Increasing Resistance Seam Welding Throughput with Adaptive Controls

To produce a gas-tight seam weld, the WeldComputer® adaptive control is used on a Tranter, Inc., heat exchanger. (Photo courtesy of T. J. Snow.)

Benefits include regulating weld consistency, operating at fast production speeds, and improving weld quality

BY ROBERT K. COHEN

Making a gas-tight seal with a seam welding machine involves making a series of overlapping spots. Each spot produced should be a fully formed nugget that is free of expulsion. Using too little heat produces an undersized spot, which can cause a leak. Using too much heat produces expulsion, which can also cause a leak. In addition to controlling the formation of each nugget, sufficient control of the spot spacing must be maintained to ensure each nugget overlaps with the next.

Each precision spot welding application generally requires selecting the correct material electrodes along with the right electrode face diameter, electrode force, current and amount of time. A capable machine with proper tooling is required to maintain control of the electrode contact area on the part and apply electrode force that is repeatable from weld to weld. A capable control is required to provide accurate delivery of the programmed current for each weld. Variation in any of these parameters will vary the spot welding results.

A spot welding machine may be used to make a gas-tight seal by making a weld, lifting the electrodes off the part, moving the part a specified distance, bringing the electrodes back onto the part to make another weld, and repeating that process until the desired length seam is produced. Spot spacing must be accurately controlled to ensure each spot produced sufficiently overlaps with the next.

When producing overlapping spots, the second weld produced is smaller than the first. This is because a portion of the current used to produce the second weld conducts through the electrical path that was created by the first weld. The third weld produced is smaller than the second. This is, because, in addition to a portion of the current used to produce the third weld conducting through the electrical path that was created by the second weld, some amount of current conducts through the first weld as well. This phenomenon is known as shunting.

Welding operations that program the same current for all welds in the seam encounter a high incidence of expulsions on first and second welds produced. If the current is lowered enough to prevent expulsions from occurring in the first few welds, then all subsequent welds in the seam end up being smaller than desired. This condition is remedied by programming appropriately lower currents for the first and second welds.

Seam Welding Details

A seam welding machine can make a gas-tight seal much more efficiently than can be achieved with a spot welding machine. The seam electrode wheels can simply roll to the next location to make the next weld instead of having to lift the electrodes off the part, advance the part a specified distance, and bring the electrodes back onto the part. Also, a seam welding machine integrated with a capable control is able to accurately control the spot spacing without having to add any special positioning mechanisms or tooling.

There are two general modes for seam welding — intermittent (also commonly referred to as roll spot) and continuous.

Intermittent Seam Welding

In intermittent seam welding, the wheels advance to the desired position and stop to make each weld. After a weld is completed, the wheels advance to the next location and stop to make the next weld. This process is repeated until the desired length seam is made.

The physical dynamics of intermittent seam welding are similar to spot welding. The control can take whatever time it needs to make a good weld. All actions typically employed by an adaptive control to regulate spot weld quality can be applied to intermittent seam welding as well. Such actions may include automatically correcting issues like part surface contamination and poor part fitup, and in instances when expulsion occurs, instantly cutting off the heat within 1 ms and automatically making a repair weld in place.

In an intermittent or roll/spot welding process, production throughput is limited by how fast the wheels can be accelerated from a stationary state after a weld, over to the next position to be welded, and then completely stopped so the next weld can be made.

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Continuous Seam Welding

In continuous seam welding, the wheels continue rolling as each weld is made. Unlike intermittent seam welding, this process imposes the constraint of a fixed time window to make each weld. Since there is no opportunity to vary the duration of each weld, all adaptive decisions and compensating actions must take place as the weld is being made. The main benefit is that production can occur at much higher speeds.

Velocity

In continuous seam welding, velocity is another fundamental parameter introduced into the welding process. Once the electrode geometry, electrode force, weld current, and weld time are determined to produce the desired weld, increasing the wheel velocity causes colder welds and decreasing the wheel velocity produces hotter welds.

Typical Operation Modes

There are three general modes of continuous seam welding typically encountered in production.

1. All welds are produced by the wheels rolling on the surface of the part at the same wheel velocity. The wheels clamp the part and start rolling. Welding doesn't commence until after the wheels accelerate to the programmed welding velocity. The last weld in the seam is completed before the wheels start decelerating back to zero.

If consistent parts are presented to a machine with consistent tooling, and control of the electrode force, wheel velocity, heat and time are maintained, then managing the shunting phenomenon during the first few welds in the seam is generally the only remaining process specific condition that needs to be addressed.

2. Welds are not all produced at the same wheel velocity. The wheels clamp the part and start rolling. Welding commences before the wheels finish accelerating to the programmed welding velocity. Welding at the end of the seam is still in process when the wheels are decelerating back toward zero.

This arrangement requires actions to be taken at the beginning and end of the seam to avoid making welds that are produced at the lower velocities too hot. The conventional method of managing this condition is to employ upslope heat at the start of the seam and downslope heat at the end of the seam. Achieving consistent welding performance requires exact scaling and coordination of the heat upslope with the rising wheel velocity at the beginning of the seam, and exact scaling and coordination of the heat downslope with falling velocity at the end of the seam. This can be difficult to achieve in practice.

As wheel speed is increased, instantaneous velocity fluctuations also increase from factors such as variable loading of the part presented to the machine. All of these variations can translate into variations in the size of the welds produced.

3. Welding occurs edge-to-edge across the entire part. Typical applications of edge-to-edge seam welding are used in manufacturing products such as water heaters, 55-gal drums, pails, and aerosol cans. As each part to be welded feeds through the machine, the seam wheels have to roll up on the front edge of the part, travel along the entire length of the part, and roll off the back edge. Seam integrity over the entire length of the part is required to prevent it from being rejected.

Conventional System

The majority of operations manufacturing these types of parts attempt to control the process by employing upslope heat at the start of the seam and downslope heat at the end of the seam. A limit switch or proximity sensor detects the part approaching the seam wheels and triggers the start of the weld schedule sequence. A sensor that detects the back end of the part approaching triggers the downslope at the end of the seam. Manufacturers employing this type of operation have high scrap rates from inconsistent weld performance.

In addition, instrumentation for seam welding operations employing this scheme reveal welds on the front edge of the part are either too cold or too hot. No matter what adjustments are made to the proximity sensors, the time uncertainty of the part front end detection system, coupled with variability in the time from when the detection takes place until the part comes in contact with the seam wheels, make it nearly impossible to accurately synchronize the start of heat with the front edge of the part entering the seam wheels.

Synchronizing the downslope on the back end of the part, and turning off the heat at the right time, creates similar issues. If the heat turns off too soon, before the wheels begin to roll off the back edge, then the welds will be too cold. If the heat stays on too long, after the wheels are rolling off the back edge, then the welds will be too hot. If the last weld on the part is still in progress when the wheels have rolled too far off the back edge of the part, then excessive sparking from expulsion and material loss will occur.

Case Study Features

A manufacturer of 55-gal steel drums in New Jersey performs edge-to-edge seam welding at a rate of 50 ft/min. To improve weld consistency and reduce scrap, the company replaced its single-phase alternating current (AC) welding transformer and silicon controlled rectifier (SCR)-based weld control with a mid frequency direct current (MFDC) transformer and conventional inverter control.

Instead of increasing production throughput and decreasing scrap, these equipment upgrades resulted in decreased production throughput and increased scrap. The manufacturer requested WeldComputer Corp., Troy, N.Y., to analyze the welding operation.

A portable WeldView® monitor was connected to a machine on the production line to instrument the existing welding process. Examination of data recorded over a course of several hours during actual production revealed multiple issues, the most dominant of which were as follows: inconsistent heat control delivery of each welding impulse and inconsistent synchronization of the start of heat with the front edge of the part, plus the stop of heat with the back edge of the part.

The first concern observed was inconsistent heat delivery of each welding impulse. The monitor documented multiple occurrences of greater than 10% current fluctuations and greater than 50% weld impulse duration fluctuations. Inconsistent high residual current during the cool interval between each weld impulse was also observed. These current fluctuations varied over a wide enough range to produce welds that were too hot and welds that were too cold.

The second concern viewed was inconsistent synchronization of the start of heat with the part's front edge, and the stop of heat with the part's back edge. The monitor documented repeated occurrences of heat starting before the part reached the welding wheels, followed by other occurrences of the wheels already rolling up on the part before the current turned on.

In instances when heat started before the part made contact with the welding wheels, the weld at the part's front edge was too hot. Sparks were produced at the onset of part contact with the welding wheels, and expulsed material was observed depositing on the welding wheels.

In instances when the wheels were already rolling up on the part before the current started, the front edge of the part was inadequately welded. A similar phenomenon occurred on the part's back edge. Excessive heating and expulsion of material occurred whenever the heat was still on as the wheels rolled off the part's back end, and inadequate welding occurred when the heat cut off before the wheels started rolling off the part's back end.

Instances were also observed of the heat starting too soon on one part and too late on the next part without any adjustments having been made on the production line. This led to the conclusion that the system in place was incapable of reliably coordinating the synchronization of heat vs. time needed to apply proper heating to every part as it passes through the machine.

The recorded monitor traces document the control delivering inconsistent heat pulses that are inconsistently synchronized with the parts feeding through the machine — Figs. 1, 2.

Adaptive Welding System

Employing adaptive control detects when the wheels start to roll up on the part's front and dynamically adjust the heat in relation to the profile pattern

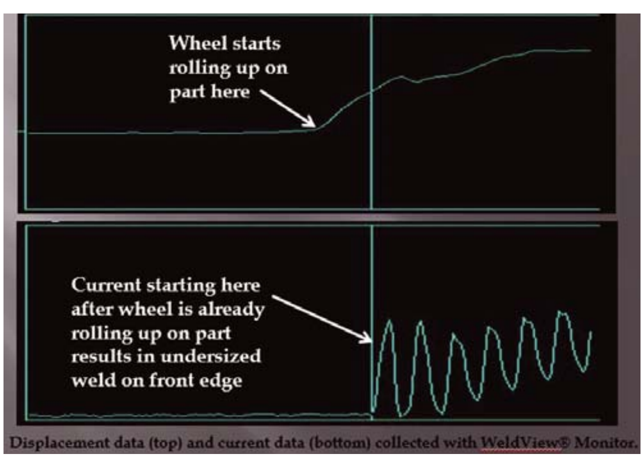

Fig. 1 — The current starting too late makes an undersized front edge weld.

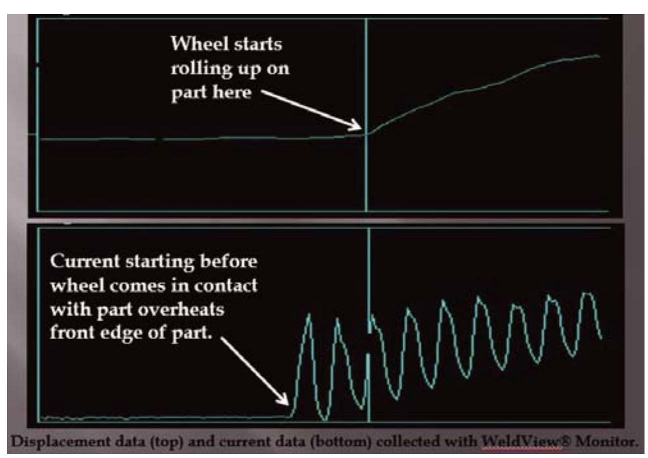

Fig. 2 — The current starting too early overheats the front edge of the part.

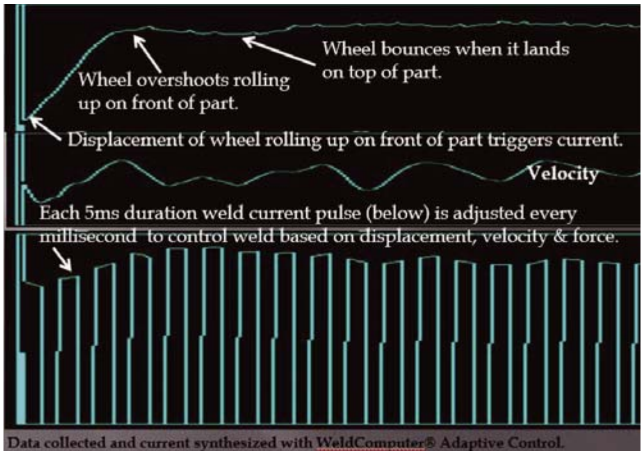

Fig. 3 — Front end of the part. Adaptive seam welding is at 22.5 in./s.

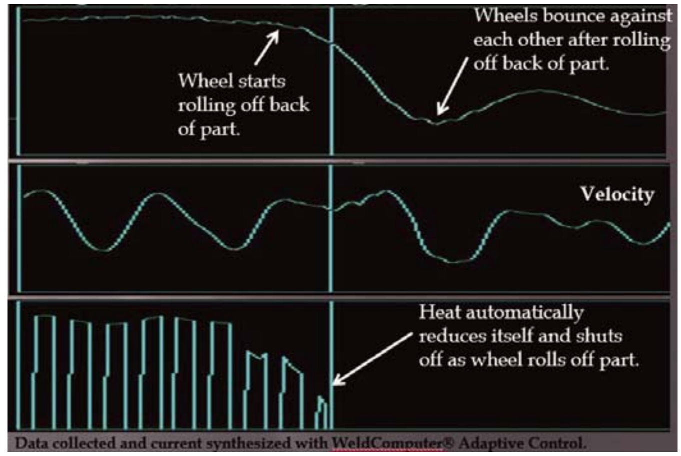

Fig. 4 — Back end of the part. Adaptive seam welding is at 22.5 in./s.

of the wheels rolling up on the part — Figs. 3, 4.

Optimum heating on the part's back end can similarly be controlled by profiling the heat in direct response to the wheels rolling off the part's back end. The adaptive control can also instantly terminate the heat, within 1 ms, upon detection that the wheels have finished rolling a specified distance off the part's back. This limits the process susceptibility to sparking and material expulsion from keeping current on too long. It also extends the amount of time that production can continue before the electrodes have to be cleaned.

Continuous Seam Welding Speed Limiting Factors

The two factors that limit how fast a production seam welding process can operate are machine capability and control capability.

As wheel velocity is increased, more current is required to produce each weld. As current is increased, more cooling is needed to keep the electrodes and current carrying conductors from getting too hot, and more electrode force is required to maintain material containment during the formation of each weld. The seam welding process speed can be increased until a limit is reached on how much one of these four parameters can be further increased.

Selecting a control with a high enough operating current limit, such that current is not the limiting factor in determining how fast welding can occur, will ensure the adaptive control will be able to run the machine at the maximum speed that can be achieved while maintaining weld consistency meeting the welding operation standards.

Velocity

As the speed of a seam welding machine is increased, variable loading of the part presented to the machine, motor torque limitation, gear backlash, belt oscillation, less than optimum tuning of the motor control feedback parameters, and machine mechanical resonances, can cause instantaneous wheel velocity fluctuations. Increasing the speed also reduces the time available to make each weld. As the weld time is reduced, instantaneous velocity fluctuations become an increasing source of weld variation.

Velocity variations on a seam welding machine translate into variations in the size of the welds produced. Reducing the velocity fluctuations from an existing machine could require engineering design changes and retrofits. The weld variations from these fluctuations can be reduced by retrofitting an adaptive control to the machine that automatically adjusts the heat up and down in response to these instantaneous velocity fluctuations.

Vibration

As the speed of a seam welding machine is increased, increased electrode force variation becomes an increasing source of weld variation. As the seam wheels roll up onto the front of the part at high speeds, the wheels will often overshoot and bounce onto the part. The momentary higher electrode force caused by the bounce can translate into an undersized weld that could cause a leak. Depending on the resonant characteristics of the electrode force system, the step of the wheels rolling up onto the part can excite a machine resonance that could take several oscillation cycles to subside. Each of these oscillation cycles can translate into a weld that is too cold as the wheel bounces down on the part, followed by a weld that is too hot as the wheel bounces off of the part.

Eliminating electrode force fluctuations caused from exciting resonances on an existing machine could require engineering design changes and retrofits. In addition to compensating for machine velocity fluctuations, the adaptive control can reduce weld variation from electrode force fluctuations by automatically adjusting the heat up and down in response to these instantaneous force fluctuations.

Current

As wheel speed is increased, in addition to requiring higher current, each weld must be produced in a shorter period of time. Less time is available to make each spot, because the spot has to be produced and completed before a substantial portion of the wheel surface rolls away from the site of the weld being produced.

Accurate delivery of short duration high current impulses are required to control weld repeatability. Cool time between each of these weld impulses is beneficial because it aids the formation of individual overlapping weld nuggets, and reduces the operating temperature of the seam welding wheels. Reducing the temperature of the seam welding wheels generally improves weld quality, extends electrode life, and reduces machine maintenance requirements.

SCR Controls

In many seam welding operations, the control is the limiting factor that limits the speed the machine can operate. As the manufacturer attempts to increase production line speed, the control often becomes the biggest variability source in the welding operation. This causes high scrap rates, high losses due to reduction in overall production throughput, losses from destructive testing, and labor losses.

Existing seam welding operations, utilizing older technology SCR-based weld controls to drive a single-phase AC welding transformer, are speed limited by the control technology being used. This limitation is coupled to the frequency of the power delivered by the power company. The number of welds per second that can be produced by the seam welding machine is equal to the number of power half-cycles per second delivered by the power company.

On 60-Hz AC power lines, this means that the seam welding operation is limited to 120 weld impulses per second. On 50-Hz AC power, this reduces to 100 weld impulses per second. The time of occurrence for each weld is predetermined because it must be synchronized with the time the power company delivers the half-cycle and not with the time it is desired to have the weld take place. As seam wheel velocity is increased, the requirement of having to synchronize the weld with the delivery time of the half-cycle, instead of with the time that the part enters the machine, becomes a bigger source of weld variability that affects weld consistency on the part edges.

The ability to regulate the heat of any individual weld impulse with a SCR control is also limited, because once the control initiates a weld half-cycle impulse, it has no further influence over what happens during the weld. The actual weld heat delivered is determined by what the power company delivers during the half-cycle interval that the weld takes place. The weld is also affected by the transient loading of other factory machines.

Another limitation of SCR control technology is that once a weld impulse is initiated, it cannot be turned off by the control.

Inverter Controls

To overcome limitations imposed by SCR control technology, manufacturers that perform high-speed seam welding are switching to inverter technology. The expectation is that the newer inverter control technology will deliver superior weld current regulation, improve weld quality, and increase production throughput.

Manufacturers seeking expert advice are often informed to take advantage of the newer inverter technology, it will be necessary to throw away the existing AC welding transformer and replace it with a newer technology MFDC welding transformer.

In case studies of seam welding manufacturers that made the conversion from single-phase AC to MFDC, they reported that instead of increasing production throughput and improving weld quality, decreased production throughput, reduced weld quality, and increased maintenance occurred instead. These issues worsened when the manufacturers programed a shorter weld impulse time and shorter cool time between each impulse in an attempt to try meeting or exceeding the 120 weld per second impulse rate realized with the older technology control.

Instrumentation of these welding operations reveal two causes, listed below, for the degraded welding performance.

The inverter control selected, when programmed to produce short duration impulses, delivers inaccurate and/or unstable current regulation that results in greater weld impulse current variability than what was previously achieved with the older SCR-based control.

During the programmed cool time between each impulse, the current decays slowly, and often doesn't decay to zero before the next welding impulse begins. This high residual current during each cool interval, which is caused by the introduction of the MFDC

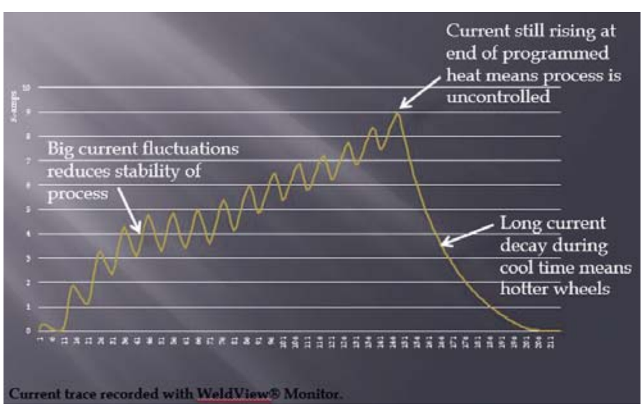

Fig. 5 — The current trace of a MFDC control documents that current has not stabilized at the programmed value prior to completion of an 8-ms duration weld, has big current fluctuations occurring twice per ms, and excessive current decay time.

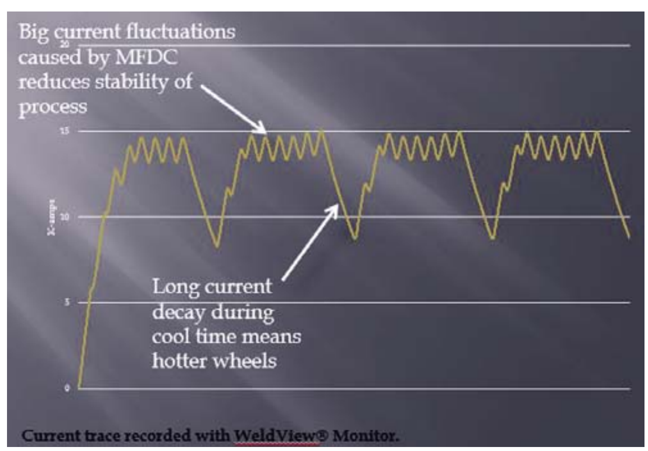

Fig. 6 — The RMS current trace of 1-Khz MFDC optimally tuned heat impulses, 4-ms heat, 1-ms cool, in a repeating pattern has 2 current fluctuations per ms. Slow current decay at the end of each heat impulse, caused by the MFDC transformer, degrades the effectiveness of the cool time function.

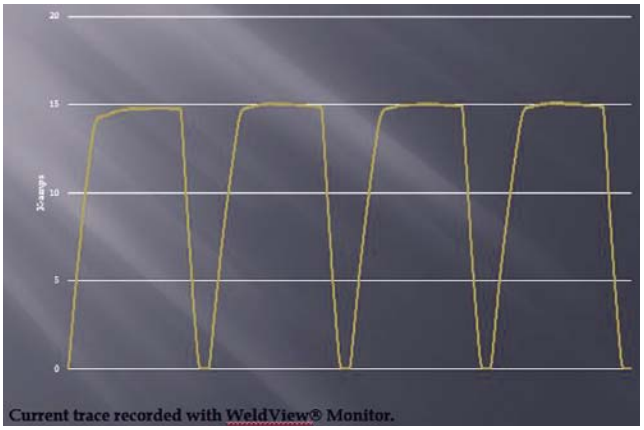

Fig. 7 — The RMS current trace of 4-ms heat, 1-ms cool, weld impulses produced with a WeldComputer® inverter wave synthesis control driving a standard 60-Hz AC welding transformer. (Monitor set to record in 10-μs intervals to document current ripple.)

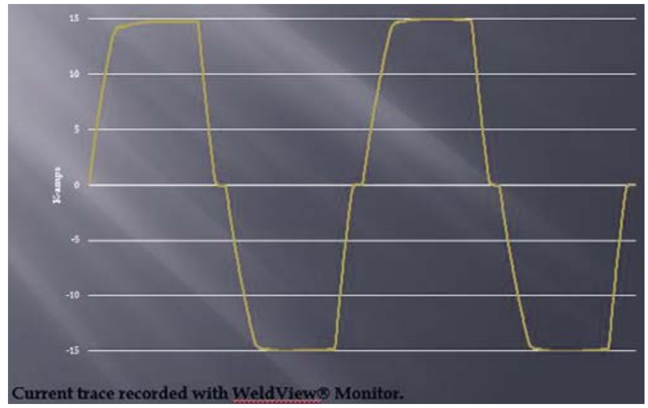

Fig. 8 — The balanced polarity welding waveform on sequential welds eliminates the issue of asymmetrical electrode wear and unbalanced electrode heating due to the Peltier Effect.

transformer, degrades the effectiveness of the cool time function — Fig. 5.

This causes the seam wheels to operate at a higher temperature to make the same size welds than what previously occurred when the current was able to be brought to zero during the majority of the programmed cool interval. The elevated wheel temperature caused from switching to a MFDC transformer creates secondary issues, including faster material pickup on the wheel surfaces.

MFDC Considerations

In addition to poorly defined cooling intervals when operating at high speeds, other factors experienced with MFDC include the following:

Increased mechanical wear on the machine. On machines with short throats, the normal switching function of 1-Khz MFDC controls cause two current fluctuations during each ms of programmed weld heat. These fluctuations cause thermal expansion and contraction, twice per ms, of many moving parts on the welding machine. The extra stress and motion on the machine from these expansions and contractions cause the bearings and moving linkages to wear out faster.

Increasing the throat size of the welding machine helps subdue these current fluctuations that occur during each programmed ms of operation, but it slows down the rate that the current can be adjusted by the control.

Machine and product become magnetized. When magnetic material is welded on a machine with a MFDC transformer, the machine and the parts being welded become magnetized. Metal filings become attracted to the machine surfaces. These accumulating filings eventually work their way into the moving bearings, guides, and linkages of the welding machine. This increases the incidence of machine failures and imposes additional maintenance requirements.

Unbalanced temperature and wear of the two electrodes. Commonly known as the Peltier Effect, the rectified secondary current created by a MFDC welding transformer causes the anode electrode (the wheel connecting to the + side of the MFDC transformer) to have a hotter operating temperature than the other electrode. In addition to creating a temperature imbalance that can shift the location of the nuggets in the welded part, instead of both electrodes wearing uniformly, the positive electrode deforms and picks up contaminants faster than the negative electrode.

AC Wave Synthesis

Analyses of several high-speed seam welding operations have revealed that proper application of inverter technology to the existing AC welding transformer produces better results than what could be achieved by replacing the AC transformer with a MFDC transformer.

In addition to incurring extra costs for reducing the performance of the welding process, the new MFDC transformer will not last as long as the existing AC transformer. The MFDC transformer has diodes built into the unit that are subject to failure. A single overcurrent event could damage the diodes. In contrast, the AC transformer is a more robust component that can handle overcurrents without degrading or reducing the transformer's life expectancy.

Outfits that instruct the manufacturer to incur the expense of throwing away an existing AC welding transformer and replacing it with a MFDC transformer are either unaware that inverter technology can be applied directly to the AC transformer or have not taken actual measurements comparing the performance of the same process with an AC transformer and MFDC transformer where the transformer selection is the only variable introduced to the process.

Figure 6 shows the root mean square (RMS) current, in 10-μs intervals, of a sequence of impulses produced by an inverter WeldComputer® control configured to produce an optimally tuned MFDC switching pattern with each impulse consisting of 4 ms heat and 1 ms cool in a repeating pattern.

Figure 7 documents the RMS current, in 10-μs intervals, of a sequence of impulses produced by a WeldComputer® inverter wave synthesis control driving a standard fixture type 60-Hz AC transformer with each impulse consisting of 4 ms heat and 1 ms cool in a repeating pattern. (This is the same heat-cool pattern as programmed with the previous MFDC configuration.)

Note that a RMS current plot does not provide information about the actual polarity of the current.

Figure 8 of the actual current waveform with the same signal acquisition shown previously reveals the alternating polarity of each weld produced by the AC inverter wave synthesis control. WJ

Conclusions

Among the AC transformer highlights are 1) allowing shorter duration welds to be produced with a good transient response; 2) providing regulation by allowing more adjustments per ms and control when short cool times are involved; 3) letting seam wheels and machine current carrying conductors to operate at a lower temperature; 4) not magnetizing the machine or parts being welded; 5) avoiding the issue with the Peltier Effect causing the anode electrode to achieve a higher temperature operating point than the cathode electrode after making several welds; and 6) preventing the issue with asymmetrical degrading of the electrodes linked to the current flow polarity.

Employing a control capable of ensuring that every produced current impulse stabilizes at the programmed setting before a new value is programmed is necessary to maintain a repeatable process that is accurately regulated by the control.

Also, the speed that a seam can be produced while maintaining control of the process can be maximized by employing multivariable adaptive control that can dynamically compensate for variations in electrode contact area on the part, electrode force, position, and velocity as the seam is being produced.

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*ROBERT K. COHEN is president of WeldComputer Corp. (*info@weldcomputer.com*), Troy, N.Y. He is also a member of the AWS C1 Committee on Resistance Welding and D17D Subcommittee on Resistance Welding in the Aircraft and Aerospace Industries.*

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