The Affects of Electrical Resistance on the GMAW Secondary Loop

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Although considered a mature welding technology, Gas Metal Arc Welding (GMAW), or MIG welding systems, still offer excellent opportunities for Electrical Efficiency (EE) optimization. Because the MIG welding process requires the use of high electrical currents to produce structurally sound weldments, even small improvements in the design and construction of the welding system secondary loop can significantly improve the EE and overall system performance.

Excessive electrical resistance is an often overlooked factor that affects the efficiency of MIG welding systems and quality of weldments produced. Recognizing the negative consequences of excessive electrical resistance, ELCo Enterprises, Inc. understood that the traditional metals used in copper torch tips and brass diffusers act as resistors, impeding the current flow through standard OEM MIG welding torches. The ELCo engineering team designed the patented Powerball® torch tip and diffuser system that incorporated a 100% copper current path through the entire front end of the welding torch. The copper current path of the Powerball® Torch System dramatically improved the performance of MIG welding torches by reducing electrical resistance, which resulted in quicker arc / weld starts, reduced burn backs, extended torch tip life, less weld spatter, lower torch handle temperatures and better overall weld quality.

The Powerball® Torch System was a significant step forward in MIG welding torch performance. However, the ELCo engineering team understood there were other components in the secondary loop that could benefit from electrically optimized copper connections through the secondary loop current path and invested significant time into the development and testing of components that would minimize electrical resistance.

## Defining Secondary Loop Electrical Efficiency:

The efficiency of an electrical system is defined as the ratio of useful power output used to melt metals, divided by the total electrical power consumed (EE=P out/P in). When considering a production MIG welding system, EE can also be expressed as the ratio of power in the welding arc (~I*Varc) divided by the power produced at the power supply (~I*V2nd). Current (I), determined by voltage applied to the secondary loop and total serial resistance of the components, has the same value through the entire secondary loop of the weld transformer. Voltage drop in each component of the secondary loop (Vi), depends on the resistance of each component (I).

The secondary loop of a MIG welding system includes all the components of the electrical circuit: power supply, ground cable, ground cable clamp, welding arc, welding wire, torch components, wire feeder and the power cable from the power supply to the wire feeder (Fig. 1). The design, materials used and quality of each component affects the EE and produces a compounding effect on the overall EE of the welding system. Welding power cable connections are commonly made with a crimping process.

### Crimped Cable Lug Connections:

Crimping is a widely accepted method for both OEM welding power cable lug attachment and for in-field cable repairs. The crimping process is accomplished by mechanically compressing a copper sleeved lug connector around the power cable's bare copper strand bundles. Crimping can be performed with a hammer and screwdriver, a cable-crimping anvil or with a power-crimping machine (Fig. 2).

Poorly crimped lug joints do not attach the lug to the cable securely. Poorly compressed lug sleeves result in inefficient power transmis-
sion, elevated electrical resistance, voltage drops, excessive joint heat and reduced joint durability. Crimped cable connections with insufficient sleeve compression are also subject to cable / sleeve oxidation and corrosion. Contamination and the resulting oxidation inside the cable lug sleeve increases electrical resistance at the joint and promotes corrosion of the cable strands resulting in a reduced service life of the cable. The EE of a poor quality lug joint degrades quickly when the cable is subjected to the rapid movements and extreme thermo-cycling of robotic weld cells.

When tested, it became clear that crimped cable lug joints, regardless of the method used to make the joint, did not provide consistently secure, electriically efficient or durable cable connections. Alternative methods to crimped cable termination can offer significantly lower resistance, durable cable lug connections and dramatically improved EE.

**Crimped Lug Joint Testing:**

Testing and analysis of hammer and anvil crimped lug joints revealed a resistance range of 17 to 50+ μΩ. This is an acceptable range of resistance for newly crimped power cable joints. However, ELCo’s testing showed that crimped joints were subject to both mechanical and electrical deterioration in a short period of time. Crimped lugs start to degrade from their original resistance values quickly and progressively deteriorate throughout the cable’s service life (Fig 4).

**Crimped joint Degradation:**

To understand the causes of crimped lug joint degradation, it is important to consider the material properties of the welding cable and lug. Welding cables and lugs are typically made of soft copper. Copper is widely accepted as the best commercial material for efficient electrical power transmission of MIG welding cables. High-capacity welding cables are typically made with thousands of small diameter wire strands ranging from 160 - 240 μm. When under compression, a crimped copper lug collar is compressed around bare copper strands producing a stable mechanical cable connection.

However, when the crimping compression force is released, the copper sleeve incrementally relaxes, resulting in a less secure joint. This phenomenon is referred to as “compression creep”. Compression creep begins immediately after the crimping force is removed and continues incrementally over the life of the joint. Welding cables experience extreme temperature cycles during the welding process. These extreme temperature changes cause the copper wire strands and lug collar to anneal and become more ductile. An annealed power cable lug joint has reduced compression-retaining properties, which will further increase the electrical resistance of the joint over time.

In addition to thermal loading, lug joints are also subject to environmental degradation from moisture, solvents, petroleum lubricants, vapors, rapid torch motion and general wear and tear. All of these factors contribute to increased cable joint resistance, instability and electrical inefficiency.

**The Mechanical Properties of a Crimped Joint:**

To the naked eye, the cross section view of a welding power cable...
reveals what appears to be a densely packed bundle of copper wire stands forming a highly effective current path.

However, when inspected at a microscopic level, the intricacies of the wire strands and the crimped lug joint reveal a much more complicated story. A microscopic view of a copper wire strand reveals an irregularly shaped oval with high and low points along the length of the wire strand. Crimped lug joints compress the wire strands together, but the cable strand compression is inconsistent within the joint. Even under high compression, the irregularities of the wire strands do not make perfect contact with the surrounding wire strands. The irregular contact areas constrict current flow, which increases resistance and excessive heat in the cable or lug joint (Fig. 5). Irregular crimping pressure also allows air spaces between the strands and traps wire contamination inside the joint. (Fig. 6)

The air spaces between the wire strands represent areas where the wire stands are not contacting the other stands consistently, creating isolated electrical current paths, which inhibit the current flow and increase resistance. Air spaces and wire strand contamination are the ingredients for joint oxidation and increased resistance over the life of the welding cable.

**Improving Power Cable Lug Joints.**

In the search to reduce electrical resistance and optimize the secondary loop, the ELCo engineering team identified a unique process for joining cable lug joints. Ultrasonic metal welding is a process that effectively addressed all the problems associated with crimped cable lug joints. Ultrasonic metal welding is an industrial process that utilizes high frequency vibrations that are locally applied to separate parts under pressure with the purpose of creating a single solid-state joint. When a power cable lug joint is ultrasonically welded, the individual wire strands of the power cable are consolidated into a quasi solid bundle and bonded to a billet copper lug (Fig. 7). An ultrasonically welded cable lug joint consolidates the wire strands into a quasi-solid block. That welding process breaks up and disperses any wire strand contamination and minimizes air spaces within the fused joint. Ultrasonically welded lug joints create a more unified electrical current path allowing the current to flow with much lower resistance than crimped lug joints. Ultrasonically welded cable lug joints are consistent, strong and durable. USW cable joints consistently withstand more than 1500 lbs. on a tensile strength shear tester. The footprint of a USW lug joint is smaller and more compact than traditionally crimped cable joints (Fig. 8). Smaller lug joints can be a significant advantage when routing cables through limited spaces.

**Ultrasonically Welded Cable Lug Resistance:**

A number of 2/0, 3/0 and 4/0 high power welding cables have been successfully ultrasonically welded and tested under typical and extreme welding parameters. The test results confirm that ultrasonically welded cable-lug joints dramatically reduce cable lug joint electrical resistance value, while maintaining a narrow range of variation over a long service life (Fig. 9). The electrical resistance of ultrasonically welded lug joints consistently tested in the 7-10 μΩ range. This indicates a significant reduction in the resistance of the USW lug joint and indicates significant improvement in the overall electrical characteristics. It is well documented in the industry that USW joints retain the initial mechanical and electrical parameters throughout the entire life of the joint with little performance degradation.
Process Capability Over Time:
Several welding cables with USW lug joints were installed on a controlled weld cell and tested under high current loads. Approximately one hundred, 100% duty cycle (10 min each) welds were produced in the current range of 250-450 A. The weld characteristics, welding gun temperatures and cable lug joint resistance were monitored and recorded in real time. The tests were conducted with a 75/25 and 90/10 Ar/CO2 shielding gas mixture, using 0.045" steel wire. The tests revealed the USW cable lug joint Process Capability (Cpk) had improved significantly when compared to previous studies using crimped cable lug joints under similar weld parameters (Fig. 10).

In one study, the Cpk improved from an already acceptable value of 1.42 with a freshly crimped lug joints, to an even better value of 1.98. The welding gun cable joints, which also utilized the USW process, resulted in a torch handle temperature reduction of 30°F (16.68°C) when compared to gun handles utilizing crimped cable joints. Analysis shows the resistance values of USW lug joints maintain their original resistance values during the entire testing process with no increase in overall resistance. On the power supply side, the USW joint exhibited no indication of excessive heating while retaining the original appearance and resistance values.

Conclusion:
When systematically tested and analyzed, it is clear that traditionally crimped welding power cable lug joint quality is inconsistent and can be a major contributing factor to excessive electrical resistance within a GMAW secondary loop. The durability of crimped lug connections are subject to significant performance degradation over the life of the cable. Conversely, ultrasonically welded cable lug joints offer dramatic electrical performance advantages, excellent joint durability and consistent process capability. Wire Wizard® Welding Products offers a complete line of MIG welding system products that address both the mechanical and electrical inefficiencies of modern weld cells. The Powerball® Torch Products line of ultrasonically welded cables, ground clamps and welding torches (Fig. 11) offer the components necessary for optimized EE in the secondary loop resulting in reduced torch operating temperatures for better operator comfort, extended cable lug life, stable process control and ultimately better weldments.

For more information on Powerball® Torch Products or any other Wire Wizard® Welding Products, please contact our customer service representatives.

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