld has joined the parts and therefore significantly reduced the joint resistance.

Hence, much of the useable energy in the second pulse will be dissipated in the electrode rather than the product, thereby increasing the likelihood of premature electrode wear and micro arcing.

In double pulse welding, the general aim should be that the first pulse is simply introduced to warm up and burn off any unwanted contaminants, oxides and/or to settle out the material surfaces into a better defined state of resistance, prior to a much larger second pulse, that is used to make the weld.

- By monitoring the total weldment energy levels from weld to weld, it is possible to gauge and track the process stability.
- As electrodes wear, deform and/or pick up plating, the overall resistance will begin to change and this will ultimately be reflected in the energy delivered to the weld.
- In deriving and setting process limits around by how much the energy levels are permitted to deviate, the welding process stability can effectively be monitored and controlled.