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Assessing the Benefits of Surface Tension Transfer® Welding to Industry

By Mr. Bruce D. DeRuntz

The Lincoln Electric Company is the first and only welding company to hold a patent on a revolutionary new welding process called Surface Tension Transfer® (STT®). Originally patented in 1988, it wasn't until 1994 that the first commercial unit was produced and sold. Today this welding process is being used by every major pipe contractor in the world, yet it is still relatively unknown in many manufacturing sectors. To test if welding educators recognized this welding process, educators at a National Association of Industrial Technology (NAIT) conference were asked if they had ever heard of STT. A unanimous response indicated that they had never heard of this new process (DeRuntz, 2001). The audience expressed a strong interest in learning more about this new technology and encouraged the presenter/author to publish a paper that would contribute to the body of knowledge for Industrial Technologists. Therefore, the purpose of this paper is to enlighten Industrial Technology professionals on one of the newest high-tech welding processes, STT, and suggest the future implications for manufacturing adopting this technology. This paper explains how the process works, examines its advantages and disadvantages, and provides case studies of its successful implementation in the world of manufacturing. While this paper is not intended to endorse any manufacturer or its products, the technology explained within is patent protected by The Lincoln Electric Company.

Process Description

STT is a new approach to what has been known as the Short Arc transfer mode or Short Arc welding. To best explain this process, it is first necessary to review the characteristics that are sought after in the Short Arc processes. The popular solid wire, Short Arc welding process is primarily selected for applications in manufacturing that require medium to low heat input. The process will work in all positions and only requires average operator skill. In this process, the operator sets the wire feed speed and average voltage, based upon the heat required for the particular application. This takes into account, but is not limited to, factors such as material size and type, joint configuration, electrode size and type, travel speed, and arc shielding gas. The Short Arc process is characterized by its undesirable explosion of molten metal known as spatter. Spatter occurs when the electrode makes contact with the base metal (shorting out the circuit), then a high current, known as Pinch Current is applied to "blow" or separate this short. The molten drop contacting both the electrode and work acts like a fuse and "blows", depositing some of itself into the weld path and surrounding fixtures, while casting other parts into the air. This process repeats itself about a hundred times per second as the machine tries to maintain the set voltage. To gain control of this volatile welding process and produce higher quality welds, the power source needs to be better controlled.

The TIG welding process precisely controls the current through a highly skilled operator that uses a foot pedal or hand control to continuously adjust the amount of current that he deems necessary during every second of the welding process. The characterization of this process is a much slower deposition rate of filler metal, but results in higher quality welds without spatter. The STT process uses sophisticated electronic technology to combine the best characteristics of the Short Arc and TIG processes. The STT process could be called an intelligent TIG welding process for Short Arc welding.

The welding scientists who invented this process have custom designed the weld current (waveform) to be modified hundreds of times per second to transfer each droplet of molten metal when the electrode is shorted, such that there is no volatile explosions, and thus eliminating spatter. According to Dodson (1999) the key to STT technology is its ability to control the current independent of wire feed speed. This means that more or less current can be applied without adding more wire. The Surface Tension Transfer® process was named after the way this technology monitors and controls the surface tension of the weld droplet as it adheres to the weld puddle. It does this through a high-speed inverter that precisely adjusts the output current waveform during the entire shorting cycle. This unique high frequency inverter technology is known as Waveform Control Technology™

The Waveform Control technology has the capability of programming the power supply for unique waveforms to optimize the arc characteristics for a specific application. Factors such as the type of joint, material and thickness, rate of travel, electrode size and type, as well as the specific arc shielding gas are all considered. Once the program(s) are entered into the power supply, the optimal arc for that application is obtained, making this technology very versatile for a variety of applications and base materials.

According to Stava (2000), the STT process operates neither in the constant current nor constant voltage mode, rather it is a high-frequency (wide-bandwidth), current-controlled machine wherein the power to the arc is based on the instantaneous arc requirements, not on an "average DC voltage." In principle, it is a power source that is capable of delivering and changing the electrode current in the order of microseconds. Furthermore, it is designed for semiautomatic applications, where rate of travel, speed, and electrode extension lengths will vary. The applications are identical to those associated with the standard short-circuiting processes. Various shielding gases, including 100% carbon dioxide and blends of carbon dioxide and argon for mild steel, as well as gas blends with helium for stainless steel, may be used with this new power source. To illustrate how this waveform technology works, figures 1 and 2 contrast the welding processes of STT and Short Arc.

The following six steps (see figure 1) illustrate the distinct steps that occur in the STT process (Stava, 2001):

1. Background current (T0 - T1): This is the current level of the arc prior to shorting to the weld pool. It is a steady-state current level, between 50 and 100 amperes. The electrode approaches the work piece.
2. Ball time (T1 - T2): Just before the electrode is about to complete the short (at the background current), the voltage sensing clip reads a decrease in voltage and the machine drops the amperage. (In conventional short circuit welding, the short circuit would occur and amperage would rise dramatically). The background current is further reduced to 10 amperes for approximately 0.75 milliseconds. This time interval is referred to as the ball time.
3. Pinch mode (T2 - T3): Wire is still being fed; therefore fusion is occurring between the electrode with the work piece. In order to transfer the molten drop, amperage must be increased. A high current is applied to the shorted electrode in a controlled manner. This accelerates the transfer of molten metal from the electrode to the weld pool by applying electronic pinch forces. (Note that the electrode-to-work voltage is not zero during this period. This is due to the high resistivity of iron at its melting point of 1550° C / 2822° F.) At T-3 the wire begins to "neck" down or melt from the outside in.
4. The dv/dt calculation (T2 - T3): This calculation indicates the moment before the wire completely detaches. It is the first derivative calculation of the rate of change of the shorted electrode voltage vs. time. When this calculation indicates that a specific dv/dt value has been attained, indicating that fuse separation is about to occur, the current is reduced again to 50 amperes in a few microseconds. This is to prevent a violent separation and explosion that would create spatter. (Note: this event occurs before the shorted electrode separates). T4 indicates the separation has occurred, but at a low current.
5. Plasma boost (T5 - T6): Amperage is again increased and a controlled uniform separation takes place and creates the weld bead with little spatter. It is at this period of high arc current that the electrode is quickly "melted back." (The geometry of the melted electrode at this point is very irregular).
6. Plasma (T6 - T7): This is the period of the cycle where the arc current is reduced from plasma boost to the background current level. In this "tail-out" period, the current goes from this higher level down to its initial background level. The cycle then repeats itself, with the time required for one waveform taking between 25-35 milliseconds.

Figure 1 depicts the process during one STT waveform. The figure illustrates amperage over time, with the time being in milliseconds.

Comparison of Traditional GMAW to STT GMAW

A comparison with conventional GMAW further improves the understanding of the STT process. In the conventional GMAW short-circuiting process, a high level of spatter and smoke results from electrode separation occurring at a high pinch current compared to STT (see figure 2). In this mode, the magnitude of the current is relatively high at the moment the droplet separates from the wire, causing the fuse to explode and generating a high level of spatter (Dodson, 1999).

Figure 2 illustrates the six distinct steps that occur in a conventional GMAW process (Stava, 2001):

1. The electrode approaches the work piece with the amps and volts maintaining steady levels.
2. As the electrode shorts, the voltage drops dramatically and the amperes begin to rise. The next two steps differentiate conventional GMAW from STT because of STT's precise control of the waveform.
3. The electrode has come in contact (shorted) with the work piece and is depositing the filler metal. At this point, the voltage is approximately zero, and the amperes have increased immensely.
4. The increase in amperes causes the filler metal to separate from the rest of the electrode in a violent and unpredictable manner, producing greater spatter and smoke than STT.
5. After the separation between the weld deposit and the welding wire, the voltage and amperes decrease back to their preset levels.
6. Repeats the process as in step one.

The comparison of these two processes is especially dramatic in pipe welding. The constant voltage GMAW process normally used for pipe welding does not control the current directly; instead it controls the average voltage. This can cause the weld puddle temperature or fluidity to be too high, and the internal bead may shrink back into the root, a reaction known as "suck back." Also, when using conventional Short Arc GMAW, the operator must concentrate the arc on the lip or leading edge of the puddle to ensure proper penetration and fusion. If the arc is too far back on the puddle, penetration will be incomplete.

The STT process also makes it possible to complete open root welds three or four times faster than GTAW, with low heat input and no lack of fusion (Stava, 2001). With STT technology, the heat affected zone is minimized. Moreover, while most conventional welding processes can have heat inputs as high as 25,000 to 30,000 joules per inch, the STT's heat input is typically 7,000 joules per inch, which ultimately leads to reduced distortion. For pipe welding, the process also makes it easier to perform open gap root pass welding, with better back beads and edge fusion. It is easier to operate than other processes, yet produces consistent, X-ray quality welds.

Figure 1. Surface Tension Transfer Process.

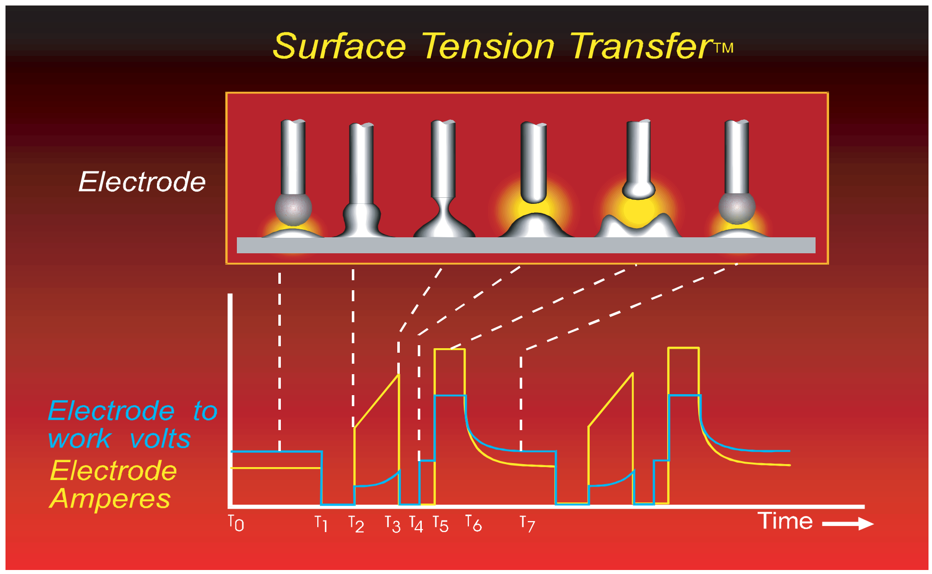
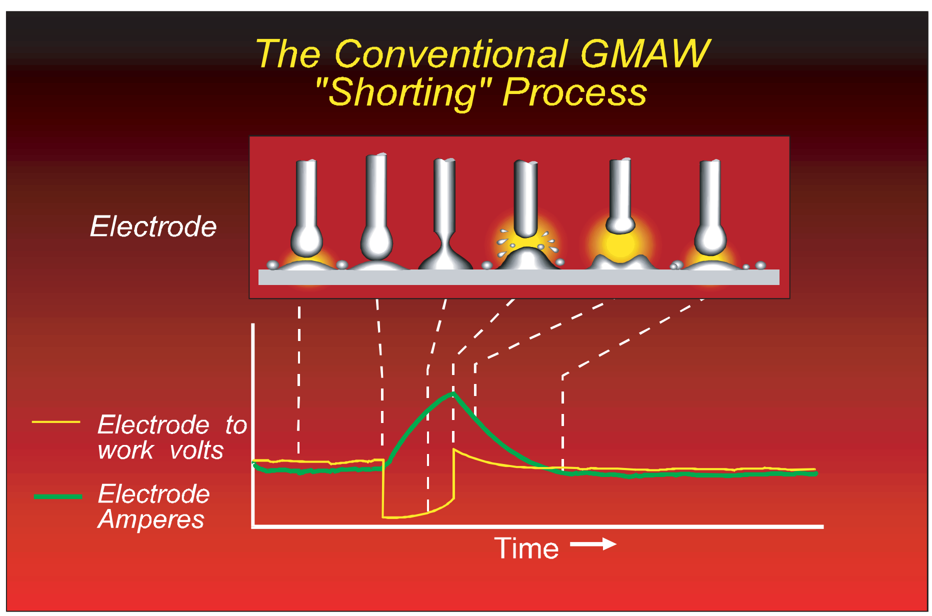


Figure 2. Conventional Short Circuiting Process.



Figures 1&2 a provided courtesy of The Lincoln Electric Co., Cleveland, OH, USA

Table 1 provides a complete comparison of the GWAW welding process to STT.

Advantages, Benefits and Limitations

The description of the processes and the technical comparison of STT to conventional Short Arc waveforms provide an important understanding of the similarities and differences between the two methods. To understand the workplace attributes, STT's advantages, benefits, and limitations will be categorized into weld quality, operation costs, and operation conditions.

Improved weld quality can be achieved in all position welding through better fusion in poor fit up areas, lower heat input and less oxidization. Better fusion is possible through the precise control of amperage throughout the entire weld cycle. The precise control of the current eliminates the volatile explosion of molten metal when the arc shorts, therefore depositing more of the consumable electrode and concentrating the arc on the base metal. The ability to concentrate the arc also aids in the elimination of cold lapping on open root joints for pipe and pressure vessels. The lower heat input provides the advantage of less material distortion and burn-through by providing only the required amount of heat to produce the weld, even in sensitive material like stainless steel. This precise control of heat means that even thin gauge galvanized sheet metal can be welded without burning off the galvanized plating on the back side of the metal.

A reduction in operation costs are realized through the use of less expensive larger diameter electrodes, less expensive CO2 shielding gas, and reduced spatter. The use of a larger diameter wire will reduce the actual weld time, and improve efficiency. A significant savings can also be realized because the STT process operates with the less expensive CO2 gas when using steel alloys. Reduced spatter translates into significant cost savings due to less "cleanup" required of fixturing and the weld surface area prior to final surface preparation, but also because more of the electrode stays in the weld joint, resulting in reduced electrode consumption. Finally, welding time is added before cleaning accumulated spatter from the gun nozzle.

Operating conditions are also improved for welders who will be more comfortable by the decrease in spatter, decrease in smoke levels, and reduction in arc radiation over Short Arc transfer. Creating a safer environment will increase the operator's comfort, concentration and confidence to produce a weld with minimal variation. Because of its superior arc characteristics, welding with STT requires less operator skill in handling the torch, thus minimizing training.

While STT offers many benefits, it is also very important to understand its disadvantages and limitations compared to conventional short circuiting process. One of the first disadvantages a manufacturer would notice is that the STT power source is initially more expensive than a constant voltage power source. This may be explained by the use of a patent protected technology and the cost savings that are realized though its benefits. The deposition rates are lower than globular, spray arc and pulse spray, but are equal to that of short circuit welding. As in pulsed spray welding, setting the welding parameters for STT are quite different than settings normally used and may require additional training. Finally, the STT process differs from the conventional short circuiting process through its inability to perform aluminum welding at this time.

Case Studies

The release of a new technology always promises remarkable advantages and benefits over an existing one. These promises carry no merit until the technology is implemented and its benefits validated by commercial end-users. The following case studies verify the benefits being realized by manufacturers, and the implications this new technology will have on the welding industry. These case studies are a cross sectional representation of the welding industry, with feature companies specializing in stainless steel, structural steel, bridge steel, and light gauge steel applications.

Advanced Bus Industries, L.L.C. (ABI) manufactures advanced design custom vehicles. These bus-type vehicles are outfitted with leather interior, televisions, VCRs and even Global Positioning Systems. The company was challenged with increasing its productivity and adopting a new commercial model. In changing over its Columbus, Ohio shop to accommodate the new model, ABI revamped its entire manufacturing process and turned to a new material for vehicle production – stainless steel. But when it comes to production, stainless steel presents a welding challenge, as it is a poor conductor of heat and therefore retains heat in the weld zone leading to warpage and distortion. To combat this stainless steel welding problem, ABI turned to STT. With STT, cleanup time at ABI has been dramatically reduced by more than 75 percent (Dodson, 2000). Additionally, since operators have more control over the arc and the entire welding process, travel speeds are up. Both of these factors contributed to increased vehicle production. "Spatter is almost non-existent with the STT, especially in critical areas where several joints meet." states Ron Estes, the Weld Shop Supervisor for ABI. "STT also provides more control of the weld puddle by offering additional settings for peak, background, tail-out and hot start, so there are many options to tailor the weld machine". The benefits of the STT process include reduced spatter, smoke and distortion – all critical elements for high-quality vehicle production. The reduced clean-up time offered by the STT represents a substantial cost savings in labor to ABI.

J.N. Rowen Limited, one of the United Kingdom's leading independent structural steel working companies, has recently branched into the design and fabrication of tubular structures requiring high integrity welds. According to Lincoln (2000), after securing the prestigious steel work contract for the new Wimbledon No. 1 Court, J.N. Rowen employed the unique inverter based STT process. The STT process

Table 1 Comparison of GMAW to STT.

	Gas Metal Arc Welding	**Surface Tension Transfer**
Metal Transfer Process needs	Short Circuiting Transfer	Modified Short Arc with the Amperage and Voltage changed based upon the of the Arc
Voltages	16V To 22V	16V To 22V
Amperages	Low Amperages: (30A to 200A)	Two Amperage Levels: • Peak Current (0A to 450A) • Background Current (0A to 125A)
Wire Electrode Size	Typically Smaller Diameters (0.025 in to 0.045 in) (0.60 mm to 1.10 mm)	Typically Larger Diameters (0.035 and 0.045)
Shielding Gases:	• 100% CO2 (Lowest Cost) • 75% Ar/25% CO2 Gas Mix	• 100% CO2 (Lowest Cost) • Custom blended to meet the optimum arc physics
Advantages	• All Position Welding • Low Cost	• Low Heat Input • Controlled Heat Input • All Position Welding • Handles Poor Fit Up • Minimal Spatter • Can Use a Larger Wire Size • Minimal Smoke • Low Cost Gas • Good Fusion
Limitations	• Spatter • Potential Lack of Fusion • Limited to Thin Material	• More Expensive Equipment • Limited to a Modified Short-Circuit Mode
Costs	$3,000	$6,000
Training/Skill	Similar	Similar
Materials	• Carbon and Low Alloy Steels • Galvanized/Zinc Coated • Stainless and Nickel Alloys • Silicon Bronze and Copper Alloys	• Carbon and Low Alloy Steels • Galvanized/Zinc Coated (plating unaffected on backside) • Stainless and Nickel Alloys (with greatly reduced spatter) • Silicon Bronze and Copper Alloys
Industries	• Automotive • Food and chemical processing • Consumer products	• Automotive • Pipe and Pressure Vessel • Power Generation • Food and chemical processing • Thin gauge consumer products

was seen as the next step in their continuing development of welding technology; offering enhanced product quality, greater productivity and increased profitability. The following benefits were identified throughout this construction project:

- Ease of Use - Optimum arc characteristics were maintained even with variations in electrode extension. This released the welder from the need to maintain exact lengths and welding gun angles in order to produce a smooth, low spatter, high integrity weld. Full welder training and welder qualifications were completed within one day.
- Controlled Arc Energy - The plasma boost caused the arc to broaden; melting a wide surface area, eliminating cold lapping and promoting good fusion, even on heavier gauge materials.
- Reduction in consumable costs - 100% CO2 Shielding Gas produced a gas savings in excess of 25%.
- Increase in productivity - Operator friendly process reduced down time and operator fatigue. High travel speeds for root passes and all position welding substantially reduced overall weld times. Also, the reduction in spatter translated into savings by minimizing or eliminating the labor time to remove spatter, plus savings in time from the ability to produce high integrity welds in any position. This eliminated the need to rotate and position the structures for welding. With over one thousand butts to weld, substantial savings on production times were achieved.

XKT Engineering Inc is located on Mare Island in Vallejo, California. The company's location on the bay and access to barge transportation, make it the perfect firm to handle bridge reinforcement and new construction projects. These projects require the use of pipe pilings that run anywhere from 60 to 160 feet in length. To handle this AWS code-quality work quickly and efficiently, XKT has turned to the STT process. According to Goetz (2000), this process is able to put in the pipe's root weld pass three to four times faster than the former process of stick welding, in addition to being easier to perform for XKT's 23 certified welders. "Prior to the STT, we were using a stick process with back-up bars," says Corkey Bates, Welding Engineer/Production Manager for XKT Engineering, Inc. "When welding a 24" diameter pipe, we would use approximately 10 to 12 consumable rods, which means a lot of starting and stopping. With the STT, we weld ¼ of the pipe at a time, so we only start and stop four times while laying the root pass. This means increased speed in welding for the root pass. And, because the STT root pass cross-section (or nugget) is larger than in the past, the hot (or second) pass goes much faster as well. Also, with fewer starts and stops, we have decreased the potential for welding imperfections like porosity and cratering." "Our welds must pass either radiographic or ultrasonic inspection to AWS D1.1 standards for cyclically loaded tension stress welds. With the STT, we were easily achieving these quality welds on our root pass," notes Bates. "We also noticed that the STT generated less spatter and fume than our previous stick process, which meant less clean-up and the ability to go right to submerged arc for the fill and cap passes."

Honda employs about 850 associates at its Marysville Ohio Motorcycle Plant. The plant produces about 150,000 units a year, of which over 90,000 are equipped with fuel tanks using the STT weld equipment. The tanks are fabricated from highly formed sections of 22GA sheet steel and are then welded together with a 100% penetration butt weld. Because of the thickness of the parts and the varying contour of the seam, welding is often a challenge. After changing to STT, almost all of the defects Honda had previously encountered with the conventional MIG process had been eliminated and rejects were reduced by more than 90% (Wall, 2000).

Summary and Implications

Industrial Technology educators make a significant contribution to the success of manufacturers everyday when they teach students about the latest technology in industry. The field of welding should be no exception and IT educators should integrate "adaptive waveforms" such as STT welding technology into their courses and laboratory experiences. STT offers many advantages primarily over the Short Arc means of metal transfer. The greatest advantages are the improved weld qualities, reduced operation costs and improved operating conditions. The backbone of STT is its revolutionary waveform technology which controls current precisely and independently of wire feed speed during the entire welding cycle. This precise digital control of the weld current represents the next generation in welding technology and a whole new future in industrial applications.

The implications for this emerging technology are far reaching as the automotive, petroleum, and structural steel industries have just begun implementation. The advent of STT has caused manufacturers to grapple with a paradigm shift in their traditional application of short-arc welding. These companies are now realizing significant cost savings by replacing their traditional MIG, stick welding, and fastener processes with STT. It is this author's estimation that up to 75% of the current short-arc sheet metal and pipe welding applications could be justifiably replaced by STT due to its tangible benefits of improved quality, lower costs, and improved operating conditions. Within the next 10 years, it is possible that STT will become the predominant steel alloy welding process used in U.S. manufacturing; therefore it is critical that we begin preparing our future technologists and engineers to exploit and optimize this latest high-tech process.

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