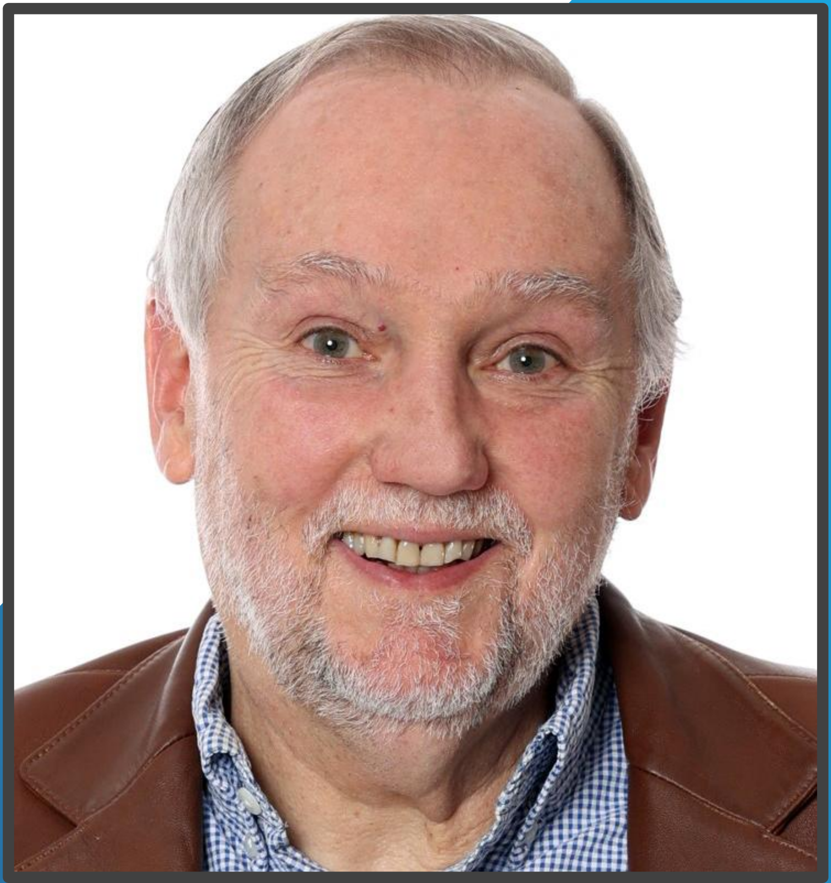
Sustainability Advantages of Alternate Power Supplies for Resistance Spot Welding Steel Sheet



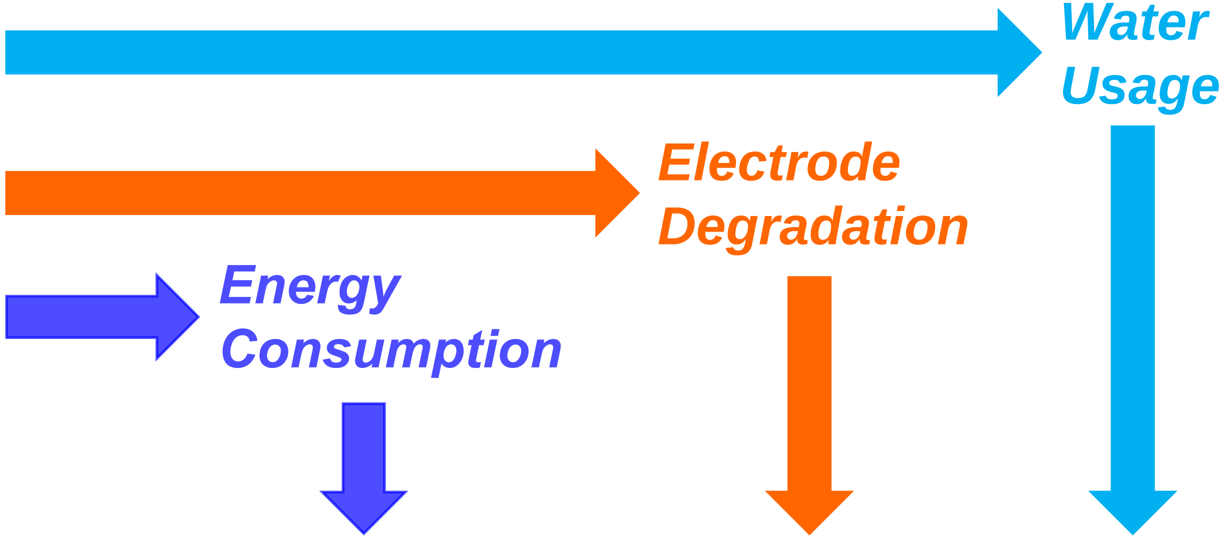
Dr. Jerry E. Gould
Senior Technology Leader
Resistance and Solid-State Welding
EWI

GREAT DESIGNS IN STEEL™

Resistance Welding and Its Relationship to Sustainability

Key Elements of Sustainability

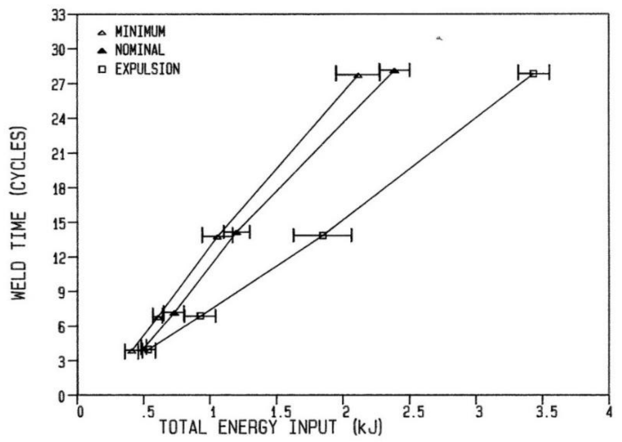
- *Waste and pollution*
- *Resource depletion*
- ***Greenhouse gas emission***
- Deforestation
- Climate change



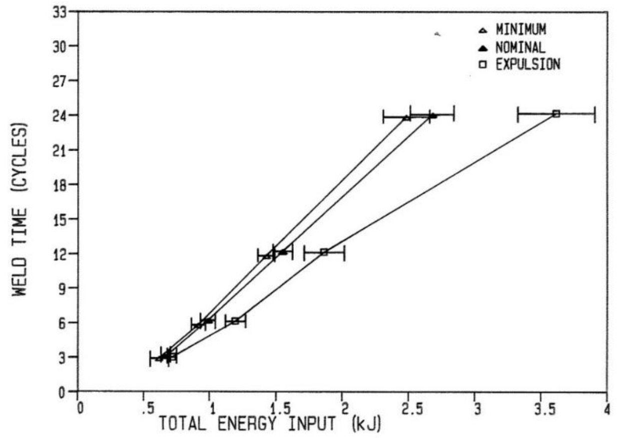
Resistance Welding!

Impact of Welding Time on Thermal Efficiency

- Measurements of energy consumption as a function of weld time
  - Energy data taken from previous work
  - Mild and galvanized steels show similar results
  - Energy for 0.8-mm steel ~3.5 kJ at 400-ms weld time
  - Energy required drops to 500-J at 50-ms
  - ***Energy variations due to heat loss to the electrodes***
- Impact of energy loss to the electrodes
  - Higher energy demands to create necessary sized welds
  - Electrode deterioration leading to consumption of copper
  - Necessary cooling water for both process and electrode stability
- ***Welding time then impacts each of the three characteristics affective sustainability.***
  - Energy consumption
  - Electrode degradation
  - Water usage

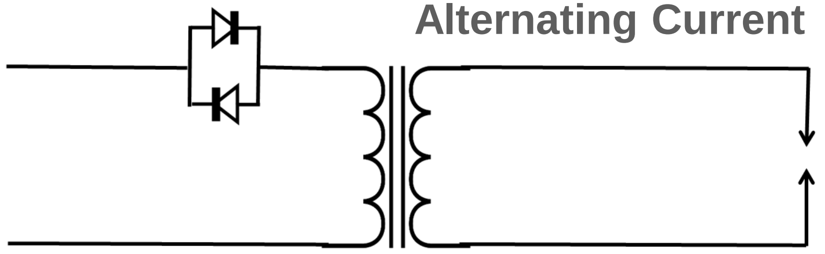


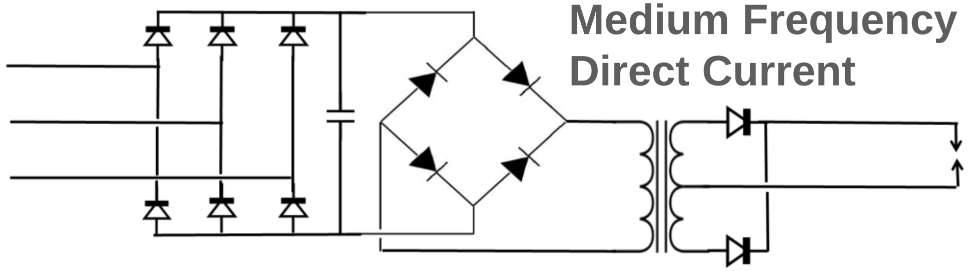
Energy Weldability Lobe for 0.8-mm Bare Steel

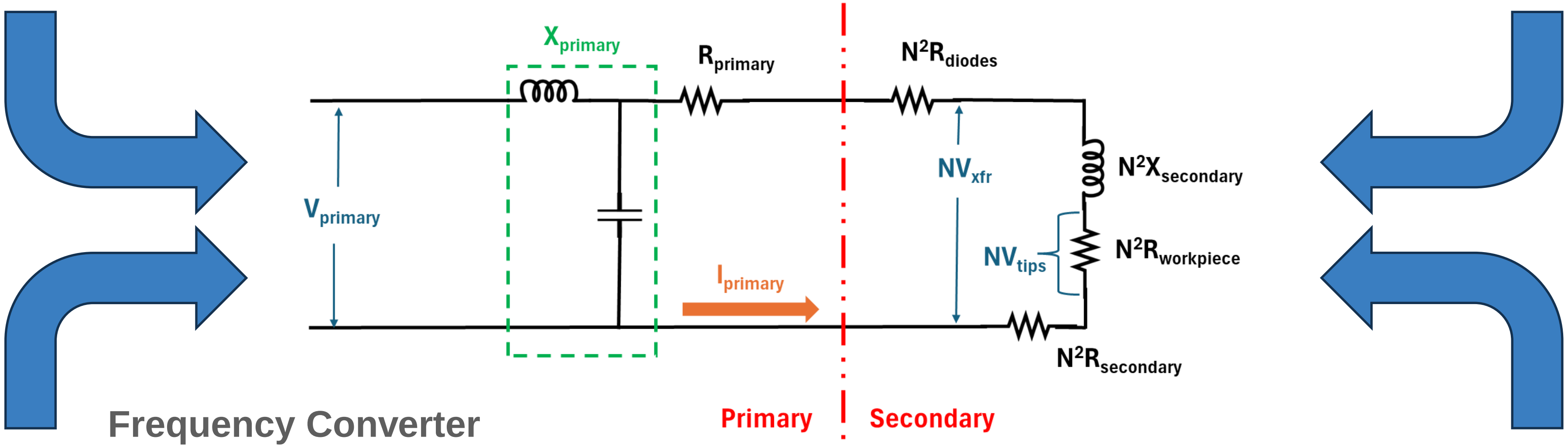


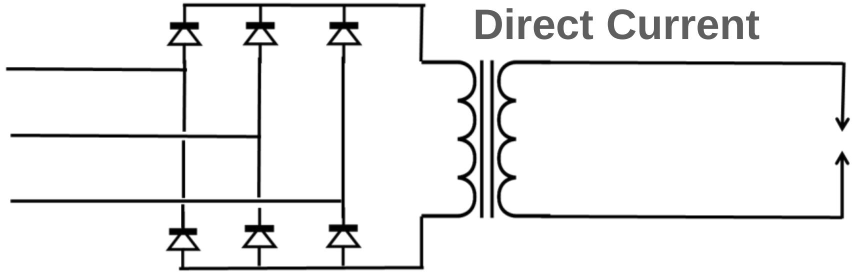
Energy Weldability Lobe for 0.8-mm HDG Steel

Impact of Power Supply Type on Electrical Efficiency







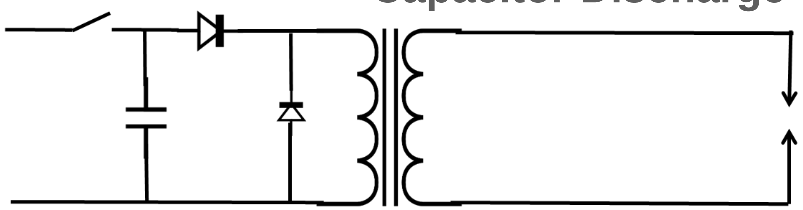


Reflective circuit analyses

Resistive losses

Inductive losses

Dependent on circuit design and power waveform



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Polarity Switching Capacitor Discharge Welding for Resistance Spot Welding

CD welding systems used for spot welding for over 70 years.

Implied high efficiency energy transfer

EWI developed technology (US Patent 10,967,454 B1)

Control based polarity switching

Weld to weld polarity changes

Adaptable to conventional AC transformers

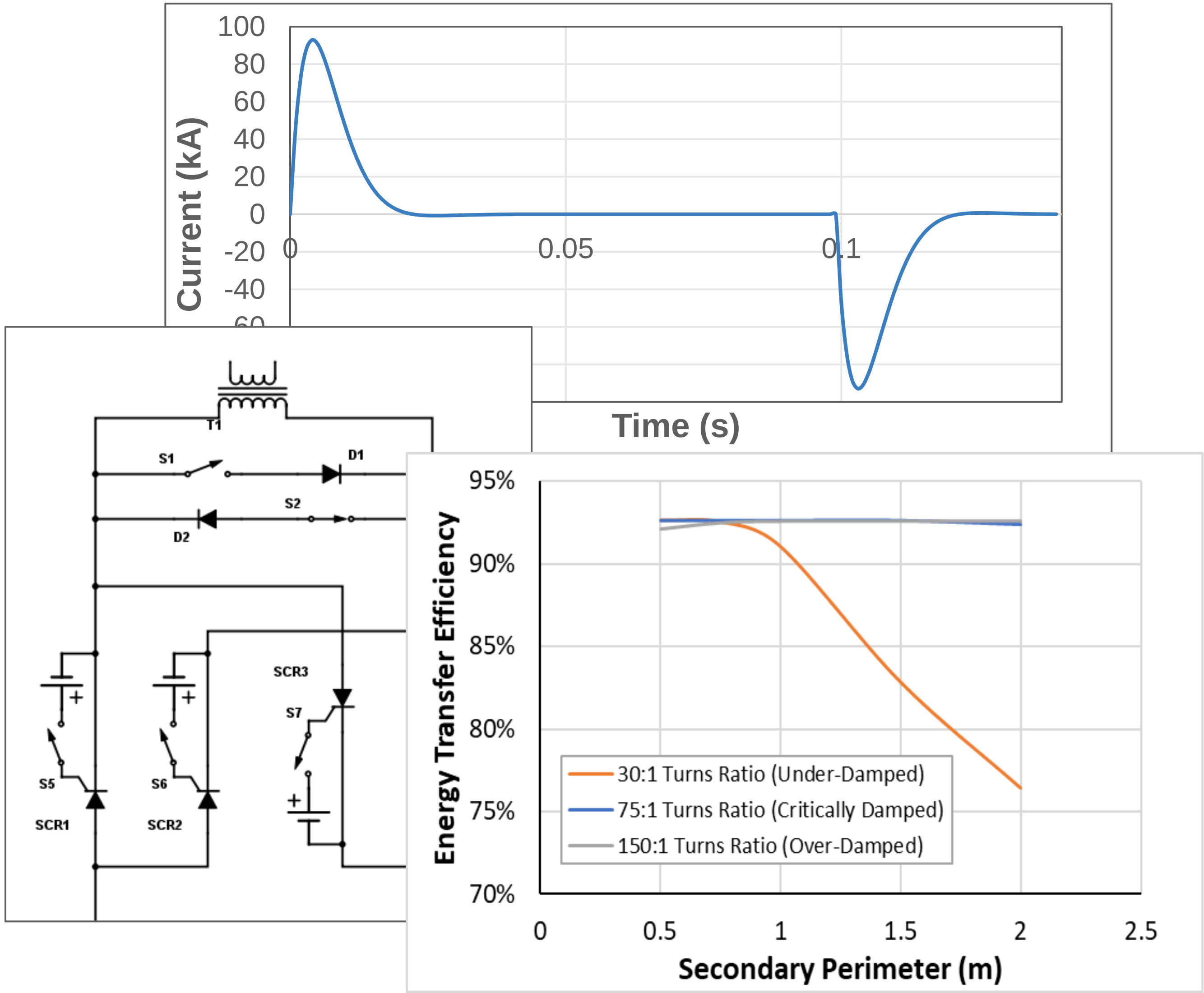
Windings ratio changes for impedance matching

- Changes in waveform profile

Initial focus for welding aluminum

- Implied short cycle times
- Mitigation of Peltier effects

Suitable for spot welding steel sheet



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So Why so Few Capacitor Discharge Welders in Automotive Production?

Advantages

High energy transfer efficiency
Reduced energy costs
Reduced infrastructure requirements
Improved weld quality
Higher joint strengths

- Disadvantages
  - Capacitor charge times
  - Achievable production rates
  - Need for capacitor multiplexing
  - Production experience
  - Vendor support
  - **High capital costs**

The ideal technology will have the pulse current benefits of capacitor discharge welding combined with the price point and infrastructure support of MFDC!

Development of a Medium Frequency – Frequency Converter (MF-FC) System for Spot Welding

Based on variable frequency alternating current concepts

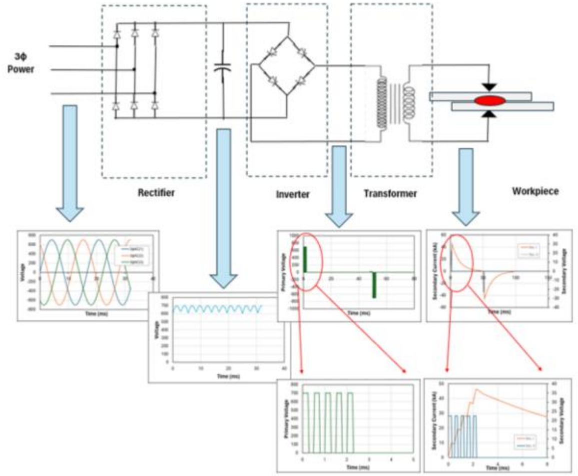
- Core medium frequency technology
- Creation of short pulses to emulate CD welding
- Polarity switching between welds to balance Peltier Effects
- No water cooling in the gun

Key attributes for reducing energy consumption

- Elimination of the secondary diodes reduces system impedance
- Shorter weld times improves thermal efficiency

Scope of the current effort

- Measurements of energy for each system
    - Input to the system
    - Output of the transformer
    - At the workpiece



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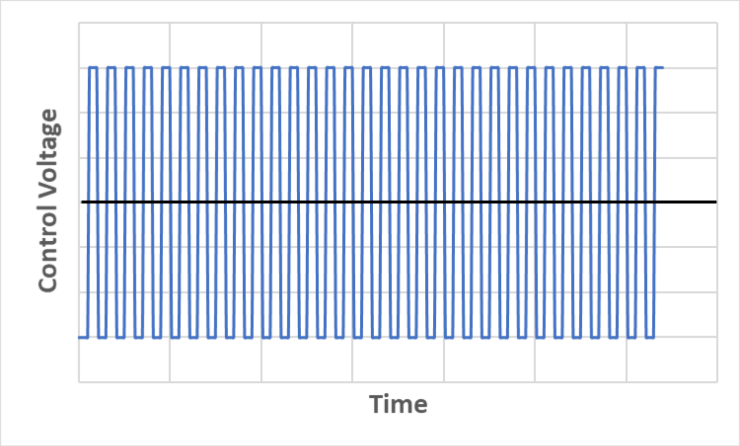
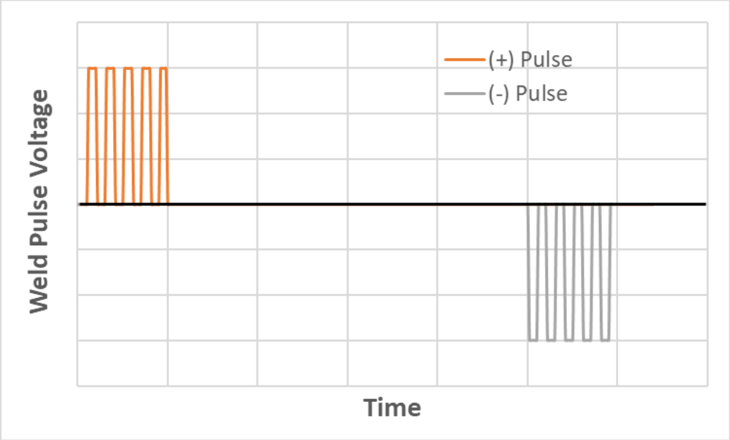
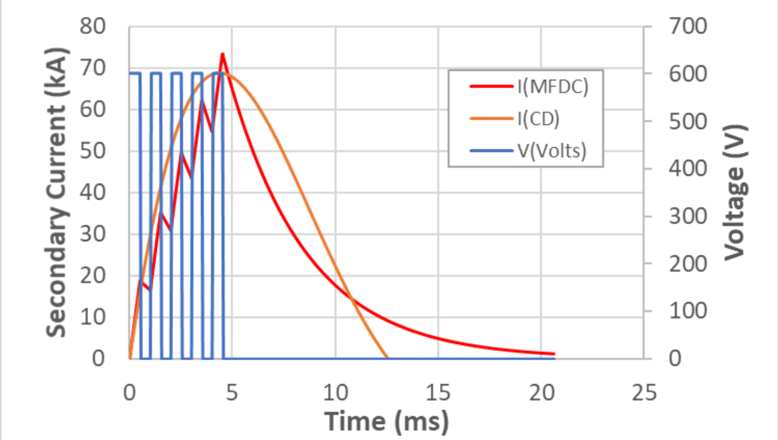
Concept for a Short Pulse Polarity Switching Medium Frequency Based Welding System



1-kHz – 2-kHz Inverter Output



Single Polarity Firing for Welding



CD Comparable Output on Secondary

Base inverter output: 1 – 2-kHz AC
Individual cycles ~500 – 1000 µs
Single polarity firing for a weld pulse
    Total heat times comparable to CD welding
Energy conversion through designed 50 – 100-Hz transformers

- CD comparable secondary current pulses
- Power supply cost comparable to current MFDC welding
- Advantages of polarity switching CD welding

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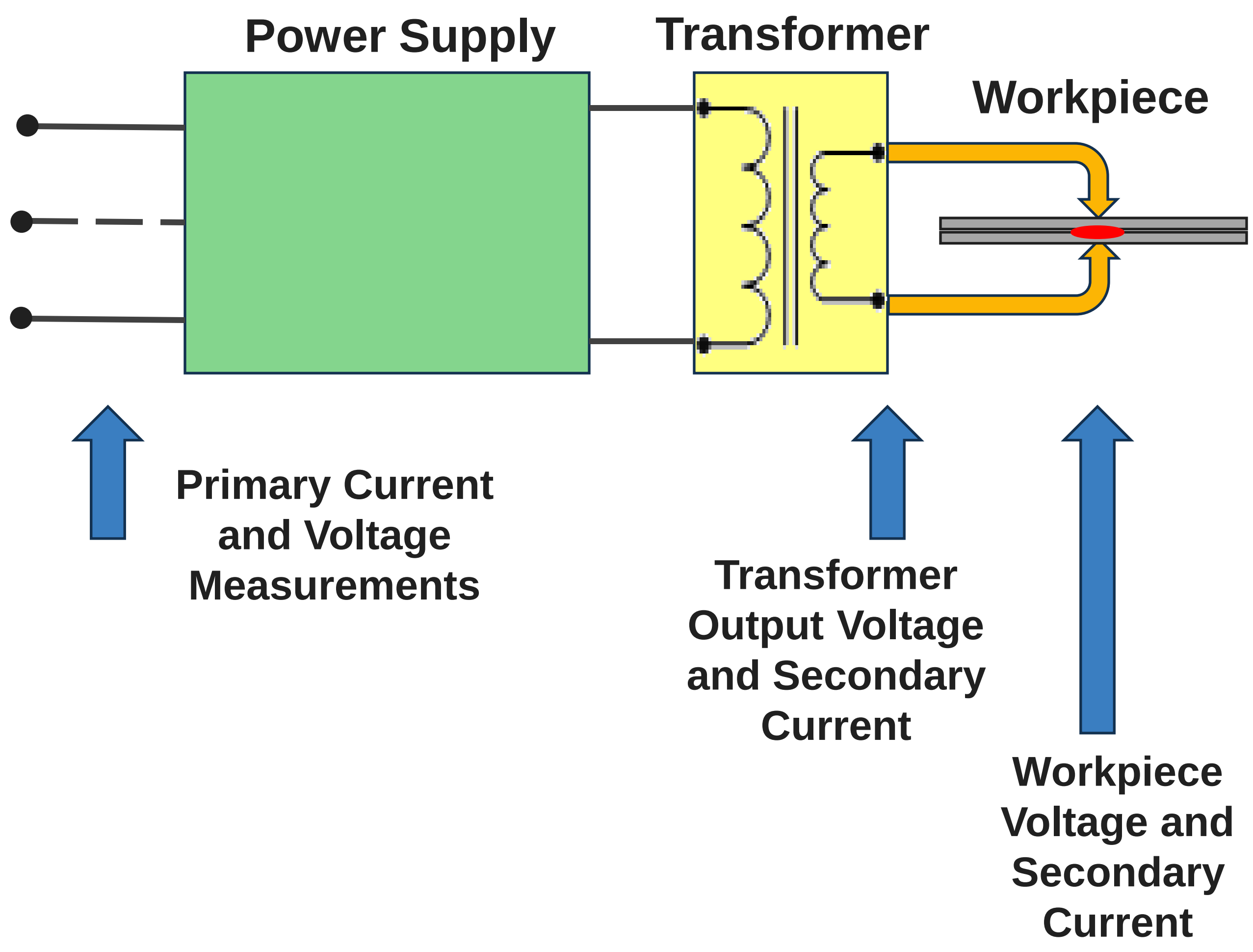
Assessments of Energy Efficiency for Spot Welding Power Supplies – Experimental Procedure

- Three separate power supply configurations
  - Alternating current (AC)
  - Medium frequency direct current (MFDC)
  - Medium frequency – frequency converter (MF-FC)
- Spot welding done on 270-MPa tensile strength, 0.8-mm thick, bare steel
- Spot welding done corresponding to AWS C1.1 recommended practices
- Current range testing to establish practices for each power supply type
- Data collected for energy analysis
  - Primary current from each supply line
  - Primary voltages
  - Voltage at the transformer output
  - Voltage across the tips
  - Secondary welding current
  - Cross sections of representative weld nuggets



Experimental Configuration of Energy Efficiency Assessments

All welding trials conducted on systems available at EWI.
- AC welding – 100-kVA pedestal type machine
- MFDC welding – Pedestal machine with an 800-A inverter
- MF-FC welding – Robotically mounted gun with a 2400-A inverter and high voltage transformer

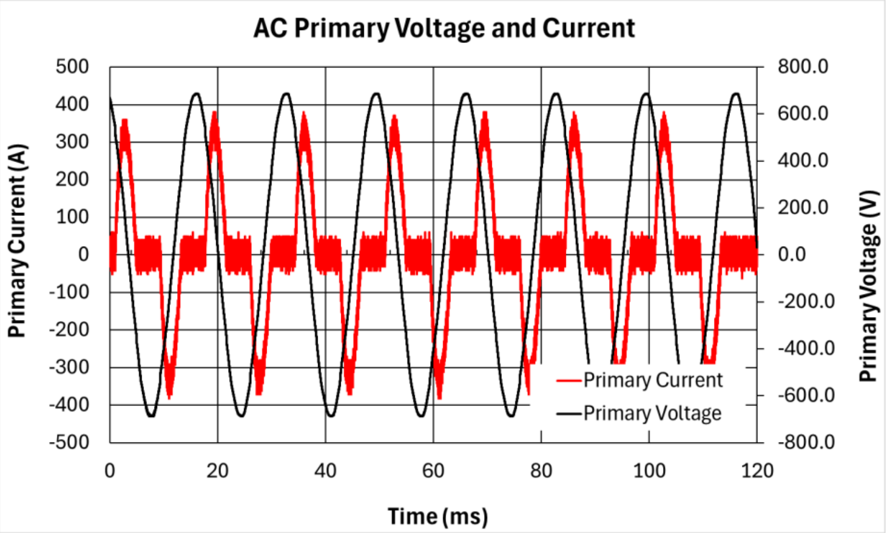
Processing conditions defined through current range testing.

Practices for AC and MFDC consistent with AWS recommended practices.
- Welding times and currents of ~110 ms and 1.8 kN, respectively
- Resulting welding currents 8-kA (AC) and 10.3-kA (MFDC)

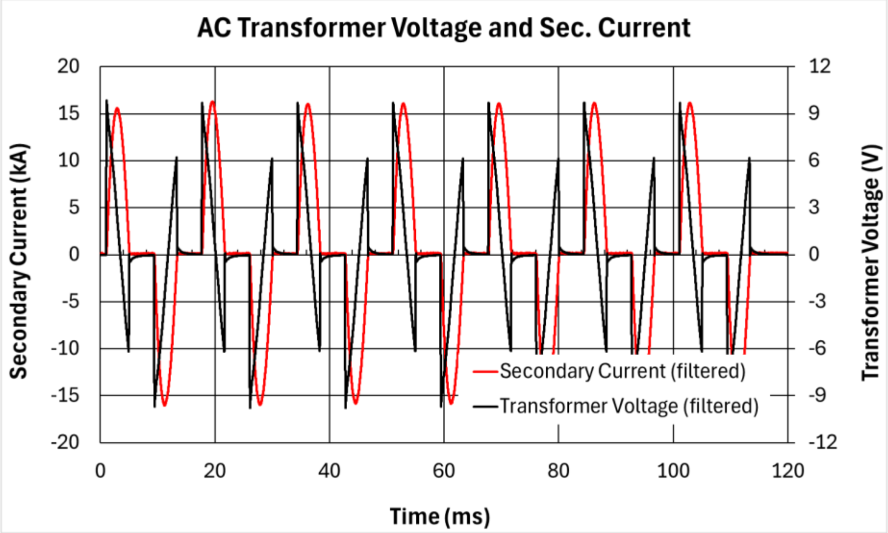
Practices for MF-FC welding based on the reduced current pulse width
- Welding times of 5 ms
- Higher required force (3.1 kN)
- High required secondary current (46 kA)

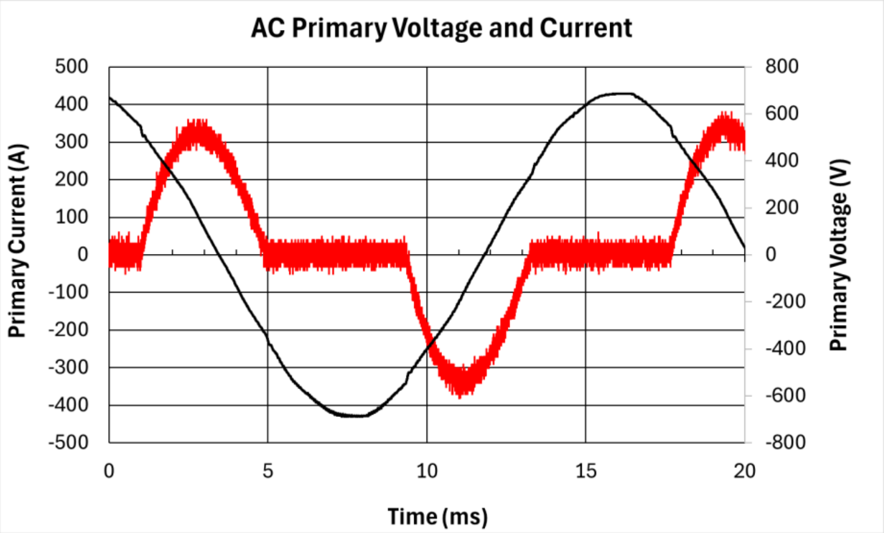
Power Supply Type	Steel Stack-up	Electrode Tip Size (mm)	Welding Force (kN)	Welding Time (ms)	Welding Current (kA)
AC	0.8 mm to 0.8 mm	5	1.8	117	8
MFDC	0.8 mm to 0.8 mm	5	1.8	110	10.3
MFFC	0.8 mm to 0.8 mm	5	3.1	5	46

Energy Measurements for AC Welding the 0.8-mm to 0.8-mm Stack-Up

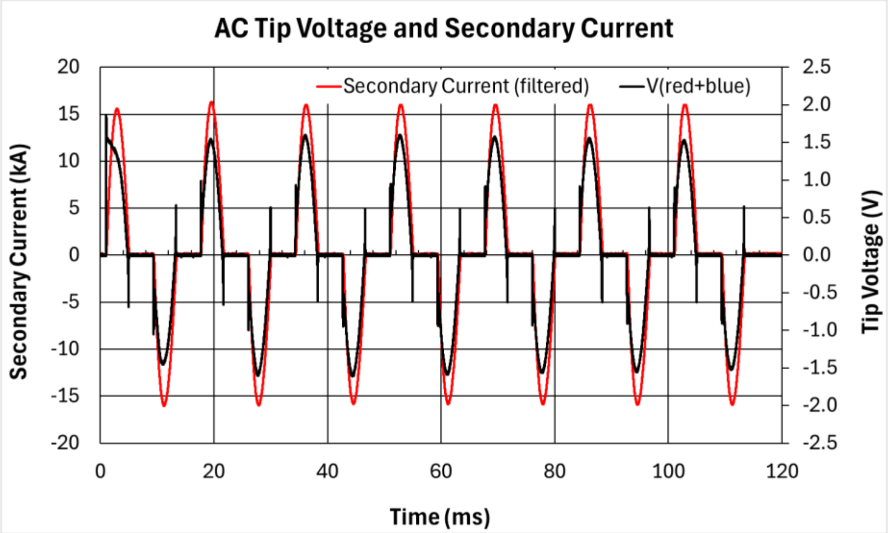


Calculated Energy(J)	
Tip Energy	698
Transformer Energy	1190
Primary Energy	4412





Efficiency Measurements	
Efficiency from Bus to Transformer	27%
Efficiency from Transformer to Tips	58.7%
Fraction Energy at the Tips	15.8%



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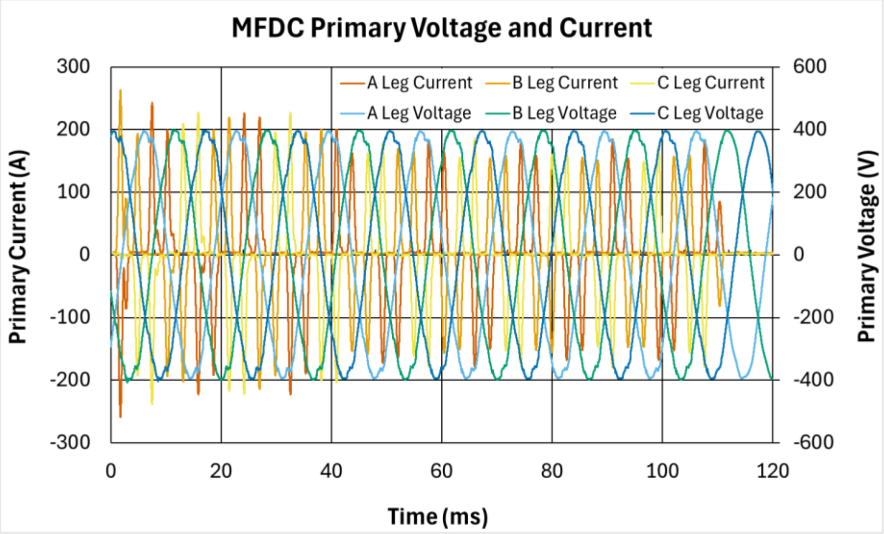
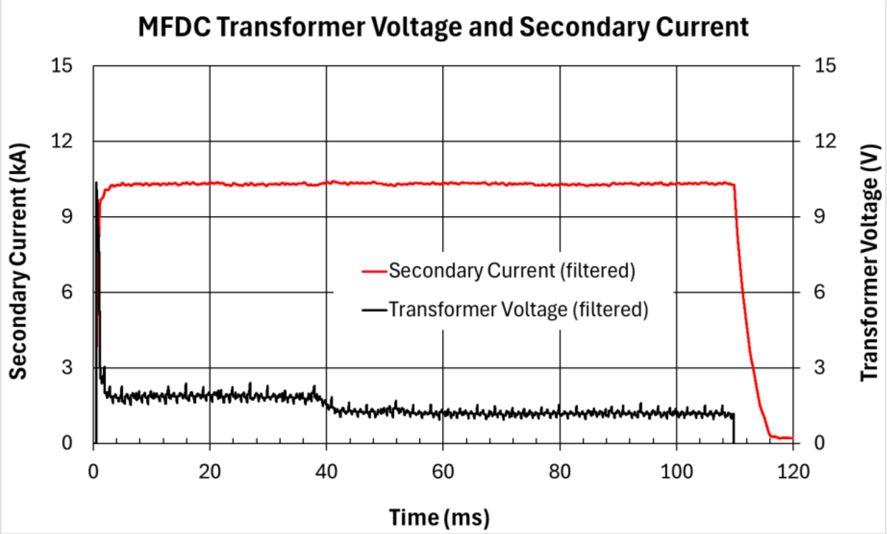
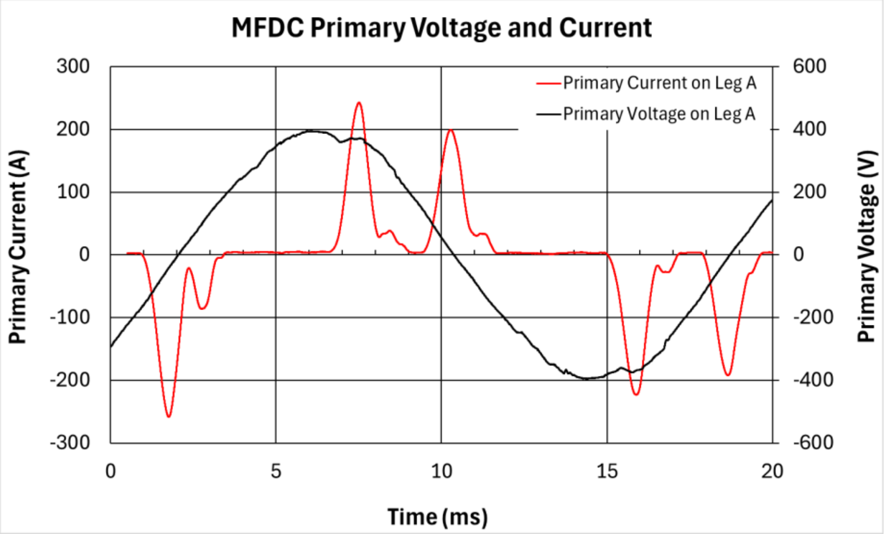
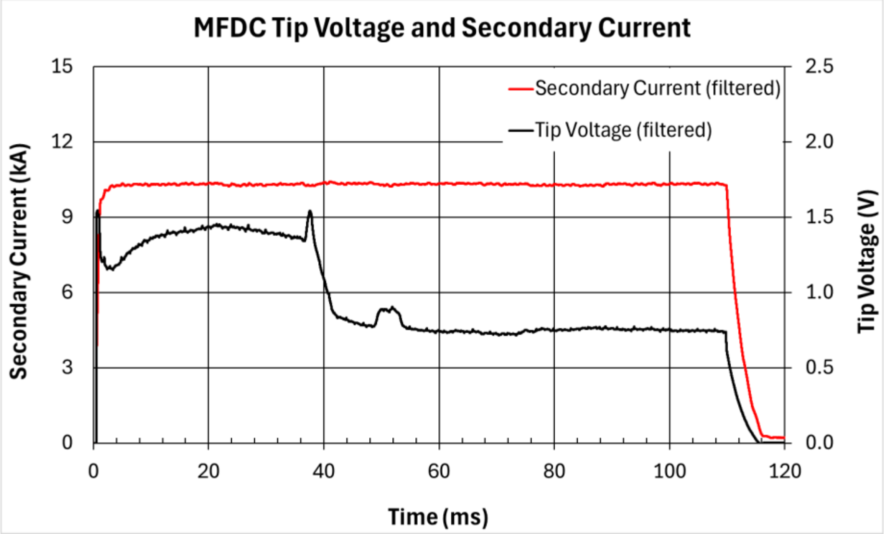
Energy Measurements for MFDC Welding the 0.8-mm to 0.8-mm Stack-Up





Calculated Energy(J)	
Tip Energy	1109
Transformer Energy	1489
Primary Energy	3724





Efficiency Measurements	
Efficiency from Bus to Transformer	40%
Efficiency from Transformer to Tips	74.5%
Fraction Energy at the Tips	29.8%

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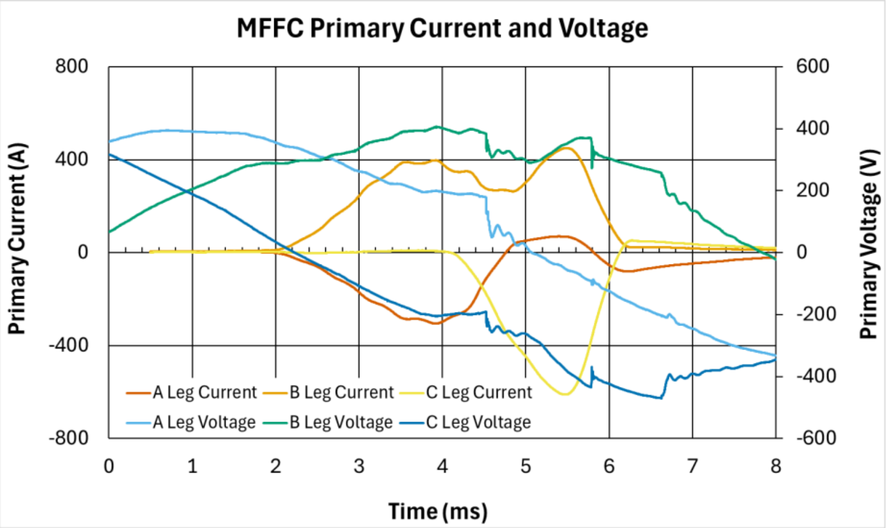
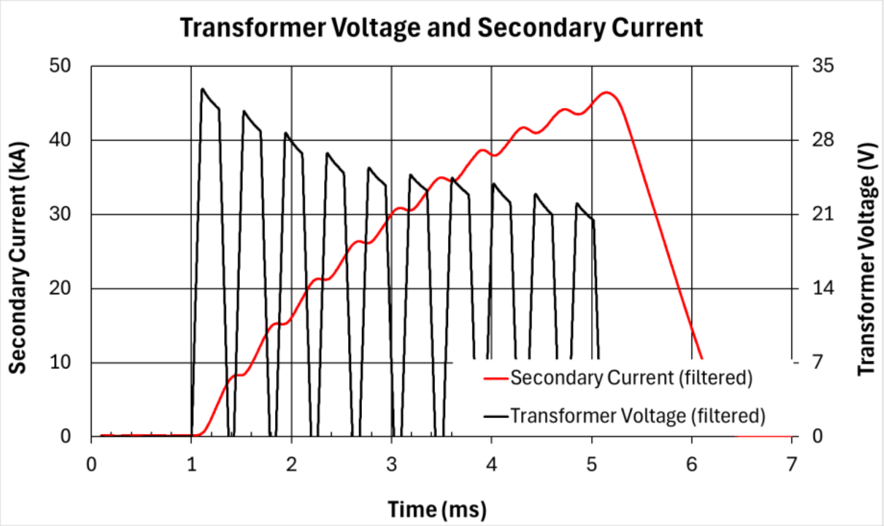
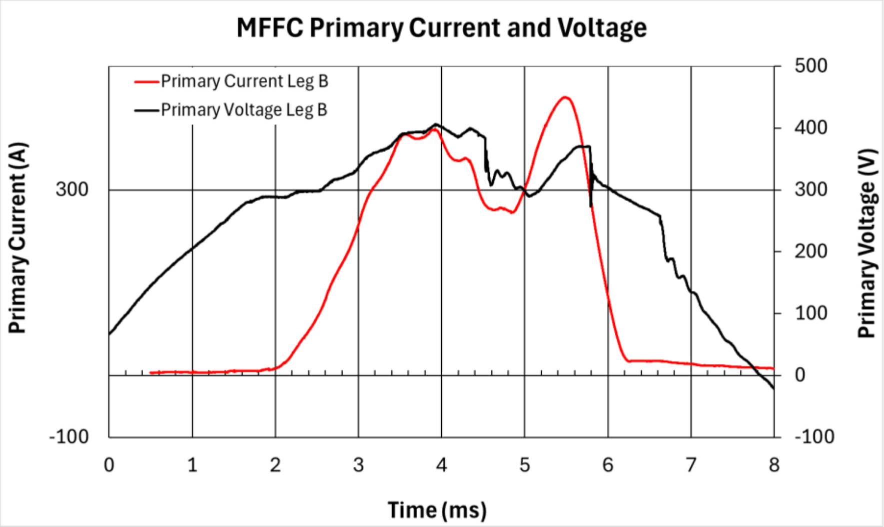
Energy Measurements for MF-FC Welding the 0.8-mm to 0.8-mm Stack-Up

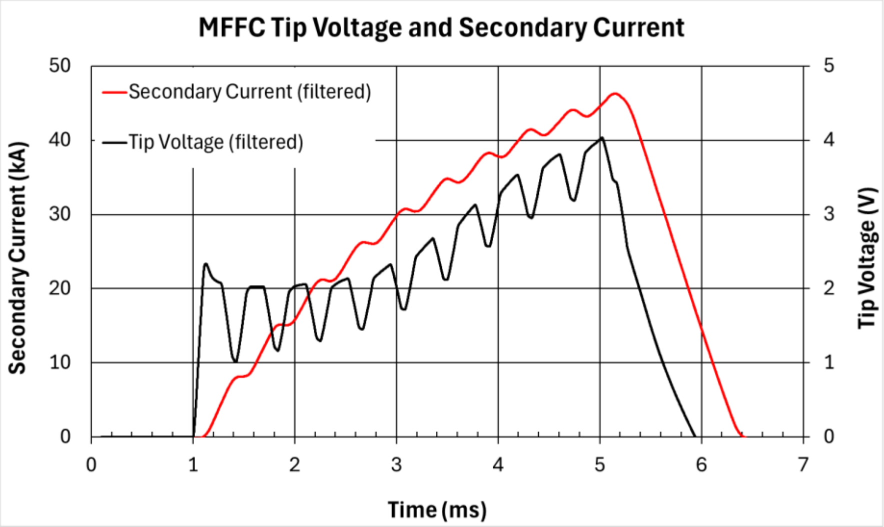




Calculated Energy(J)	
Tip Energy	361
Transformer Energy	515
Primary Energy	654



Efficiency Measurements	
Efficiency from Bus to Transformer	78.4%
Efficiency from Transformer to Tips	70.4%
Fraction Energy at the Tips	55.2%



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Replicate Measurements of Energy Consumption for the Various Power Supply Types

Calculated energy (J) and Energy Losses	MFFC				AC				MFDC			
	13	14	15	AVG	16	17	18	AVG	22	23	24	AVG
Tip Energy	361	363	347	357	698	694	725	706	1109	1163	1161	1144
Transformer Energy	513	518	499	510	1190	1186	1241	1206	1489	1547	1535	1524
Primary Energy	654	649	651	**651**	4412	4405	4584	**4467**	3724	3734	3743	**3734**
Efficency from wall to xfrmr	78.4%	79.8%	76.7%	78.3%	27.0%	26.9%	27.1%	27.0%	40.0%	41.4%	41.0%	40.8%
Efficiency from xfrmr to tip	70.4%	70.1%	69.5%	70.0%	58.7%	58.5%	58.4%	58.5%	74.5%	75.2%	75.6%	75.1%
Efficiency from wall to tip	55.2%	55.9%	53.3%	**54.8%**	15.8%	15.8%	15.8%	**15.8%**	29.8%	31.1%	31.0%	**30.6%**

Welds were created achieve nominal 5√t buttons (~4 mm).

Triplicate tests were done measuring both primary and secondary electrical data.

In all cases, measurements were consistent to within ±3%.

For MF-FC power, energy consumption per spot was:

85% less than for AC spot welding

83% less than for MFDC spot welding

MF-FC spot welding showed nearly **80%** energy efficiency from the wall to the transformer output.

MF-FC efficiency showed **70%** electrical efficiency from the transformer to workpiece.

MF-FC provided an overall electrical efficiency of **55%.**

AC welding showed an overall efficiency of 16%.

MFDC welding showed an overall efficiency of 31%.

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Nugget Cross sections for MFDC and MF-FC Welds

Metallographic sections for assessing theoretical minimum energies for creating spot welds

Care taken to section the welds to reveal maximum diameters

Use of a Keyance microscope for assessing penetrations and cross-sectional areas of the welds

AC welds:

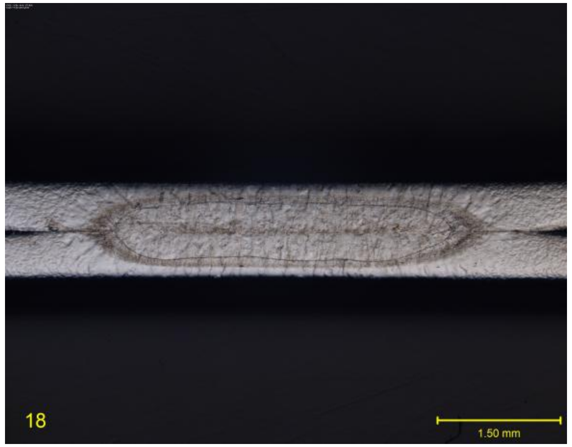
- High penetration weld nugget
- Limited heat affected zone
- Extended ferrite grain growth zone

MFDC welds:

- Similar morphology to the AC welds

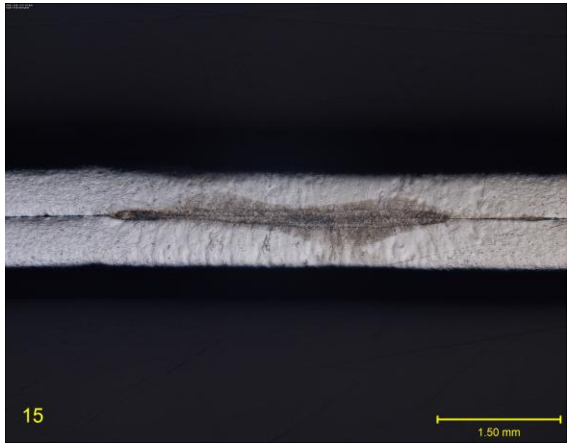
MF-FC welds:

- Low profile weld nuggets
- Similar button diameters to those seen in the AC and MFDC welds
- Restricted heat affected zone



AC Spot Weld on a 0.8-mm to 0.8-mm 270-MPa Steel Stack-up

MFDC Spot Weld on a 0.8-mm to 0.8-mm 270-MPa Steel Stack-up



MF-FC Spot Weld on the 0.8-mm to 0.8-mm 270-MPa Stack-up

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Estimates of Energy Efficiency at Various Locations in the MFDC and MF-FC Welding Systems

Electrical efficiencies calculated as a fraction of buss delivered energy.

Thermal efficiencies calculated as the fraction energy delivered to the tips.

AC showed relatively low efficiencies through the power supply.

MFDC showed the best transformer to tip efficiency due to reduced inductive effects.

MF-FC showed high electrical efficiencies throughout the system.

Low thermal efficiencies reflected heat losses back into the electrodes.

MF-FC showed the best overall thermal efficiency.

Power Supply	Stack-up	Energy Efficiency (%)		
		Buss to Transformer	Transformer to Tips	Overall Electric Efficiency
AC	0.8 mm to 0.8 mm	27%	58.5%	15.8%
MFDC	0.8 mm to 0.8 mm	40.8%	75.1%	30.6%
MF-FC	0.8 mm to 0.8 mm	78.3%	70.0%	54.8%

Sustainability Advantages of Alternate Power Supplies for Resistance Spot Welding Steel Sheet: Summary

Characteristics of MF-FC power supplies

- Outgrowth of capacitor discharge technology
- Inverter based technology
- Short pulse welding cycles
- Polarity switching

Thermal characteristics

- Dramatically improved thermal efficiency
- Reduced thermal losses during welding
- ***Potential elimination of gun cooling water***

Electrical characteristics

- Lower system impedances due to the elimination of secondary diodes
- Impact on overall electrical efficiency affected by secondary gun loop size
- ***Total energy demands reduced by 80 - 85%***

Comparisons of MF-FC to AC and MFDC power supplies

- Reduction in required energy per spot by 80% - 85%
- Increased thermal efficiency of 30% - 100%

Manufacturing benefits

- Balanced line loading
- Reduction in water consumption
- Potential improvements in electrode life (Reduction in raw materials (copper) consumption)

MF-FC contribution to sustainability goals:

- ***Reduced energy consumption***
- ***Reduced water usage***
- ***Reduced raw materials demands***

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Questions?

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