PROCESS

LINCOLN ELECTRIC
THE WELDING EXPERTS

WAVEFORM CONTROL TECHNOLOGY™

Pulsed Spray Metal Transfer

Have you ever wished for a welding process that promotes higher electrode efficiency (98% of the molten electrode is deposited in the weld), low hydrogen weld deposit, and reduced cleanup costs? How about higher travel speeds, in excess of 70 inches per minute, with low spatter? Maybe you would like to use a welding process capable of performing in-the-flat, horizontal, vertical up, or overhead welding positions, without a slag system?

Advances in electronic technology have provided Lincoln Electric with the tools to design a welding process to fulfill these wishes. Increasing your productivity and improving weld quality are our primary goals, and the fastest way to achieve them is with Waveform Control Technology™.

Waveform Control Technology and pulsed spray metal transfer are readily available in the Power Wave and Power MIG 300 family of inverters. Optimized GMAW-P waveforms are ready to use for aluminum, carbon steel, high strength low alloy steel, stainless steel, and nickel alloys.

LINCOLN ELECTRIC NEXTWELD™

The earliest application of pulsed spray metal transfer (GMAW-P) was for out-of-position ship hull fabrication.Pulsed spray metal transfer is now being used for offshore oil rig pipe welding applications.

advantages

IMPROVED WELD QUALITY

- Lower hydrogen weld deposit (<5 mL H_2/100 grams)
- Lower heat input with less distortion
- Excellent weld fusion
- X-ray quality weld deposits on thick or thin base metals

INCREASED COST SAVINGS AND PRODUCTIVITY

- Minimum formation of slag and very low weld spatter levels reduces or eliminates weld cleanup costs
- Higher travel speed and higher deposition rates than other GMAW processes
- Higher efficiency metal transfer (98%) for solid or metal-cored electrodes

FLEXIBLE

- GMAW-P is used in all welding positions
- GMAW-P can be used in hard automation and robotic applications
- GMAW-P is increasingly used for high production semiautomatic welding
- Custom waveforms can be created to adjust the GMAW-P arc performance with the Wave Designer software available from Lincoln Electric

The future of welding is here.®

Pulsed Spray Metal Transfer

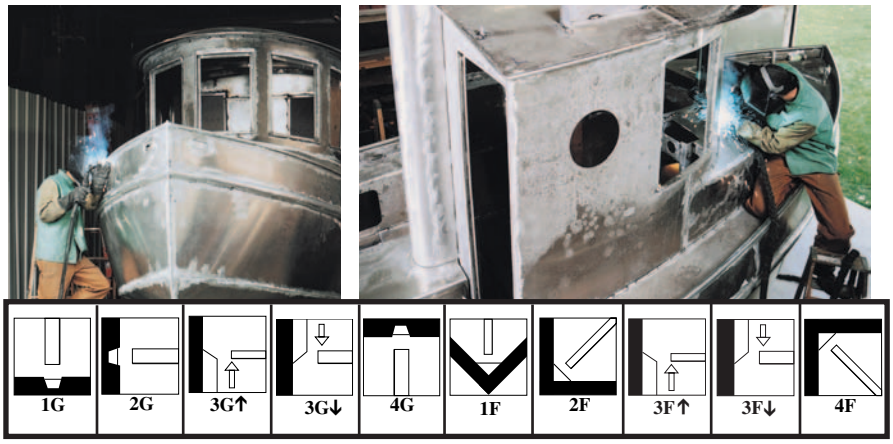
What

is Pulsed Spray Metal Transfer?

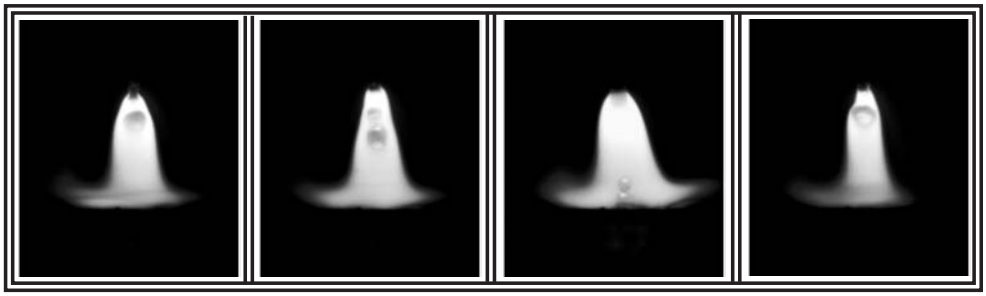
Pulsed spray metal transfer (GMAW-P) takes advantage of the high energy of Axial Spray Metal Transfer, and alternates this high energy (peak) current with a lower energy (background) current. Each cycle is called a period, and the period can repeat several hundred times per second.

The benefit of the pulsed energy is that it produces desirable fusion characteristics, but reduces the heat input considerably when compared to axial spray transfer or other welding processes. The dynamics of the pulse permit the use of GMAW-P for out-of-position welding.

Out-of-position welding coupled with lower heat input assists in achieving excellent weld metal mechanical properties and Charpy Impact test values.



The dynamics of the pulsed spray metal transfer offer the flexibility of welding in 1G, 2G, 3G (up), 3G (down), 4G, 1F, 2F, 3F (up), 3F (down), and 4F positions.



The molten droplet forms and detaches from electrode.

The droplet is forced across the arc by the peak current.

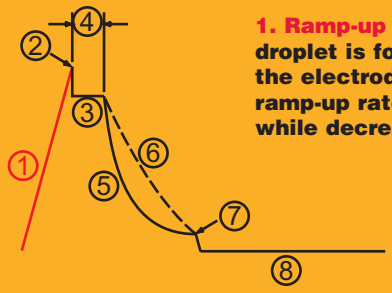
The molten droplet fuses with the weld puddle.

An increase in ramp-up rate to form a new droplet stiffens the arc.

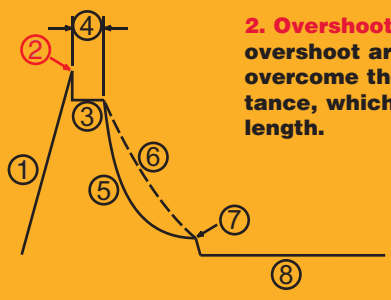
How

Pulsed Spray Metal Transfer Works

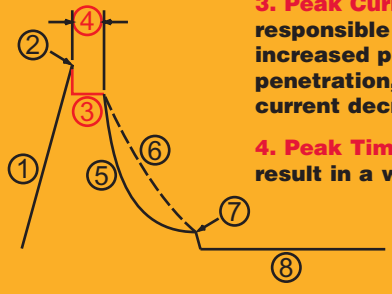
The pulsed waveform can be broken into nine components. Bear in mind that increases in any of these components for a given waveform increases energy and subsequent penetration.



1. Ramp-up rate — the molten droplet is formed at the end of the electrode; increases to the ramp-up rate "stiffen" the arc, while decreases "soften" the arc.

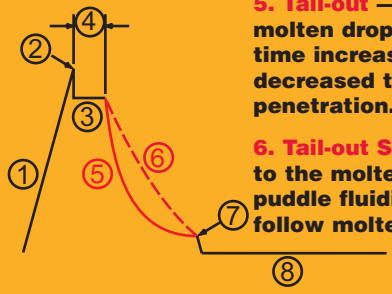


2. Overshoot — increases to the overshoot are necessary to overcome the influence of inductance, which varies with cable length.



3. Peak Current — largely responsible for weld penetration; increased peak current increases penetration, while decreased peak current decreases penetration.

4. Peak Time — longer peak times result in a wider bead shape.



5. Tail-out — adds energy to the molten droplet; increased tail-out time increases penetration, while decreased tail-out time decreases penetration.

6. Tail-out Speed — adds energy to the molten droplet; increasing puddle fluidity permits a fast follow molten puddle.

Pulsed Spray Metal Transfer

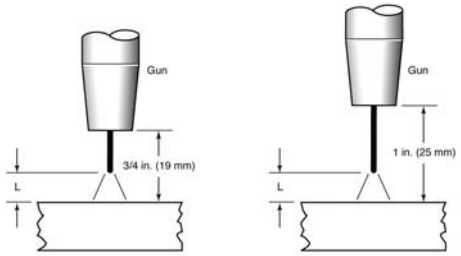
Learning

Pulsed Spray Metal Transfer

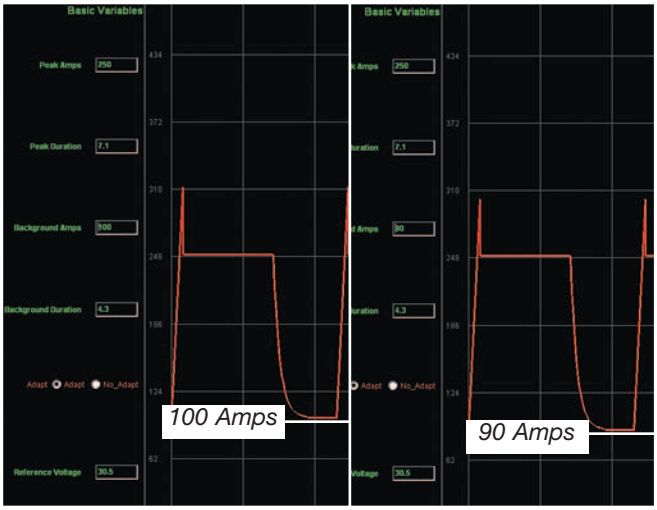
The Adaptive Loop

Many pulsed spray metal transfer software programs are designed with an “adaptive loop”, which dictates the way that the waveform will respond to a change in the output. This control helps maintain a constant arc length in the presence of a changing contact tip to work distance (CTWD). For example, in a constant current scenario, if the CTWD increases, then energy delivered to the arc decreases, increasing arc length. This stability is particularly important in semi-automatic welding applications. The adaptive loop is designed to regulate the arc length as the CTWD fluctuates between 0.50 and 1.25 in. (13 to 32 mm).

Frequency, background current, peak time, and peak current are the components of the waveform typically used to control arc length. These components are termed “Scale Factors” and they are programmed to compensate to changes in the arc as a percentage of the whole. For example, if a pulsed spray metal transfer weld is programmed at 100 Amps background current at a 10% scale factor, and the CTWD increases, then the background current will decrease by 10%, or fall to 90 Amps. Conversely, if the same pulse program experiences a decrease in the CTWD, the background current will increase by 10%, to 110 Amps. Other scale factors will behave in the same manner.



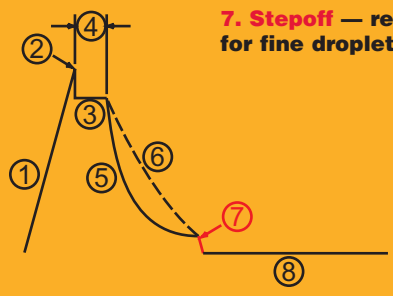
The length from the end of the gun to the base metal is referred to as Contact Tip to Work Distance (CTWD). Here, CTWD changes from 0.75 to 1.00 in.



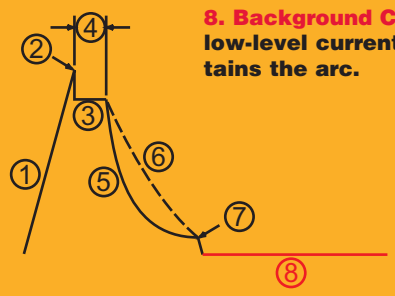
As CTWD changes from 0.75 to 1.00 in., background current changes from 100 to 90 amps

How

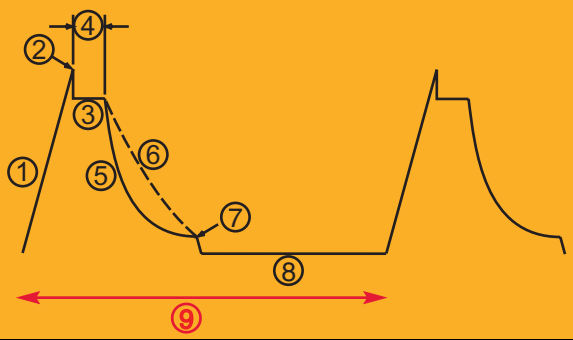
Pulsed Spray Metal Transfer Works (cont.)



7. Stepoff — reduces the tendency for fine droplet spatter.



8. Background Current — low-level current that maintains the arc.



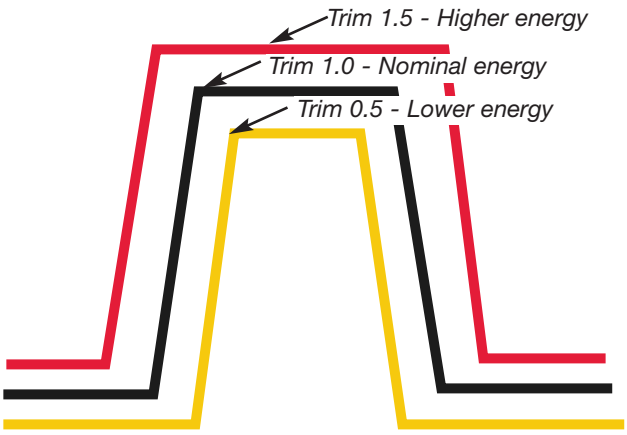
9. Frequency — increased frequency narrows the arc cone, decreased frequency broadens the arc cone.

Pulsed Spray Metal Transfer

Learning

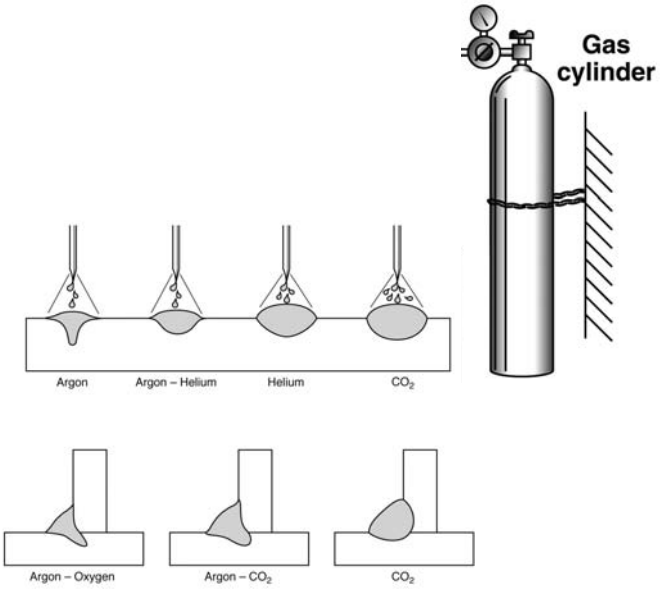
Pulsed Spray Metal Transfer (cont.)

The components of the waveform, or scale factors, work in unison to deliver the appropriate amount of energy to the arc. This is referred to as trim value. As the trim decreases from a nominal value of 1.00, the scale factors are applied in unison to decrease the arc length. As the trim value is increased to a value greater than 1.00, the scale factors work together to increase the arc length. It is important to understand that none of the scale factors work independently of one another. A change made to the frequency affects the input value of background current, peak current, and peak time, just as a change to the peak current will affect peak time and background current.



Selecting Shielding Gas

Shielding gas is responsible for the overall distribution of energy within the arc, and affects the penetration profile and the finished weld bead appearance. Some of the shielding gases used in pulsed spray metal transfer have the ability to carry arc energy better than others, which is referred to as thermal conductivity. Some components of a shielding gas, such as CO_2 or O_2 contribute an oxidizing effect on the molten weld puddle. Finally, some of the shielding gas components, such as Argon and Helium ionize differently and have an affect on the cleaning action of the molten puddle.



Thermal conductivity influences the amount of voltage required. High thermal conductivity cools the arc, increasing the required voltage input. Reactivity is a prediction of how a particular gas will react with the chemistry of the weld pool. Single shielding gases react differently with the arc plasma than do gas blends. Tables 1 and 2 identify gas types and their typical behavior with the arc plasma and weld puddle.

Table 1: Shielding Gases and Arc Performance

Shielding Gas	Density	Thermal Conductivity	Effect on Finished Weld and Arc Performance
Argon (Ar)	1.78	30.6	Argon promotes arc starting, increased droplet pinch rate, and deep finger-like penetration profile. Argon is also a poor thermal conductor.
Carbon Dioxide (CO_2)	1.98	41.6	As the CO_2 content increases, the overall penetration also increases. Argon mixed with 18% CO_2 or less is required to support true axial and pulsed spray transfer. CO_2 shielding gas releases energy from the process of dissociation and recombination.
Helium (He)	.178	252.4	The use of helium requires more watt energy for arc stability, which broadens the penetration profile and eliminates the finger-like projection typical of higher Argon content. Helium is an excellent thermal conductor.
Hydrogen (H_2)	.0899	230.4	Hydrogen is used as a substitute for Helium for Stainless and Nickel alloy applications because it increases puddle fluidity. Hydrogen is also an excellent thermal conductor.
Nitrogen (N_2)	1.25	44.0	Nitrogen was recently used to promote higher energy for stainless steel gas metal arc welding.
Oxygen (O_2)	1.43	48.1	Oxygen acts as an arc stabilizer in Argon rich blends. It reacts with the weld pool, but to a lesser extent than CO_2. Oxygen is a good choice of shielding gas for sheetmetal pulsed spray metal transfer.

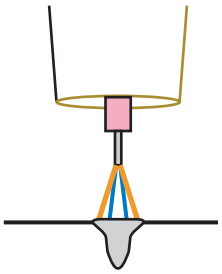
Pulsed Spray Metal Transfer

Learning

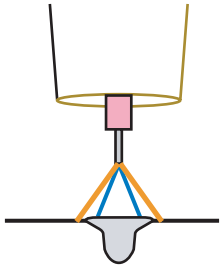
Pulsed Spray Metal Transfer (cont.)

Selecting Shielding Gas (cont.)

As shown in the images here, Argon forces the metal vapor to ionize readily, but is a poor thermal conductor. The result is a deep, finger-like penetration called a papillae. This type of penetration profile should be expected with high Argon concentration shielding gases. The addition of CO_2 will broaden the penetration, but will also make it more shallow.



High Argon content causes deep finger-like projections called papillae.



Adding CO_2 broadens the penetration profile, making the weld more shallow.

Table 2: Shielding Gas Selection

Base Material	Electrode Type	Mode of Metal Transfer	Shielding Gas Blends
Mild Steel	ER70S-3 ER70S-4 ER70S-6 E70C-6M	GMAW-S or STT™	75-90% Argon + 10-25% CO_2 100% CO_2
		Axial Spray or GMAW-P	82-98% Argon + 2-18% CO_2 95-98% Argon + 2-5% O_2
Low Alloy Steel	ER80S-Ni1 ER80S-D2 ER100S-G ER110S-G E90C-G E100C-G	GMAW-S or STT™	100% CO_2 75-80% Argon + 20-25% CO_2
		Axial Spray or GMAW-P	95% Argon + 5% CO_2 95-98% Argon + 2-5% O_2
Aluminum	ER1100 ER4043 ER4047 ER5356 ER5554 ER5556	Axial Spray or GMAW-P (No GMAW-S)	100% Argon 75% Helium + 25% Argon 75% Argon + 25% Helium 100% Helium
Austenitic Stainless Steel	ER308LSi ER309LSi ER316LSi	GMAW-S or STT™	98-99% Argon + 1-2% O_2 90% Helium + 7.5% Argon + 2.5% CO_2 55% Helium + 42.5% Argon + 2.5% CO_2
		Axial Spray or GMAW-P	98-99% Argon + 1-2% O_2 98% Argon + 2% CO_2 97-99% Argon + 1-3% Hydrogen 55% Helium + 42.5% Argon + 2.5% CO_2
Nickel Alloys	ERNiCr-3 ERNiCrMo-4 ERNiCrMo-3 ERNiCrMo-10 ERNiCrMo-14 ERNiCrMo-17	GMAW-S or STT™	90% Helium + 7.5% Argon + 2.5% CO_2 89% Argon + 10.5% Helium + 0.5% CO_2 66.1% Argon + 33% Helium + 0.9% CO_2 75% Helium + 25% Argon 75% Argon + 25% Helium
		Axial Spray or GMAW-P	100% Argon 89% Argon + 10.5% Helium + 0.5% CO_2 66.1% Argon + 33% Helium + 0.9% CO_2 75% Helium + 25% Argon 75% Argon + 25% Helium 97-99% Argon + 1-3% Hydrogen
Duplex Stainless Steel	2209 2304	GMAW-S or STT™	66.1% Argon + 33% Helium + 0.9% CO_2 90% Helium + 7.5% Argon + 2.5% CO_2 98-99% Argon + 1-2% O_2 98% Argon + 2% CO_2
		Axial Spray or GMAW-P	75% Helium + 25% Argon 75% Argon + 25% Helium 100% Argon 100% Helium 66.1% Argon + 33% Helium + 0.9% CO_2
90/10 Copper Nickel Alloys	ERCuNi Type 70/30	Axial Spray or GMAW-P	100% Argon 75% Argon + 25% Helium 75% helium + 25% Argon
Copper Alloys	ERCu (Deoxidized)	Axial Spray or GMAW-P	100% Argon 75% Argon+ 25% Helium 75% Helium + 25% Argon
Aluminum Bronze	ERCuAl-A1 ERCuAl-A2 ERCuAl-A	Axial Spray or GMAW-P	100% Argon

Pulsed Spray Metal Transfer

Using

Pulsed Spray Metal Transfer

Use Pulsed Spray Metal Transfer to Reduce Weld Cycle Times

RapidArc™ is a pulsed spray metal transfer program specifically designed to perform in applications where high travel speeds and reduced cycle times are a must. Travel speeds in excess of 50 inches per minute (ipm) have been achieved on sheet metal with this specialty process.The optimal energy of the arc (higher energy than short arc, but lower energy than axial spray) in this high-speed pulse waveform also aids in the volatilizing of zinc-coated or aluminum-coated materials. Cycle times have been reduced by as much as 75%, while a reduction in spatter has reduced the need for after-weld grinding, which means that this pulse process provides huge cost savings.

Use Pulsed Spray Metal Transfer to Reduce Aluminum Weld Defects

Pulse-On-Pulse™ is a pulsed spray metal transfer program designed to combat the welding defects commonly associated with aluminum. Again, the optimal energy of the arc makes this process suitable for welding nickel alloys. The TIG-like bead appearance of the finished weld has proven to have appeal to aluminum product fabricators.

Use Pulsed Spray Metal Transfer for Welding Thin Materials

The lower average current achieved by the pre-programmed pulsed spray metal transfer waveform in the Power Wave 355M, 455M, and Power MIG 300 power sources make it ideal for thin material welds. With the reduced distortion and elimination of burn-through that pulsed spray metal transfer offers, added to the heightened sidewall fusion and penetration characteristics, thin material welding has never been easier.

Use Pulsed Spray Metal Transfer for Out-of-Position Welds

Typical in-the-flat welds can be made with a number of different welding processes. Take the same materials and put them overhead or vertical, and suddenly your choices narrow. Use the built-in strengths of the pulsed spray metal transfer program to avoid the troubles usually encountered when welding out-of-position, such as incomplete fusion and arc wander.

Pulsed Spray Metal Transfer

Lincoln Welding Systems Featuring Pulsed Spray Metal Transfer

Power Wave 455M
Power Wave 455M/STT

These Power Waves are designed to be part of a modular, multi-process welding system.

- The Power Wave 455M and 455M/STT are high performance, digitally controlled inverter welding power sources capable of complex, high-speed waveform control.
- Digital Communications enable the Power Wave to connect seamlessly to robot controllers and hard automation PLCs. Semi-automatic applications are also supported.
- Optional DeviceNet and Ethernet communication modules provide networking capabilities and allow process and production monitoring.
- Software-based controls can be upgraded as new features become available.

Power Wave 655 Robotic

The Power Wave 655 Robotic was designed for Robotic and Hard Automation applications that require extra power (650 Amps at 100% Duty Cycle).

- Digital Communications enable the Power Wave to connect seamlessly to robot controllers and hard automation PLCs. Semi-automatic applications are also supported.
- The Ethernet/DeviceNet Gateway provides networking capabilities and allows process and production monitoring.
- Software-based controls can be upgraded as new features become available.
- The Power Wave 655 Robotic has an output range of 20 to 880 Amps.

Power Wave 355M/Power Feed™ 10M

The Power Wave 355M is the smaller, lighter version of the Power Wave 455M — same machine, just leaner and lighter.

- The Power Wave 355M/Power Feed™ 10M welding system is factory-programmed with over 60 standard welding programs to optimize the arc for a variety of materials or applications, including steel, stainless steel, aluminum, nickel alloys and others.
- ArcLink Digital Communication between components allows unprecedented waveform control and expansion capability. Simply select a program and you have the right arc characteristics for your application.
- The software is upgradeable, so your Power Wave 355M will grow with your business. If you want to reduce costs by buying a versatile machine that will do multiple jobs and last for years to come, the high-efficiency Power Wave 355M delivers.

Pulsed Spray Metal Transfer

Lincoln Welding Systems Featuring Pulsed Spray Metal Transfer

Power MIG 300

The Power MIG 300 — a single phase, multi-process, synergic power source/wire feeder combination welding package for the professional welder.

The Power MIG 300 offers:

- Superior multi-process welding.
- Synergic design for ultimate control over the arc,by automatically aligning wire feed speed and voltage.
- Top-quality aluminum welds with push-pull wire feed capability, not typically available in competitive models.
- True MIG pulsing and Pulse-on-Pulse™ capabilities, which ensure that superior feeding is matched by high quality arc performance.
- PowerMode™ — the best traditional short-circuit transfer in the welding business.

Power Wave F355i

The Power Wave F355i is fully integrated with the FANUC ARC Mate™ R-J3iB controller and designed for the most demanding robotic applications.

- This compact unit delivers 350 Amps @ 60% duty cycle for MIG, Pulsed MIG or Flux-Cored welding applications.
- The Power Wave F355i/ARC Mate R-J3iB communicates via ArcLink™, allowing all welding procedures and process controls to be managed through the ARC Mate robot teach pendant — one central control for setup, process control and diagnostics.

WHAT IS NEXTWELD?

The challenges facing industrial fabricators today are increasingly difficult. Rising labor, material, and energy costs, intense domestic and global competition, a dwindling pool of skilled workers, more stringent and specific quality demands.

Through our commitment to extensive research and investments in product development, Lincoln Electric has established an industry benchmark for applying technology to improve the quality, lower the cost and enhance the performance of arc welding processes. Advancements in power electronics, digital communications and Waveform Control Technology™ are the foundation for many of the improvements.

NEXTWELD brings you a series of Process, Technology, Application and Success Story documents like this one. NEXTWELD explains how technologies, products, processes and applications are linked together to answer the important questions that all businesses face:

- *How can we work faster, smarter, more efficiently?*
- *How can we get equipment and people to perform in ways they've never had to before?*
- *How do we stay competitive?*

NEXTWELD is the future of welding but its benefits are available to you today. Ask your Lincoln Electric representative how to improve the flexibility, efficiency and quality of your welding operations to reduce your cost of fabrication.

LINCOLN® ELECTRIC

THE WELDING EXPERTS

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