APPLICATION

WAVEFORM CONTROL TECHNOLOGY™

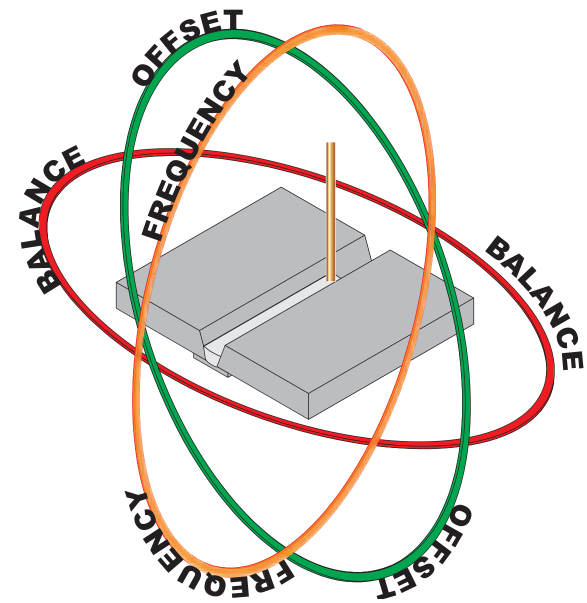
Making Butt Welds with Power Wave AC/DC 1000™ Technology

Welding Guide

Now from Lincoln - the power to increase butt welding productivity and quality with Power Wave Technology!

Butt-welded joints can involve a multitude of differing geometries ranging in thickness from sheet metal to inches-thick plate. Additionally, the service requirements of the weld can involve very stringent mechanical properties. In the past, these conditions have severely limited the choice of useable welding procedures.

Lincoln Electric Power Wave technology, based on the new Power Wave AC/DC 1000™ power source, provides the ability to tailor the output to efficiently meet the job requirements — with just a flick of a switch!



advantages

CHOICE AT THE "FLICK OF A SWITCH"

- Constant current (sometimes referred to as variable voltage)
- Constant voltage
- Square Wave AC

UNLIMITED AC OUTPUT TAILORING

- Choice of AC frequency (from 10 Hz to 100 Hz).
- Wave balance control to allow more or less positive AC
- Offsetting the AC wave to change the magnitude of the negative or positive component

REDUCTION IN DEFECTS

- Virtual elimination of arc blow
- Virtual elimination of arc-striking problems

LOWER COSTS

- Tailoring the arc to suit the job will permit productivity increases over conventional submerged arc welding

Patented. This product is protected by one or more of the following United States patents: 6,809,292; 6,795,778; 6,700,097; 6,697,701; 6,683,278; 6,660,966; 6,600,134; 6,683,278; 6,596,570; 6,570,130; 6,536,660; 6,489,952; 6,472,634; 6,636,776; 6,486,439; 6,441,342; 6,365,874; 6,291,798; 6,207,929; 6,111,216; 4,927,041; 4,861,965 and other pending U.S. patents. Similar patents are maintained in other countries.

The future of welding is here.®

Understanding the World of Butt Welds

Butt joints consist of a group of butt welds that have specific weld volume requirements to be successfully produced. Butt welds can, in general, be grouped into four different types:

- Volumetric fill with good fusion (Figure 1A).
- Volumetric fill with some base metal penetration (Figure 1B).
- Deep base metal penetration with little volumetric fill (Figure 1C).
- Deep base metal penetration with some volumetric fill (Figure 1D).

There are numerous variations of weld joint configurations, but the examples in Figure 1 illustrate the basic types. There are three key points regarding welding butt joints:

1. Butt joints requiring a lot of metal deposit generally require less penetration.
2. Joints requiring penetration require less or little fill.
3. Increasing penetration is usually accomplished by increasing amperage which also increases the metal deposit rate.

The Power Wave AC/DC 1000™ allows increased deposit rates without increased current to best suit the joint!

Figure 1A

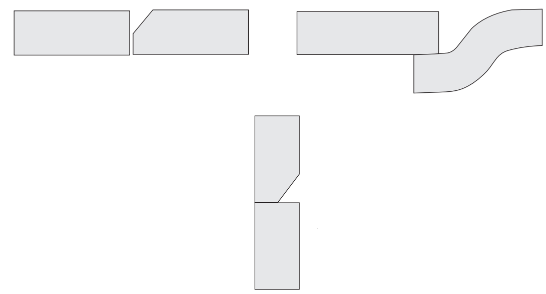


Figure 1B

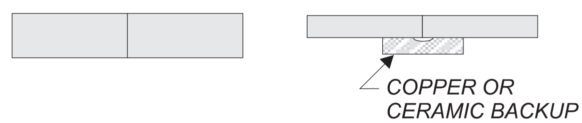


Figure 1C

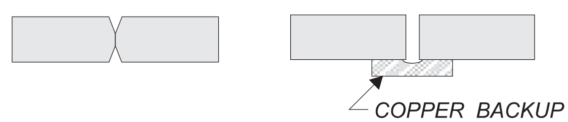


Figure 1D

Submerged arc welding has long been recognized as the best process to deliver low cost, high quality weld metal. In some instances, the resultant weld metal may need only be sound, plate-strength matching. However, many applications are far more demanding, requiring the meeting of stringent mechanical properties in the as-welded and sometimes heat-treated condition. Frequently, Charpy V-notch (CVN) test values at low temperature are mandated. It is here Power Wave technology using the Power Wave AC/DC 1000™ easily permits shaping the weld bead (or individual beads) to produce optimum size and controlled heat input without sacrificing productivity.

Power Wave AC/DC 1000™ Output Characteristics

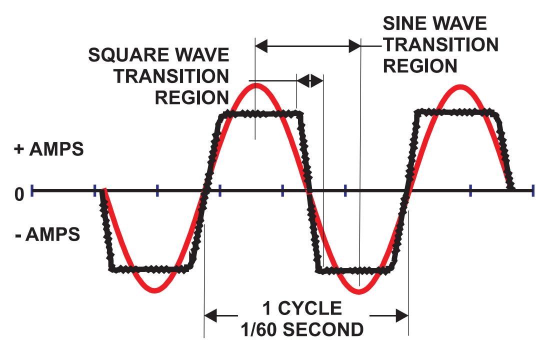
The Power Wave AC/DC 1000™ is unique in that in addition to providing DC positive or negative output, it allows tailoring the AC output to deliver specific characteristics. This is accomplished by using major components of:

- Square wave (vs a conventional sine wave)
- Square wave balance
- Square wave offset
- Square wave frequency.

Figure 2 The Power Wave AC/DC 1000™

Square Wave vs Conventional Sine Wave

Figure 3 illustrates one cycle of a true 60 Hz sine wave with a square wave superimposed upon it. Note that while the rms² values are the same for both waves, the transition time for peak-to-peak is much shorter for the square wave. This transition period is what has always caused instability with conventional AC welding, but due to the rapid transition associated with the Power Wave AC/DC 1000™, arc stability is greatly increased.



60 Hz SINE WAVE vs 60 Hz SQUARE WAVE

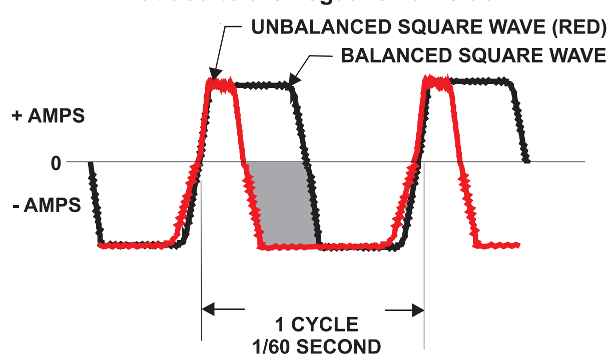
Figure 3

Square Wave Balance

Square wave balance allows the arc to function more as a positive or negative polarity. The balance is always referenced to the percentage of the square wave cycle that is positive. For example, 25% balance means that 25% of each cycle is positive and 75% is negative. This is illustrated in Figure 4.

This ability can be used to tailor the arc to achieve desired results by increasing deposition rate and decreasing penetration, or decreasing deposition and increasing penetration.

Greyed area is portion of positive half-side added to the negative half-side



UNBALANCED SQUARE WAVE

Figure 4

Rms²: root-mean-square value of current or voltage. For example, when someone refers to, "110 volts," this is actually an rms value as is "30 volts AC", etc.

Square Wave Offset Effect

Offset is illustrated in Figure 5. Offset is the ability to shift the square wave to increase the magnitude of either the positive or negative portions of the total current amplitude. Shifting toward the positive side increases penetration with a slight decrease in melt-off relative to a normal balanced square wave. Conversely, shifting toward the negative side increases melt-off and decreases penetration. The Power Wave AC/DC 1000™ allows shifting offset continuously between +25% and -25%.

This ability is very powerful. It allows the arc to be tailored in order to meet specific arc characteristics of a particular butt weld, or of specific passes within a butt weld. (For example, root, fill, and cap passes in a multiple pass weld.)

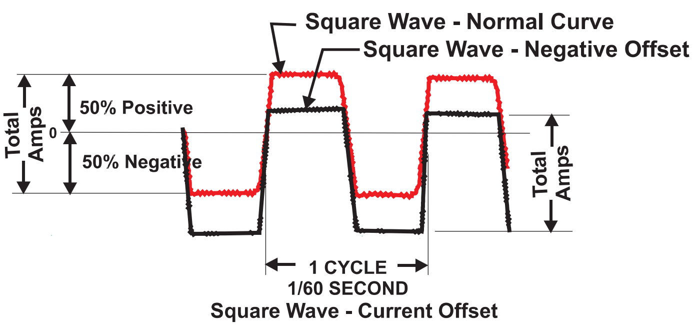


Figure 5
Square Wave Offset Effect

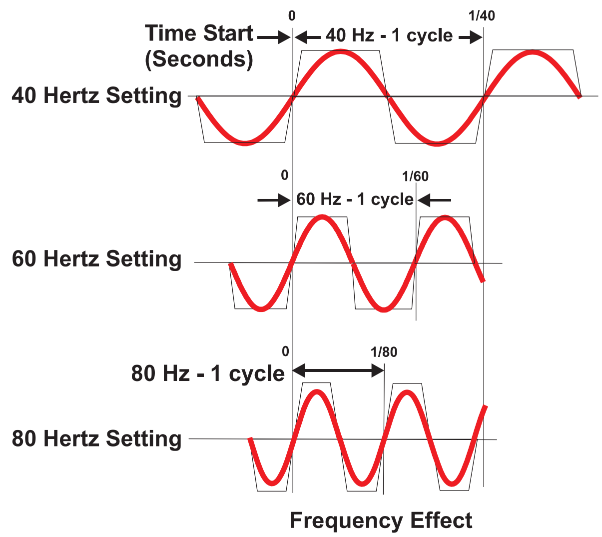


Figure 6
Square Wave Frequency Effect

Square Wave Frequency Effect

Figure 6 illustrates conventional sine waves (in red) overlaid upon Power Wave AC/DC 1000™ square waves to illustrate frequency effect. The Power Wave AC/DC 1000™ permits adjusting the frequency continuously from zero (DC) to 100 Hz. The voltage and current values are identical for all three curves.

As the frequency of the AC wave is altered, the amount of time spent at peak current and voltage varies, and the amount of time spent transitioning from positive to negative values also changes. Using the Power Wave AC/DC 1000™, more time is spent at peak values and less time transitioning as the frequency is lowered. As the frequency is increased, the opposite occurs. This is a distinct advantage that a square wave has over a conventional sine wave power source.

These changes can have an effect on deposition rate, penetration, and arc stability. Used in conjunction with other Power Wave AC/DC 1000™ control functions, the arc can be tailored to best suit specific job requirements. This ability is especially useful in controlling the bead shape of penetration welds and in welding light gage material.

Deposit Rate vs Output Mode

The graph shown in Figure 7 shows the relative deposit rates for several output modes using a 3/16" (4.8mm) diameter electrode at 1.25" (32mm) electrical stickout. Deposit rates can be varied greatly at equal amperage to best suit the joint need. For a joint that can benefit from increased deposit rate but without increased amperage, an increase of almost 43% (at 800 amperes) can be made by using a 25% balanced square wave mode rather than DC positive. Figure 7 shows that at 800 amperes, a spread of 10.3 lbs. (4.7Kg) is possible. This presents the possibility of a significant deposit rate increase without increasing amperes!

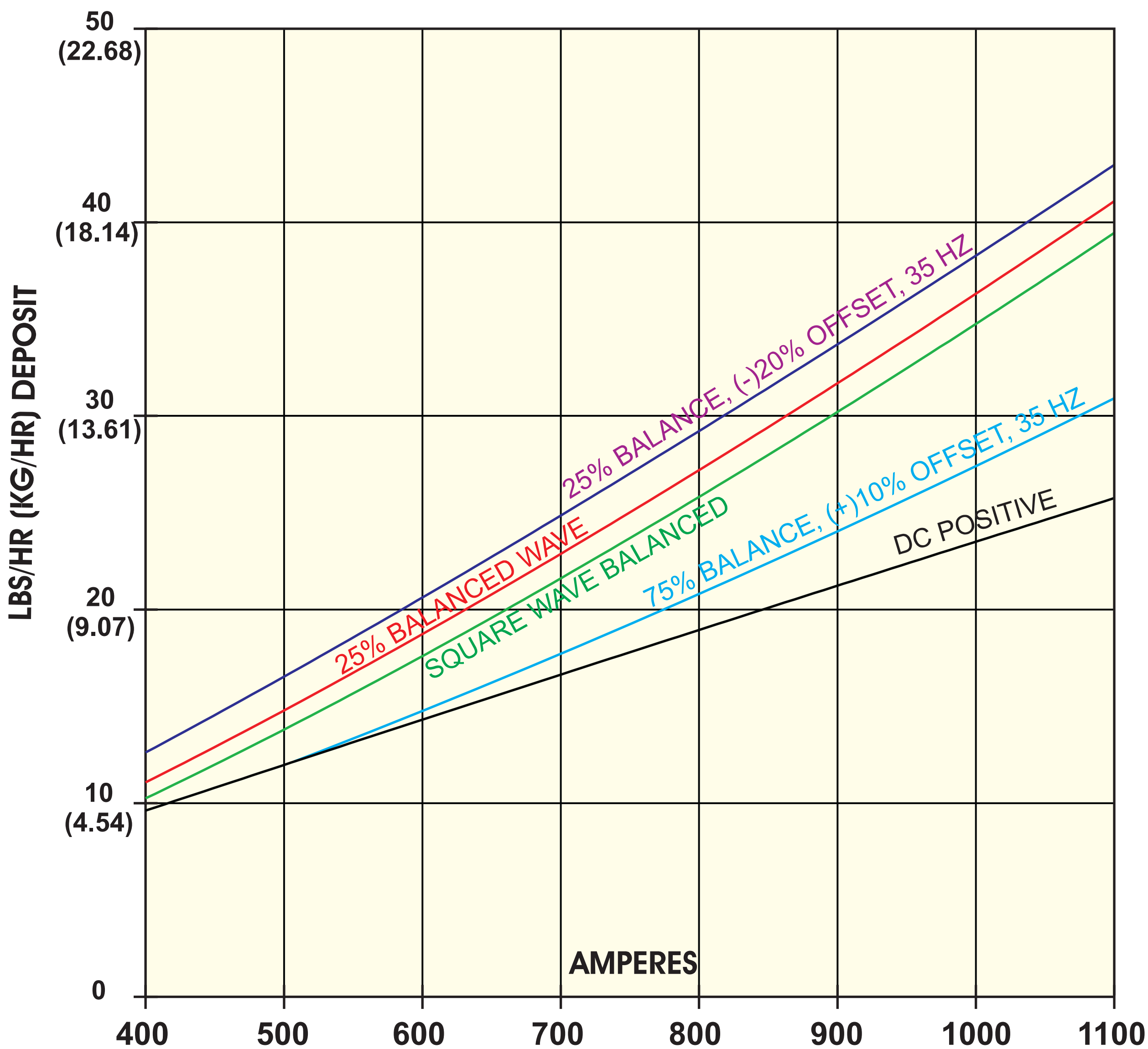


Figure 7

Butt Welds With Single Electrode Submerged Arc

DC positive electrode welding with constant current (variable voltage) has been the method of first choice for many years and with good reason:

1. DC- welding, while offering the potential of increased deposit rates, is more prone to magnetic arc interference (arc blow) which can result in increased internal and external defects.
2. Conventional AC sine wave power has earned a bad reputation for arc starting problems. Another issue has been the single-phase primary power requirement that can create input power line balance problems. There are some notable exceptions where conventional AC is very successfully used.
3. DC+ electrode welding with constant potential (sometimes simply referred to as “CV”) is usually only successful with smaller diameter electrodes and/or small volumetric passes. Large weld pools associated with larger electrodes tend to cause large current excursions that result in excessive arc flashing through the flux. Harsh freeze lines sometimes cause the finished weld surface to be rough.

There are two categories into which butt welds fall. The first category includes butt welds that must comply with a recognized code such as the American Welding Society (AWS), American Society of Mechanical Engineers (ASME), American Bureau of Ships (ABS), etc., or perhaps even a detailed proprietary code. These welds are frequently referred to as “code quality.”

The second category is that the weld must possess a good quality appearance that based upon the weld metal classification will meet the strength of the parent material. These are referred to as commercial quality welds.

Some welding codes restrict the maximum amperage for a single electrode to 600 amperes if both sides of the butt weld are being joined by the weld bead. Some codes either directly or indirectly limit heat input by specifying Kilojoule input limits.

Some codes and some fabricators, require detailed documentation to verify how the weld was made and to provide a permanent record of the welding procedure.

The Power Wave AC/DC 1000™ incorporating Power Wave technology makes it possible to efficiently produce all types and categories of butt welds — and usually with significantly increased productivity.

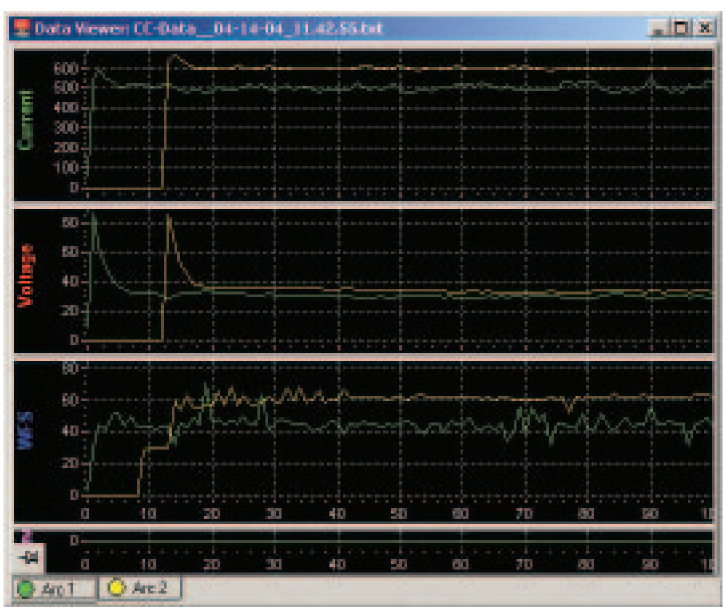


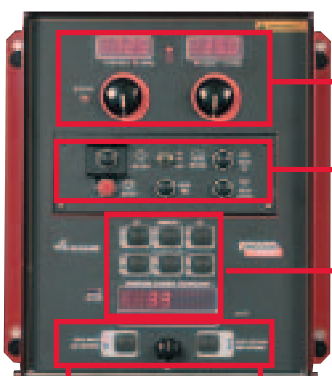
Figure 8
Production Monitoring Screen

Using the Power Wave AC/DC 1000™ For Efficient Butt Welds

The Power Wave AC/DC 1000™ has many features that make it the most effective automatic welding power source available today. Five of these features make it possible to precisely configure the output and monitor the results:

1. All output configurations are made at the PF-10A Control Panel (Figure 9). There is no need to make internal or external connections to the power source. This means there is no lost time waiting for a maintenance electrician or other support people.
2. All output choices may be visually seen on the control panel.
3. Up to six independent welding schedules may be preprogrammed (Figure 9). This can be very helpful on circumferential welds where the diameter and perhaps the joint geometry is changing with each revolution of the work. This is also very helpful where a specific root pass is required prior to succeeding passes.
4. The square wave output results in less time spent transitioning from positive to negative cycle portions. This results in greatly increased arc stability, especially as compared to conventional (sine wave) AC power supplies.
5. The entire welding sequence can be monitored and data recorded in real-time to verify results (Figure 8).

Factor in the 100% duty cycle output rating, the high 87% electrical efficiency, the 95% power factor with evenly balanced line input and it can easily be understood why the Power Wave AC/DC 1000™ is the choice of fabricators who require precise welding results and demand high performance up-time.



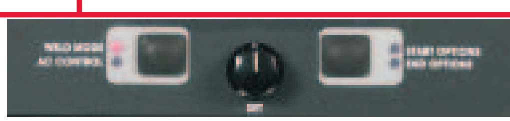
Two **control knobs** can increase or decrease Wire Feed Speed (WFS), Voltage, and Amps. Any of these adjustments can be made "on-the-fly".

The **switch panel** can also be used as a remote pendant. From here, start and stop the weld, inch the electrode wire, activate the flux hopper, and control travel.

Memory panel can store up to six welding procedures.

Limits are set from the memory panel.

On-the-fly procedure changes can be made.



Left Pushbutton:

- Selects **Weld Mode** based on weld procedure and wire diameter
- Sets **AC Control: Balance, DC Offset, Frequency**

Right Pushbutton:

- Sets **Start Options: Strike WFS and Volts, Start WFS, Volts, Time Start Arc Force Upslope Time**
- Sets **End Options: Downslope Time Crater WFS/Amps, Volts, Time, Arc Force Burnback Time**

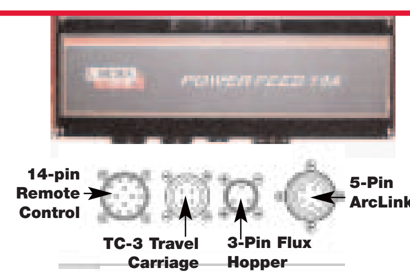


Figure 9 PF10A Controller

Controlled Penetration Butt Welds

Welds of the type shown in the figures below can range from light gauge material to moderately heavy plate. Figures 10, 11, and 12 illustrate welds of this type. Notice the procedure used for each and how a particular Power Wave AC/DC 1000™ setting was able to “tailor” the right characteristics to do the job. The requirement for the 3/16” (4.8 mm) thick weld in Figure 10 is to have a backside bead with equal appearance to the topside bead. The welds in Figure 11 and 12 require minimum surface reinforcement.

5/32” (4.0 mm) dia. Electrode
580 amperes, 30 volts,
AC square wave, 50% balance,
90 Hz., 40 ipm (1.02 m/min) travel

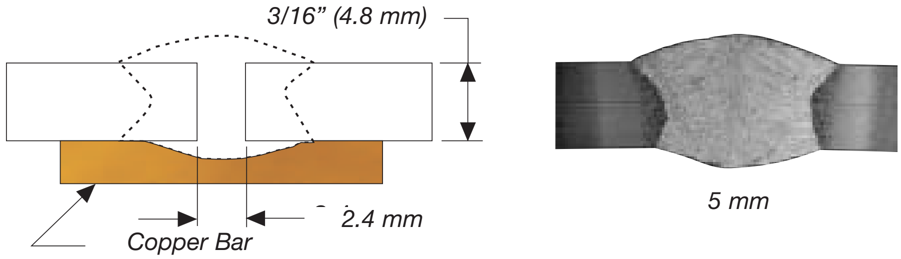


Figure 10
3/16” (4.8 mm) Plate

3/16” (4.8 mm) dia. Electrode
Side 1: AC square wave balanced, +10% offset, 40 Hz
725 amperes, 35 volts, 37 ipm (.94 m/min) travel
Side 2: AC square wave balanced, +10% offset, 40 Hz
775 amperes, 35 volts, 40 ipm (1 m/min) travel

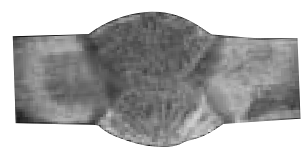


Figure 11
3/8” (9.5 mm) Plate

3/16” (4.8 mm) dia. Electrode
Side 1: AC square wave balanced, +15% offset, 40 Hz
725 amperes, 35 volts, 37 ipm (.94 m/min) travel
Side 2: AC square wave balanced, +10% offset, 40 Hz
850 amperes, 36 volts, 31.5 ipm (1 m/min) travel

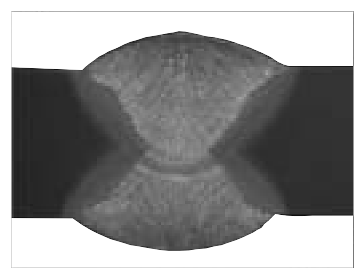


Figure 12
1/2” (12.7 mm) Plate

Heat Input Advantages

Many butt welds are made in materials that are of higher strength or alloyed. When required to comply with welding codes, specific mechanical properties are usually mandated. In many instances, Charpy V-notch requirements and crack-toe open displacement (CTOD) requirements prove to be the most difficult to achieve. The best overall practice is to control heat input (joules/in) during welding. Values in the range of 45 Kilojoules (kJ) to 60kJ generally produce good results providing the welding practice also incorporates small welding beads. (Approximately .16-.25 lbs/ft/pass or .24-.37 Kg/m/pass.) Workmanship is an important factor to obtaining good results, as individual bead placement is important. This frequently results in DC+ procedures at relatively low amperage.

Using the Power Wave AC/DC 1000™ may allow an increase in deposit rate of as much as 40% by selecting an appropriate combination of wave offset, wave balance, and wave frequency. As an added benefit, thick plates or large weldments requiring preheat and interpass temperature control, Power Wave technology use may also result in a significant energy savings.

An AWS BU3c-S joint in .75” (19 mm) thick plate was welded and tested. A drawing of the joint, the welding procedures and the result of testing are shown in figures 13 through 15. Note that the same number of weld passes are used in both welds.

Heat Input Advantages (con't.):

Two sets of plates fit-up as shown in Figure 13 were welded using the procedures indicated below. One plate was welded using DC electrode positive and the other plate was welded using a Power Wave AC/DC 1000™ setting of 30% balanced AC square wave at 40 Hz. Both assemblies required 14 passes to complete. The placement of each weld pass is illustrated in Figure 14. A code quality weld with good low temperature notch toughness is specified.

The individual weld beads were kept the same size throughout both welds.

Both welds are made using 3/16" (4.8mm) electrode with 1.25" (32mm) electrical stickout. Lincoln L-61 electrode with 888 Flux (AWS EM12K - F7A8-EM12 K-H4 classification).

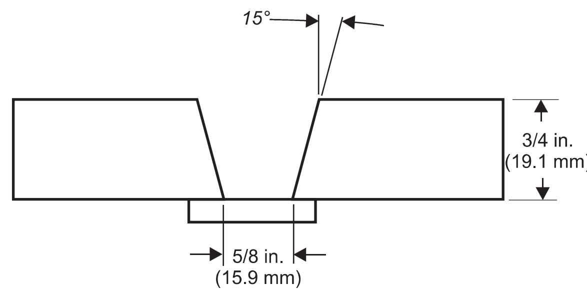


Figure 13

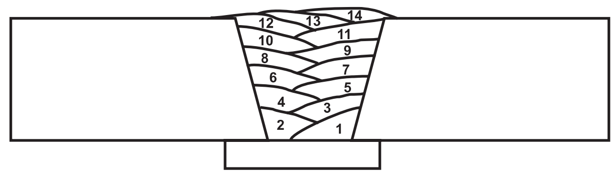


Figure 14

Welding Procedures Used:

Welding Mode	No. Passes	Amps	Volts	Travel ipm/pass	kJ/in (per pass)	Net Travel ipm
DC+	14	600	28	18	56.0	1.29
AC 30% Balance 40 Hz	14	600	32	24	48.0	1.85

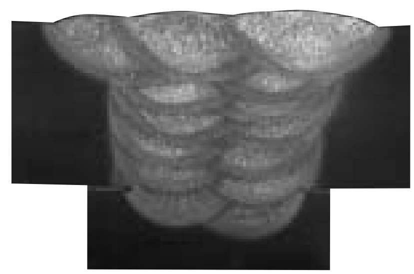


Figure 15 DC Positive

Mechanical Testing Results:

Welding Mode	Tensile KSI	Yield KSI	Elongation 2 Inches	Ave CVN @ -60F*	Ave CVN @ -20F*
DC+	78.1	66.6	30	63	95
AC 30% Balance 40 Hz	82.3	69.7	28	57	100

*tested in accordance with AWS rules

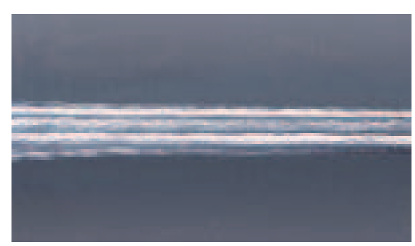


Figure 16 AC 30% Balance, 40 Hz

COMPARISON OF RESULTS AC SQUARE WAVE vs DC+

1. Heat input per pass is decreased by 16.7%.
2. Increase in net travel speed of 43.4%
3. Increase in deposition rate of 40.6%
4. Excellent mechanical properties that are essentially the same

Cost Analysis To Produce This Weld

With a burden charge of $40/Hr and an operating factor of 40%, and the need to produce this weld (similar to an AWS Bu2-S configuration) a comparison between the two procedures is shown in the next table, based on a 2000 man-hour year.

Producing 3/4" (19mm) Thick Plate Bu2C-S Type Welds	
Present weld method: DC +	Net ipm of joint; 1.29 . . . . $15.50/Ft
Power Wave: 30% Balance, 40 Hz	Net ipm of joint; 1.86 . . . . $10.81/Ft
Dollar saving per foot of weld . . . . $ 4.69	
Annual Saving Based on a 2000 Hour Year $34,706.00	

In addition, the Power Wave technology based procedure represents an increase in productive capacity of 43.4%!

An Approach To Converting An Existing Procedure To A Power Wave Procedure

An easy approach to converting an existing procedure to a Power Wave procedure is to use the table below, as a general guide and follow these steps.

1. Start with the existing variable voltage DC positive procedure as the base or reference procedure.
2. Select AC balanced square wave mode and use the reference procedure travel speed, voltage and electrical stickout.
3. Adjust the frequency from 35 to 85 Hz. (Stop if the current begins to drop.)
4. Shift the AC balance to 25%
   - A. Increase voltage 2-3 volts
   - B. Increase travel speed to 1.2 times the reference procedure value.
5. Add 5 to 10% negative (minus) offset.
   - A. Increase voltage an additional 1-2 volts
   - B. Raise travel speed to 1.3 time the reference procedure speed.

% Positive	% Offset	Deposit Rate	Arc Volt Change
100 DC+	NA	1.0	Reference
50	0	1.11	+0
25	0	1.20	+3
25	-10	1.30	+4
0 (DC-)	NA	1.35	+3

This will yield a good starting point for converting a DC positive welding procedure. Note that the ampere setting has not been changed. Fine tuning these steps will yield the maximum increase with equal or improved weld appearance.

Contact Your Local Lincoln Technical Representative — They Will Be Glad To Assist In Reviewing Your Applications For Potential Savings Using The Power Wave AC/DC 1000™

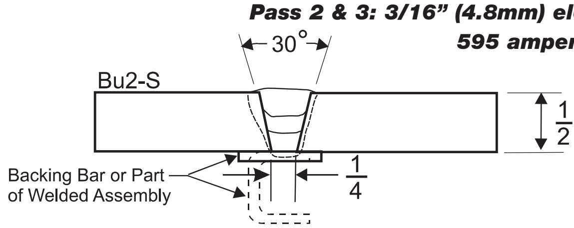
CONTROLLING PENETRATION TO SUIT THE JOB

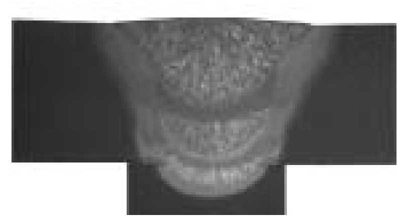
The Power Wave AC/DC 1000™ permits tailoring the arc to most efficiently execute all types of butt welds. The following welds are additional examples of this ability.

Example 1

Groove weld requires penetration (fusion) to backing bar or bottom member of the assembly. Some welding codes restrict the allowable current to a maximum of 600 amperes when both sides of the groove are joined by a single weld pass. The graph in figure-7 suggests that with DC+, deposition rate would be limited to 14.5 lbs/hr. The square wave procedure using offset capability provides the needed penetration at the root and also delivers an average deposition rate of 18.6 lbs/hr. This is a 28.6% increase over a conventional DC + procedure.

1/2" (13 mm) Groove Weld (Similar to AWS Bu2-S)
Root Pass: 3/16" (4.8mm) Electrode,Square Wave Balanced, +10% Offset, 60 Hz,
575 Amps, 28 Volts, 23 ipm (.58M/min) Travel
Pass 2 & 3: 3/16" (4.8mm) electrode, Square Wave 25% Balanced, -10% Offset,
595 amperes, 28 volts, 17 ipm (.43M/min)

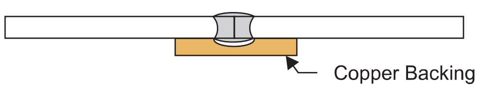


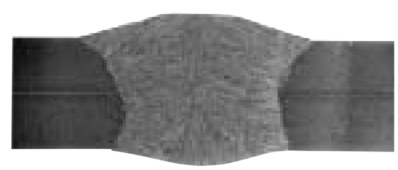


Example 2

Square edged butt welds, welded from one side. Just enough metal needs to be added for a bit of reinforcement. Frequently these thinner joints are welded with copper backing in a seam welding fixture. Arc blow is a common problem resulting in porosity. Conventional sine wave AC, while eliminating the arc blow, usually results in some arc instability issues that affect productivity.

1/4" (6.4 mm) Square-edge butt weld, from one side
Square Wave 50% Balanced, 90 Hz
5/32" (4.0mm) electrode, 680 amperes, 35 volts, 35 ipm (.89M/min)



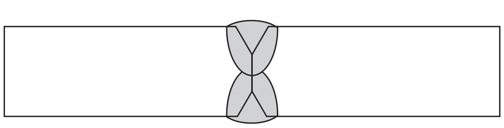


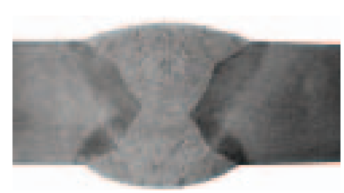
Macro Photo 1/4" (6.4 mm) Square Butt

Example 3

Double-bevel, complete penetration welds (similar to AWS Bu3C-s joints) require a definite amount of fill with considerable penetration. The ability to tailor the output of the Power Wave AC/DC 1000ô makes welding this joint easy with just the amount of required fill and reinforcement.

3/4" (19 mm) Double-bevel butt weld
side-1: Square Wave 25% Balanced, +20% Offset, 60Hz,
3/16" (4.8mm) electrode, 800 amperes, 35 volts, 17 ipm (.43 M/min)
Side-2: Same except 875 amperes, 36 volts





Macro Photo 3/4" (19 mm) Double-Bevel Joint

Making Butt Welds with Power Wave AC/DC 1000™ Technology

Welding Guide

Medium and large diameter fabricated gears being produced at a customer location. Single bevel groove weld, 2" deep, located in a "T-joint". AC Squarewave delivers reduced arc blow for a directed arc at the bottom of the groove. Increased melt off (deposition) compared to DC+ using Balanced and Unbalanced Squarewave AC welding current.

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.

THE WELDING EXPERTS

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