SLOPE CONTROL IN WELDING AND FUSING

by
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Slope control is the method of cushioning power during a resistance welding or fusing operation, when working with a machine that is designed to operate using the A.C. welding or fusing process. A type of Slope Control is also used in D.C. fusing and resistance welding. There are two types of slope control – Up-Slope and Down-Slope. Basically, the slope control varies the energy of the welding or fusing machine, either up and/or down for a predetermined time period.

What Is Welding?
Resistance welding (spot welding) is the process of joining metals by locally heating them to their plastic state and then forging these plastic metals together. The metals being joined are heated internally by passing low voltage current through them. The natural resistance of a metal and the electrode contact, creates in conjunction with the current, what can best be described as electrical friction, which produces heat. In order to weld, this current must be directed through the metals by means of electrodes, whose electrical resistance is lower than the parts being welded. These electrodes must make contact under sufficient pressure to pass the current without arcing, but with not too much pressure, or there will not be enough contact resistance between the parts being welded and the electrodes, to create sufficient heat. The electrodes act both as the current carrying devices, as well as the forging tools. Therefore, the heat is developed in the work and not in the electrodes. The electrodes do get hot, but this is because heat is dissipated into them from the metals while being welded. Either AC or DC electrical power can be used. Functionally, AC and DC produce the same level of thermal energy from comparable inputs of electrical power.

What Is Fusing?
Fusing is a method of joining low resistance metals with a type of resistance welding machine, but without appreciable distortion of the parts being joined. Magnet wire is normally fused to terminals or commutators, without prior removal of the wire's film insulation. This insulation is removed during the fusing process. What actually happens is that the parts are heated and pushed together until all space between them is eliminated and the high points of one part are pushed into the low points of the other, and vice versa. A surface adhesion contact will then hold the parts together. The surface adhesion contact is not a weld. It is a thermo-compression joint which affects only about 0.0002 of an inch (.005 mm) of surface depth with no amalgamation of metals. As the strength of this joint is not too great, fusing must be used only with parts specifically designed to be fused.

In fusing we heat one or two of the electrodes, whose electrical resistance is higher than the metals being joined. We then dissipate this heat into those metals while clamping them under very high pressure. This pressure is normally quite a bit higher then when welding. As with welding, AC or DC current can be used.

Basic AC Principles
Good results can be obtained most of the time when fusing or welding, without slope control. However, under certain circumstances, slope control must be used to obtain a reliable joint. Other important reasons for using slope control will be outlined later in this paper. Normally, we control the output of the welding or fusing machine on the primary side of the transformer. The slope control also controls the primary side output of the transformer. By controlling the primary we will get proportional control of the secondary side of the transformer, or output of the machine.

When controlling the welding or fusing machine, we have four functions that control its output or heat.

1 – Output fusing or welding voltage
2 – The welding or fusing time period
3 – Phase shift control
4 – Output fusing or welding current

Output Voltage
Output voltage is normally controlled by taps on the primary of the welding or fusing transformer. Occasionally, taps on the secondary of the transformer, or actual control of the mains voltage is used.

Time
Time is an important control of the ultimate heat created at the electrodes or the joint. Exact accurate control is, therefore, very important. Two methods of timing are used with A.C. machines. They are synchronous and non-synchronous conduction of the welding or fusing current. As we are using the A.C. mains line to supply the welding machine, we might as well use the A.C. half cycle as our basic time period. Using 60 hertz mains power, a half cycle is 1/120 of a second or 0.0083 second. When using a 50 hertz mains power, a half cycle is 1/100 of a second or 0.010 second. Assuming that the mains line's frequency is accurate, we have an excellent time base with which to time the actual welding or fusing operation.

If we arbitrarily turn the current on during a half cycle, count that half cycle, and as many additional half cycles as we desire, we basically have a non-synchronous timer. For the purposes of this paper, we will not consider the non-synchronous timer.

However, if we turn the current on at a predetermined point during the first half cycle and at the same or another predetermined point during each successive half cycle, we basically have a synchronous control timer. Essentially, the synchronous timer senses the crossover point of one half cycle to another and conducts current for the predetermined portion of each half cycle. Normally, in welding or fusing, we use either one half cycle of time, or multi half cycles in multiples of one cycle.

Phase Shift
Phase shift is the most important way we control the ultimate heat generated by the fusing or welding machine. Basically, phase shift is a method of drawing a specific predetermined amount of energy from each half cycle. The phase shift principle uses a time base to achieve its results. By adjusting the phase shift, we can start each half cycle at any point from a practical 2 percent to 99 percent of the half cycle's time base. We do this by retarding the firing point of the contactors (normally thyristors) for a predetermined amount of time past the crossover point of the A.C. wave.

By setting the phase shift from 50 percent to 99 percent of the possible current output of each half cycle, we can keep our secondary voltage constant but control the current output because of the adjustable time base. If we set the phase shift below the 50 percent point, we actually lower the transformer's secondary output voltage.

The phase control is important in that we can keep the time and transformer secondary voltage constant, while controlling the heat generating output of the machine, in very small increments. Too high a voltage or too long a welding or fusing time, of course, can be detrimental.

Constant Current Controls

Constant Current Controls have been used for specific resistance welding applications since the early 1960's. However, they were not popular because they were extremely expensive.

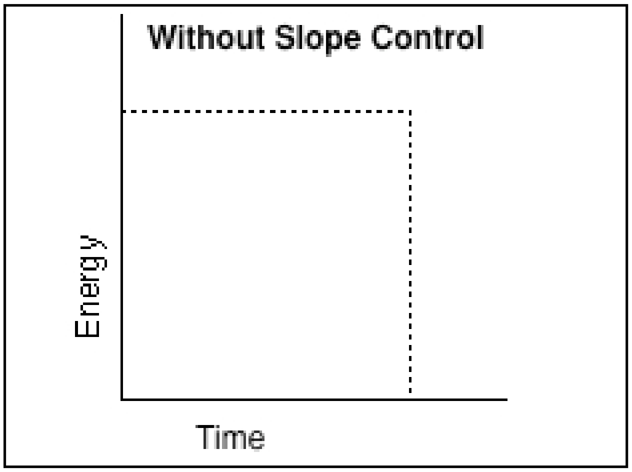
For the fusing process, where one component of a closed loop circuit is heated because it has a higher resistance than the others, a reasonably priced constant current control is a major advantage. In the late 1980's microprocessor components were developed to a point where they were quite inexpensive and powerful enough to function in a constant current welding and fusing control. Also, and more important, software technology evolved to a point where reasonable development would be required to author a constant current software control system.

The reason for using a constant current welding or fusing system is that it can correct the one electrical variable, which is a detectable and correctable component of welding and fusing, namely current change. The work being welded is the component that changes its temperature and thus resistance substantially during the welding process. The fusing electrode however, is the component in the closed loop secondary circuit that changes its temperature and resistance drastically during the fusing process. All of the other closed loop secondary circuit components (transformer's secondary circuit, electrode holders, etc.) are made of low resistance metal alloys, and maintain a relatively stable temperature and resistance. The fusing electrode becomes hotter than the other alloys in the closed loop circuit, because its resistance is higher. The same occurs to the work when being welded. Any metal's electrical resistance increases as its temperature is increased, and vice versa. Therefore, we start with a high resistance fusing electrode, or a high resistance workpiece being welded, and pass electrical current through a closed loop secondary circuit where they have the highest resistance. As electrical current continues to pass through the closed loop circuit, these materials (fusing electrode or work piece being welded) get hotter, and their resistance increases.

As the resistance increases, the amount of the current passing through the closed loop circuit decreases, assuming the voltage is constant. This is a function of Ohm's Law. As a component of a circuit has a resistance increase, the circuit has a corresponding current decrease, again assuming the input and the output voltage is constant. When fusing or welding, we use a relatively stable voltage source, the utility mains lines.

When using a "normal" welding or fusing control (without a constant current feature), actual fusing or welding takes more time than when using a constant current control. This is because a specific level of energy is required to pass through the closed loop circuit, in order for the work or the fusing electrode to reach the exact perfect temperature it must reach, so that a welded or fusing joint is properly made. As the level of current through the closed loop circuit drops, less energy passes through the circuit. More time is, therefore, needed for the specifically required amount of energy to be reached.

With a constant current control, a toroidal coil is placed around one of the leads of the secondary of the welding or fusing transformer. This coil transmits a representation of the amount of current actually passing



A representation of energy and time showing Resistance Welding or Fusing output when Slope Control is not used.

through the closed loop secondary circuit, to a microprocessor control circuit which varies (raises or lowers) the voltage passing through the closed loop circuit. Normally, when fusing or welding, the current will drop, and the constant current control will compensate for this by raising the voltage. This cycle of monitoring the current and raising or lowering the voltage occurs for each mains power line half cycle (0.5 hertz).

Integrated with this raising or lowering of the fusing voltage is the ability to control preset power with phase shift, and to start the welding or fusing cycle with Up-Slope, and end it, if need be, with Down-Slope.

Up-Slope

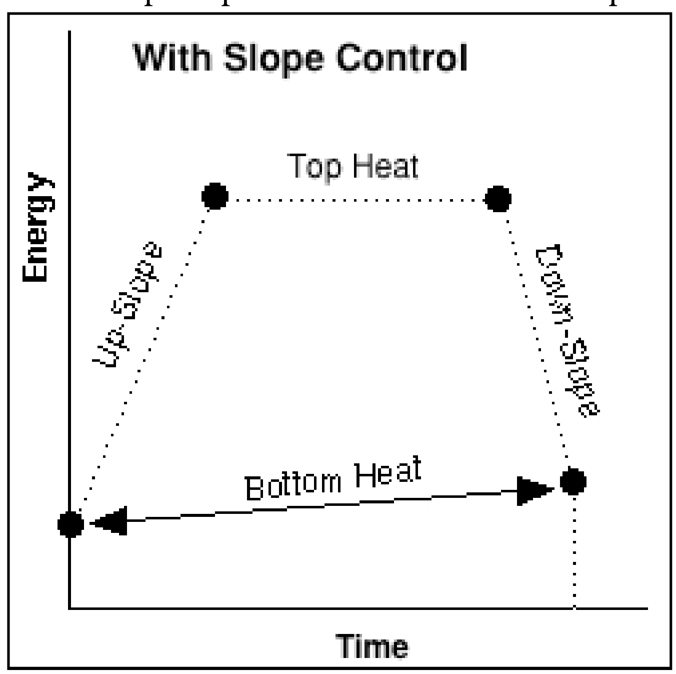
The following advantages can be achieved by using an Up-Slope control for welding.

- •• Greatly increased electrode life.
- • Less total power required.
- • Lower electrode pressures.
- •• Cleaner appearance due to less indentation of the work being welded.
- •• Reduced electrode tip temperature.
- •• Less electrode pickup.
- •• Less flashing during the welding or fusing operation.
- • Low starting heat burns off any impurities, thus less pre-cleaning of the parts being welded is required.
- • Critical welding schedules eliminated.
- • Different gauges and dissimilar metals more easily weld.

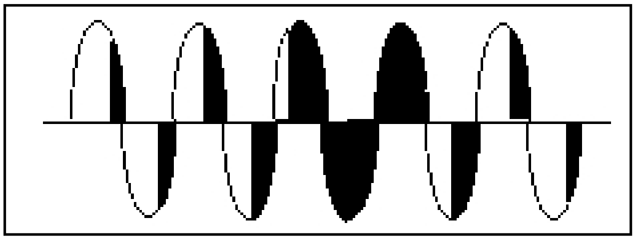
The above listed advantages which have double bullets to their left also apply to fusing. Other advantages that normally apply only to fusing are:

- •• Reduction of wire crushing when fusing fine wire to tang terminations.
- •• Controlled terminal annealing with tang terminal or wire fusing.

The electrical resistance of a metal increases upon being heated. The higher it is heated, the greater the increase in its resistance. If we control the current so that it is gradually built up to its maximum, we achieve a rise in the metal's resistance by controlled pre-heating. This gradual rise in current is preset in the Up-Slope control. The Up-Slope control increases the per-

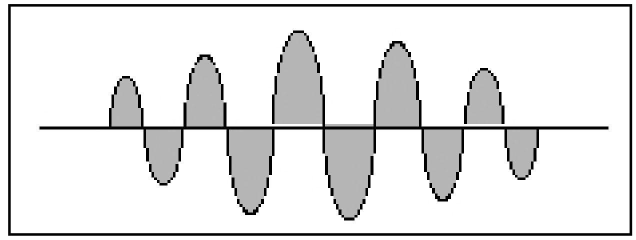


A representation of energy and time showing Resistance Welding or Fusing output when Slope Control is used.



Up-Slope — Full Heat — Down Slope

Up & Down Slope Oscillograph Representation of Voltage

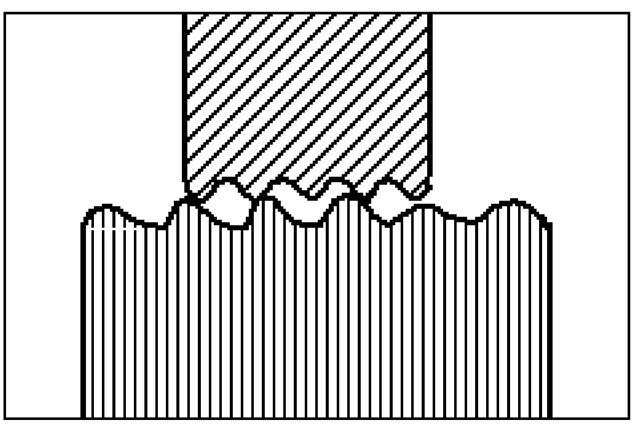


Up-Slope — Full Heat — Down Slope

Up & Down Slope Oscillograph Representation of Current

centage of phase shift automatically, from a preset bottom heat, until a preset top heat is reached.

We can start the Up-Slope current rise at the absolute practical bottom, 2%, or at any other desired bottom heat. This bottom heat is preset on the Up-Slope control's input panel. Also, on the input panel is a setting for Up-Slope time. This allows the presetting of the desired amount of time in whole cycles for the rise from the bottom heat to the top heat. The final setting on the panel is the top heat. The only restriction on the top heat setting is that it must be set above the bottom heat. Normal practice calls for the top heat to be set above the 50 percent phase shift setting. As explained above, this allows the use of a constant voltage while controlling the time

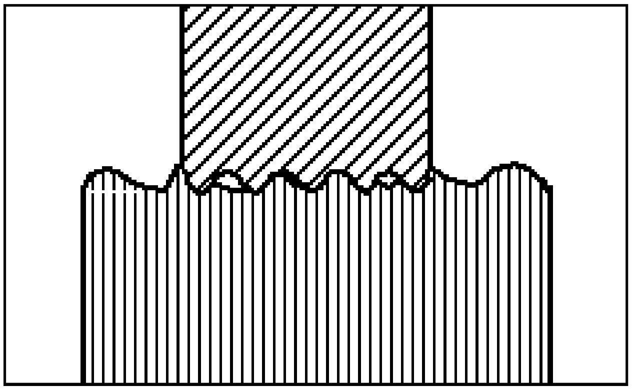


A Micro Representation of Electrode Contact Under Pressure, Prior to Welding or Fusing Heat Being Applied.

base, which, in turn controls the output energy.

The main reason for the Up-Slope, is that it allows equal seating of the electrodes before full current is passed through them. When the electrodes are placed on the metals being joined, they normally do not seat themselves across the entire electrode tip surface evenly, because of their irregular tip surface and the irregular surface of the work-piece, until the first few half cycles of welding or fusing current are conducted. If full current is applied, it passes through the small contact area of the electrode's tip, which touches the parts being fused or welded. High current is localized, which causes high electrode surface heat, as well as localized overheating of the work being joined. This excessive heating will shorten electrode life and possibly damage the parts being joined. This over-heating can be corrected by using an Up-Slope control, which slowly heats the work and allows the electrodes to evenly seat themselves. Fusing and welding electrode life is increased over two fold when using Up-Slope, because full current is only passed when the electrode is fully seated.

Before ending our discussion, a point should be brought up concerning commutator fusing and tang termination fusing. It is essential to use an Up-Slope control when fusing fine wire, smaller than number 30 AWG (.010 inches or .254 mm in



A Micro Representation of Electrode Contact Under Pressure, Prior to Welding or Fusing, But After UpSlope Heating Was Applied.

diameter). This is because the electrode will seat itself too sharply without an up-slope, and mechanically flatten the wire to a point of weakening it. The Up-Slope will allow the electrode to seat itself slowly. During the fusing operation, if the electrode can slowly seat itself, the commutator or terminal will engulf the wire rather than crush it. It is advantageous to use an Up-Slope when fusing larger wires, but the advantages lie in mainly longer electrode life.

Down-Slope Control

Down-Slope is just the opposite of Up-Slope. First comes a top heat, down to a bottom heat. There is also a Down-Slope time setting. All the principles of how Up-Slope works apply to Down-Slope, only in the reverse.

Down-Slope is not the same as quench and temper, which ends the passing of current for a predetermined period and then re-establishes it at a lower level. Quench and Temper is used to anneal metals just after welding.

After a metal is welded by utilizing the resistance welding method, it cools extremely fast. During this cooling time, great stresses are placed on the metal's structure around the weld. These stresses can cause the welded area to become brittle and can easily lead to the metal's cracking.

This brittleness can be eliminated by using a Down-Slope control. The Down-Slope allows the current to be gradually reduced from its maximum, thus allowing the metal to cool as slowly as desired. Normally, the Down-Slope does not completely anneal the welded area.

The Down-Slope control is not as efficient at relieving stresses as is a Quench and Temper Control. Its main advantage is that it is less expensive. Normally, when a Quench and Temper control is used, Up-Slope is also incorporated into the welding control timer. When a Down-Slope control is used, it is normally incorporated into a combined Up and Down-Slope control.

No valid functional use has been found for Down-Slope or Quench and Temper in fusing. At times, it has been used to reflow coating alloys, such as tin, after fusing. During fusing, coating alloys tend to clump away from the joint. The Down-Slope can possibly reflow them around the joint.

DC Control

The controlling of a DC welding or fusing system is similar to controlling an AC system. Phase shift, however, is not used, as phase shift is only available when using AC equipment. There are a number of methods used to control DC fusing and welding systems. Rather than describe these systems in detail, all we have to understand is that they functionally duplicate what is accomplished in an AC system. Energy is brought to the electrodes starting from a low predetermined level, to a predetermined top heat, in a predetermined amount of time.

It doesn't matter what form of electrical energy is used, AC or DC. When this electrical energy is used to heat either a fusing electrode or a welding work-piece, heat is heat. Functionally, the systems, at the electrode level or work-piece level, are exactly the same.

The Up and Down Slope effect can be created when using DC current, for fusing or welding, by controlling the contactors, which are normally power transistors. Functionally, Up and Down Slope works exactly the same with either AC or DC power.

Conclusion

The Up-Slope control has solved many so called unsolvable welding and fusing problems. The Down-Slope control has helped when welding high carbon ferrous metals. When using an Up and Down-Slope control, most claimed advantages are because of the Up-Slope, not the Down-Slope.

The slope control can solve some of the most persistent welding and fusing problems at a very low cost. It should be considered for production welding or fusing.

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