

Digital Servo Wire Splicer

US-3020WS2

U.S. Patent Pending

*The World's First Servo
Ultrasonic Wire Splicer*



Dynamic Force and Amplitude Control™ with Multi-Step Welding

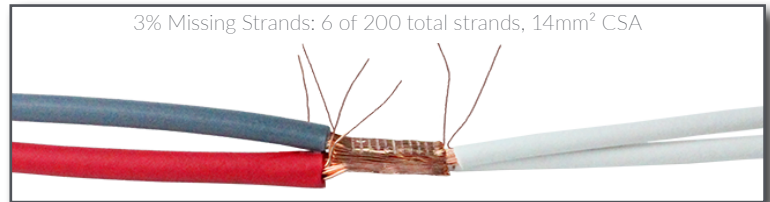
- Ability to adjust force and amplitude during the weld cycle to optimize parameters for each specific wire application
- Capability of over 20 weld steps with unique force and amplitude parameters while energy and frequency remain constant

Industry Leading Missing Strand Detection Under 3% CSA

- Can detect single missing strands from 0.13mm² wires
- Detects partially retracted wires, missing wires, and added insulation within 3% of total cross section area

Specifications

- Frequency** 20 kHz nominal
- Ultrasonic Power Output** 3.0 kW max Power Supply 220-240 VAC single phase; 20 Amp max; Nema 6-20r outlet
- Pneumatic Pressure** 5 bars / 72.5 psi; Air Filter built-in; requires 6mm OD Hose
- Weld Force** ~1,200 Newton maximum
- Weldhead** 23 kg / 20.3 x 50.8 x 18.5 cm
50 lb / 8 x 20 x 7.3 inches
- Controller Cabinet** 33 kg / 50.8 x 70 x 22.9 cm
71 lb / 20 x 24 x 9 inches
- Visual Display** 17 inch LCD display and mouse
- Additional Options** Wire Cutter
Barcode Scanner



Welding Capabilities

- Cross Section Area** 0.26mm² - 42mm²
- Heavy Duty Upgrade** 0.26mm² - 60mm²
- Wire Type** Copper (Cu)
Aluminum (Al)
Enamel Coated
Magnet

Load Cell Force Feedback

- Single micron resolution
- Consistent measurement and ultrasonic output produce high cPk values
- Measurement of pre-weld and post-weld height and width
- Cross section area measurement and calculation for additional quality control

Network Compatible

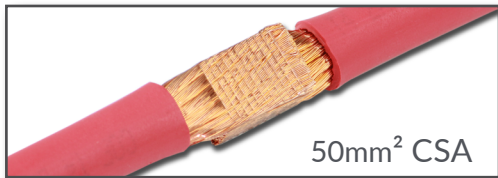
- Logs weld height, weld energy, & weld time
- Saves last 20,000 welds; export via USB or TCP/IP

TECH-SONIC

ULTRASONIC METAL WELDING

Proven Solution in the Automotive Wire Harness Industry

TECH-SONIC has been providing industry support on a Multi-National level for over two decades



Weld Program Settings

Program: (555)

Section	Welding	Taught	Tolerances	Tooling	Customer
Force [N]	Duration [mSec]	Amp [µm]			
300	100	0.0			
700	200	20.0			
800	300	23.0			
200	700	21.0			
300	100	0.0			

Weld Mode: Energy

Weld Energy: 900 J

Weld Width: 3.79 mm

H/W Ratio: 60 %

Buttons: Add, Edit, Delete, Back, Save, Teach

Multi-Step Welding: this teach screen displays the ability to utilize multi-step welding with variable force and amplitude control. The first-step is a compression stage without ultrasonic energy, followed by the changing of parameters over the next three steps, and a final compression stage to measure height.

TECH-SONIC offers comprehensive multi-national support and service!

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YouTube

[US-3020WS2 Servo Wire Splicer Demo](#)

[US-3020WS2 Missing Strand Detection Demo](#)

[US-3020WS2 0.39mm² Missing Strand Detection](#)

[US-3020WS2 50mm² Splice Capability](#)

Vzaar (International Safe Link)

[US-3020WS2 Servo Wire Splicer Demo](#)

[US-3020WS2 Missing Strand Detection Demo](#)

[US-3020WS2 0.39mm² Missing Strand Detection](#)

[US-3020WS2 50mm² Splice Capability](#)

TECH-SONIC Introduces World's First Digital Servo Ultrasonic Wire Splicer

The new line of TECH-SONIC digital servo ultrasonic metal welders combines the precision of servo control with the proven strength of ultrasonic welding to produce the most significant advance in ultrasonic welding technology in the last 20 years. Ultrasonic metal welding technology uses a welding horn to direct high frequency ultrasonic vibratory energy to the material surfaces between the metals being welded. The vibratory energy disperses the contamination and oxidation from the work pieces, creating a strong metallurgical bond. No materials are melted, no flux or fillers are introduced, and no substrate degradation occurs, making the welding process not only very strong, but also energy efficient and environmentally friendly.

TECH-SONIC's patent-pending digital servo ultrasonic wire splicer, model US-3020WS2, one in a new line of TECH-SONIC digital servo metal welders, goes far beyond conventional pneumatic ultrasonic wire splicers to combine an ultrasonic power generator and embedded high-speed digital microprocessor control with a servo-controlled weld head utilizing force feedback sensors for precise control. This unique combination provides a stress-free weld joint with CPK values which were previously impossible using conventional, pneumatic wire splicers. Its unique capabilities are also revolutionizing the wire splicing industry with its small wire splicing capability and industry leading missing strand detection.

Using ultra-high-speed digital control based on load cell and motion sensors, the US-3020WS2 provides Dynamic Force and Amplitude Control™ with multi-step welding through real-time force monitoring during welding to adjust both the ultrasonic amplitude and the applied force. This produces optimum welding conditions by adjusting both power and force so it can weld wires of many different sizes to provide better quality welds while improving yields, all without the need to change tooling.

Employing force feedback via precise servo control, the US-3020WS2 can also detect missing strands more accurately and consistently than a pneumatic wire splicer, below 3% of the total cross section (Figure 2). A typical pneumatic wire splicer can only detect missing strands if they are greater than 5% of the total cross section of wires. Many automobile manufacturers require the wire harness producers to detect less than 3% of missing strands, and have determined that the limitations of the pneumatic process prevent them from providing consistently acceptable part quality.

The US-3020WS2 also provides precise, reliable, and repeatable splicing for many wires ranging from combinations 0.26mm² to 38mm² without need for tooling change. Conventional pneumatic wire splicers require the application of higher pressure and ultrasonic power (typically exceeding 3 kW) to overcome energy losses and expand their splicing capabilities beyond this approximate range. They also cause additional stress on the tooling by using excessive force, diminishing the life of the horn and anvils, and often resulting in wire breakage due to excess stress on strands. However, by utilizing servo welders with Dynamic Force and Amplitude Control™, TECH-SONIC has simply expanded the size of tooling to accommodate wire combinations up to 60mm² without having to increase power or force. The application of ideal welding parameters preserves the integrity of the wires and prevents over welding. In many cases, the US-3020WS2 tooling can last over one million cycles due to the precise application of pressure and energy.

The US-3020WS2 also provides ample storage for user-defined wire splicing combinations, each having its own set of weld parameters, available by screen selection or barcode scanner input. It is based on the reliable Windows CE operating system and includes a TCP/IP interface for transfer of production information to a host system, where it can be saved and analyzed.

Advantages of Digital Servo-Controlled Ultrasonic Metal Welders to Traditional Pneumatic Ultrasonic Welders

Overview

Ultrasonic metal welding is one of many processes used for bonding metals including resistance welding, soldering, and laser welding. Although ultrasonic metal welding can be utilized to join many different materials, it is best suited for the welding of nonferrous metals. Ultrasonic metal welding technology is prominent in key manufacturing sectors such as electric vehicles, lithium batteries, automotive wire harness, solar cells, power electronics, and many others. Weld applications in these industries could benefit considerably from innovative servo-controlled ultrasonic welding technology, which offers much greater precision during welding than the pneumatic driven systems.

TECH-SONIC's innovative servo controlled ultrasonic metal welder, patent pending, is the first and only one of its kind on the market today. TECH-SONIC has pioneered the development of servo controlled ultrasonic metal welders to meet market expectations for critical applications that require extreme precision and quality control. TECH-SONIC's servo-controlled ultrasonic metal welders provide more consistent and repeatable welding than current pneumatic welding systems and boast the ability to set extremely tight quality windows for monitoring important weld parameters such as energy, time, weld height, weld width, and weld force. TECH-SONIC has engineered novel ultrasonic, servo, and load cell feedback processes that provide ultimate digital control throughout the welding process.

Additionally, TECH-SONIC's servo welders include user friendly ergonomic features, advanced graphical user interface, more accurate process control capabilities, and advanced quality control monitoring capabilities compared with pneumatic welders. Due to the enhanced features, servo driven precision control, and innovative feedback processes, TECH-SONIC's new servo ultrasonic metal welders are well positioned to satisfy the growing demand for smarter ultrasonic metal welding technologies.

Ultrasonic Metal Welding Design and Process

Ultrasonic welding has been widely used in joining plastics for many years and is therefore a well characterized process. Conversely, ultrasonic metal welding has not been as widely adopted and hence, is not as largely understood in the industry. With the growing need for welding nonferrous metals such as copper, aluminum, nickel, and others, ultrasonic metal welding has been recognized for its unique capability by the industry.

Ultrasonic metal welders are compact, easy to incorporate into automation, and economical. They produce high quality welds with short cycle times. Ultrasonic metal welder's hardware consists of an ultrasonic generator, a transducer, a booster, and a welding horn. The process of ultrasonic metal welding depends on controlling the transfer of ultrasonic energy into the weld and two welding parameters that must be controlled to achieve a good result: power (amplitude) and force (pressure).

The power is precisely controlled by the generator and determines the horn's vibration amplitude. The force applied to the weld determines how well the power is transferred into the weld. The generator converts standard line power into a high-frequency, high-voltage sine wave, which is sent to the transducer. The transducer converts the electrical energy into a high frequency compression wave, which is then modified by the booster and passed through the horn into the part(s) to be welded.

The horn has a knurled or waved surface to grip the parts to be welded. In combination with the horn, there is a stationary anvil. The material to be welded is positioned between the horn and anvil while the force presses the horn into the materials. The ultrasonic motion of the horn and the friction coefficient of the material causes a

scrubbing action between the various members to be welded. This friction softens the materials under contact. There is a metallurgical diffusion between the parts being welded and a bond is formed. There is no melting of the materials. The welding occurs in a solid state which allows welding of different nonferrous metals.

Advancement of Servo Technology

In the early 1980s, ultrasonic plastic welding showed a significant effect on the weld strength when optimum welding forces were applied. Research has suggested that dynamic force can produce greater weld strength when properly applied for both plastic and metal welding purposes. Force profiling, or adjusting the weld pressure during the weld cycle, has been shown to maximize weld strength while simultaneously decreasing weld cycle time. The development and implementation of servo-controlled ultrasonic metal welding technology is an important step in precisely controlling all welding parameters and providing superior digital process control, the greatest advantage of servo-controlled ultrasonic metal welders.

Force (pressure) in pneumatic ultrasonic metal welders cannot be controlled with the precision and speed achieved by servo force control, which causes excessive deviation in terms of welding quality. With servo-controlled ultrasonic metal welders, the force (pressure) is measured, monitored, and controlled by using a combination of servo motor and load cell feedback. Multi-step welding, where force is applied before the weld energy is introduced in a compression stage, before automatically moving into the welding stage makes it capable of Dynamic Force Control™. Ultrasonic amplitude (power) can also be varied during the weld process, providing additional energy according to the parameters. Servo control also provides for rapid part placement and withdrawal, resulting in shorter cycle times than conventional pneumatic ultrasonic metal welding can achieve.

Advantages of Servo Technology

While the greatest advantage of servo-controlled ultrasonic metal welding is Dynamic Force Control™ and the ability to precisely control all welding parameters throughout the weld process with multi-step welding, there are several other advantages which cannot be achieved using traditional pneumatic ultrasonic welders.

One such advantage is the increased life cycle of the replaceable tooling parts. Whereas pneumatic ultrasonic welders will often introduce more force and power than needed, thus overworking the tooling, servo-controlled ultrasonic welders only introduce as much force and power that is needed for each weld. This leads to much longer tooling life cycles as the horn and anvil are not transferring more energy than needed. They also boast the ability to weld wider ranges of material sizes, which is crucial in eliminating downtime in a production setting and allows the user to quickly change back and forth between wire sizes.

Being 100% digital, servo-controlled ultrasonic welders also simplify the calibration process by removing pneumatic components. Validating the ultrasonic metal welding process becomes easier and more reliable than ever through the automatic process which requires no manual adjustment. The removal of pneumatic components also saves money that would normally be spent on compressed air.

Additionally, servo-controlled ultrasonic metal welders have a feature with the capability to change the way several industries set their production standards: missing strand and missing leaf detection.

Missing Strand/Foil Detection

TECH-SONIC's servo-controlled ultrasonic metal welders have one micron resolution of linear encoder built into the servo. Due to height measurement compensated by the force measurement, the precise servo control using force feedback provides an improved capability to detect missing wire strands and copper foils. The new US-3020WS2 ultrasonic wire splicer and US-3020SRT ring termination machine can detect single missing wire strands, even on wires with cross sections as small as 0.13mm², and below three percent (3%) of the total weld cross section.

Conversely, pneumatic ultrasonic wire splicers and ring termination machines can only detect missing strands if they are greater than five percent (5%) of the total cross section.

Currently, many automobile manufacturers require wire harness producers to detect missing strands within three percent (3%) of the total cross section. The importance of this lies in the fact that during the stripping of wire insulation, strands will sometimes be cut unintentionally by the stripping machines without the user's awareness. Fewer strands in the wire lowers the conductivity of the wire, which at a certain point can become problematic for automobile manufacturers. The ability to detect below three percent (3%) of the total cross section of wires will give automobile manufacturers increased confidence in their electrical wiring and their overall production process.

Additionally, the new US-3020S servo-controlled spot welder, using the same force feedback, has the capability to detect single missing copper or aluminum foils which are base materials as anode and cathode in lithium battery designs. With individual thicknesses of ten microns, the US-3020S has been tested to detect one missing or one additional foil in a stack of sixty (60). Typical pneumatic welders do not have this missing foil technology, so the introduction of the servo technology can improve confidence in the production process for battery manufacturers.

TECH-SONIC servo-controlled ultrasonic metal welders are programmable to hold thousands of weld recipes. The user can set their desired parameters and if the servo force feedback detects materials outside those parameters in the compression stage of multi-step welding, it will signal the error to the user and stop the operation before the welding process occurs.

Conclusion

With the integration of servo technology in the ultrasonic metal welding process, TECH-SONIC has proven the ability to achieve significant improvements in many key areas of wire splicing, ring termination and spot welding. Dynamic Force Control™ and multi-step welding not only allow for the digital monitoring and adjustment of all weld parameters during the weld process, but also boast the industry's best three percent (3%) missing strand, wire, and foil detection. Servo technology allows for the welding of a wider range of material sizes than are currently possible with pneumatic ultrasonic welders and helps to reduce costs and production downtime. These factors will help to provide reliable solutions across many industries that surpass the standards currently being met by the previous generation of ultrasonic metal welders.

TECH-SONIC, Inc. is headquartered in Columbus, Ohio, USA with subsidiaries in China, and sales and service offices in Mexico, Germany, India, Thailand and the Philippines. It has been designing and manufacturing high-tech ultrasonic metal welders since 1996. In recent years, the company has devoted its research and development to servo controlled ultrasonic metal welding – the “Holy Grail” of ultrasonic metal welding. As a pioneer in servo ultrasonic metal welding technology, it integrates the latest electronics, hardware, location and force sensors, and control software in new and unique ways.

TECH-SONIC has been serving global companies in electrical, automotive, EV, battery, wire harness, appliance, HVAC, solar, and military industries throughout the world, and its engineers have many years of experience in custom welding systems. The company specializes in designing its automated systems for the customers who seek high productivity, precision welding, and improved yields. To demonstrate that TECH-SONIC equipment can meet your welding needs and assembly specifications, the company provides free welding sample testing. For more information and to apply for free sample testing, please visit our website www.tech-sonic.us. For immediate assistance, call Frank Myers in marketing and sales at +1-614-792-3117 or email frank.m@techsonicultrasonic.com.

Wire Splicing Testing Report

Model: US-3020WS2 Servo Ultrasonic Wire Splicer



Wire Splicing Analysis of Consistency and Detection of Weld Failures

Testing performed by TECH-SONIC, Inc. USA
Compiled: January 31, 2018
Testing Completed: April 2017 - January 2018

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Introduction

The purpose of this research is to test TECH-SONIC’s US-3020WS2 servo-controlled wire splicer’s ability to identify wire splice defects. Defects included in this research are missing strands, retracted wires, and added insulation. These defects can occur through many stages of producing a wire splice. They can occur from stripping of wires insulation, operator error, and defective equipment. If these defects go undetected, they can result in failure of the electrical system due to /high resistances and low tensile strengths. Currently, detection of these defects using standard pneumatic-controlled wire splicers is relatively difficult. For pneumatic-controlled wire splicers to detect defects consistently, tolerance windows are set to point where welds without defects are rejected at high rates. Not only is the US-3020WS2 ability to detect defects is being tested, but also its ability to prevent non-defective wire splices from being falsely rejected.

Testing Procedure

The welds were performed on TECH-SONIC’s US-3020WS2 wire splicer. Nominal splice cross sectional areas that have been tested are outlined in the table below. Detailed images of each splice are displayed in Appendix. Welding parameters and tolerance windows for each splice combination were kept constant for the entire experiment. Start height and end height tolerance windows were turned on, so welds could be rejected on start height prior to welding or end height after welding. Post-weld start height, end height, cross sectional area, and time were recorded from the output of the machine. Additionally, the end height and width of the completed splice were measured using a digital micrometer, these are denoted as measured end height and measured width. These measurements were taken in the same position for each weld, being careful not to measure flash. Each configuration was tested in four groups: no defects, missing strands, retracted strands, and added insulation. Details of each group are outlined below.

Nominal Splice CSA	Splice Configuration
0.39mm ²	1 (0.13mm ²) x 2 (0.13mm ²)
1.05mm ²	1 (0.35mm ²) x 2 (0.35mm ²)
2.25mm ²	1 (0.75mm ²) x 2 (0.75mm ²)
2.7mm ²	2 (0.35mm ²) x 4 (0.50mm ²)
3.5mm ²	5 (0.35mm ²) x 5 (0.35mm ²)
3.75mm ²	2 (0.75mm ²) x 3 (0.75mm ²)
3.8mm ²	2 (0.35mm ²) + 3 (0.50mm ²) x 2 (0.80mm ²)
4.0mm ²	2 (1.0mm ²) x 2 (1.0mm ²)
5.85mm ²	5 (0.35mm ²) x 5 (0.50mm ²) + 2 (0.80mm ²)
6.25mm ²	2 (1.0mm ²) + 1 (0.75mm ²) + 1 (0.50mm ²) x 2 (1.0mm ²) + 2 (0.50mm ²)
14.0mm ²	2 (2.50mm ²) x 1 (4.0mm ²) + 1 (5.0mm ²)

No Defects

The no defects group was the control group for this experiment. It represented a splice with no defects, meaning it had no missing strands, no retracted wires, and no added insulation. The completed

welds were pull tested. The smallest wire furthest from the horn and any other vertically in line wire across splice was pulled. Figure 9 in the appendix is an example picture of the pull test configuration. The pull tester was set to pull at a rate of 100mm/min. The Cpk value was calculated for the pull tests, and minimum pull test specifications were taken from the latest publication of USCAR-45.

Missing Strands

Missing strands were tested by removing individual strands from the weld area. To calculate percent missing strands, the percent missing is based on the actual CSA of the wire combination. The actual CSA is the sum of the individual strands CSA, as opposed to just adding nominal wire CSA to get to get nominal splice CSA. The strands were removed from the same wires each trial. Missing strands detection was tested at different levels, nearest to 3% and significantly below 3%.

Retracted Wire

Retracted wires were tested by retracting the smallest wire which was furthest from the horn. The wire was retracted a percentage of the horn's length. To get a percentage of the horn's length the wire had to be retracted percentage of horn's length + brush end length (see Figure 12 in appendix for brush end definition). To keep percent retraction consistent, the wire below the wire being retracted had a line draw around its circumference at the desired distance from the end of insulation. Prior to initiating welding cycle, the top wire was retracted so its end of insulation lined up with the circumferential line drawn on the wire below it. See Figure 10 in appendix for an example visual of retracted wire test procedure.

Added Insulation

Added insulation was tested by moving the smallest which was furthest from the horn wire into weld area. The wire was moved into weld area a percentage of the horn's length. To get a percentage of the horn's length the wire had to be moved percentage of horn's length plus transition length (see Figure 12 in appendix for transition definition). To keep added insulation consistent the wire which was being moved into the weld area had a line drawn around its circumference at the desired distance from the end of its insulation. Prior to initiating welding cycle, the wire was moved into the weld area so that the circumferential line lined up with the end of insulation on the wire below it. See Figure 11 in appendix for visual of added insulation test procedure.

Results

0.39mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (µm)	Energy (J)	Width (mm)
1	150	250	0	80	0.9
2	100	250	20		

Tolerances		
Start Height	End Height	Pull Test Cpk
0.79 - 0.90	0.68 - 0.73	3.49

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	0.805	0.681	0.725	0.680	0.880	0.470	88.000
Maximum	0.895	0.720	0.806	0.747	0.919	0.570	108.000
Average	0.834	0.698	0.750	0.715	0.901	0.515	98.400
Std. Dev.	0.02400	0.00985	0.01260	0.01408	0.01038	0.02801	4.61950

Alarms		
Start Height	End Height	Total
0 / 30	0 / 30	0 / 30

1 Missing Strand -- 4.76% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	0.743	0.647	0.582	0.666	0.880	0.490
Maximum	0.850	0.679	0.611	0.728	0.908	0.590
Average	0.797	0.669	0.602	0.697	0.896	0.536
Std. Dev.	0.02606	0.00872	0.00785	0.01689	0.00869	0.03181

Alarms		
Start Height	End Height	Total
14 / 30	16 / 30	30 / 30

1.05mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (µm)	Energy (J)	Width (mm)
1	200	300	0	85	1.3
2	200	350	20		
3	200	370	23		

Tolerances		
Start Height	End Height	Pull Test Cpk
1.25 - 1.37	1.05 - 1.10	3.08

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	1.250	1.050	1.360	1.045	1.293	0.360	80.000
Maximum	1.360	1.108	1.440	1.122	1.310	0.380	94.000
Average	1.290	1.080	1.405	1.084	1.302	0.369	89.033
Std. Dev.	0.02652	0.01475	0.02030	0.02014	0.00403	0.00583	3.68314

Alarms		
Start Height	End Height	Total
0 / 30	0 / 30	0 / 30

1 Missing Strand -- 4.76% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.192	1.015	1.320	1.018	1.296	0.360
Maximum	1.282	1.044	1.360	1.031	1.301	0.390
Average	1.232	1.030	1.340	1.025	1.300	0.377
Std. Dev.	0.02115	0.01037	0.01414	0.00564	0.00176	0.01033

Alarms		
Start Height	End Height	Total
24 / 30	6 / 30	30 / 30

2.25mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (μm)	Energy (J)	Width (mm)
1	100	600	0	250	1.85
2	150	450	22		
3	125	400	25		
4	75	30	0		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
1.7835 - 1.8564	1.4647 - 1.5704	1.8282

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	1.787	1.492	2.760	1.447	1.523	0.580	133.000
Maximum	1.852	1.568	2.900	1.832	1.856	0.810	170.000
Average	1.815	1.536	2.841	1.525	1.821	0.636	159.560
Std. Dev.	0.01558	0.01703	0.03164	0.04748	0.05173	0.05024	8.12444

Alarms		
Start Height	End Height	Total
0 / 100	0 / 100	0 / 100

2 Missing Strands -- 2.6% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.690	1.440	2.670	1.432	1.831	0.600
Maximum	1.800	1.450	2.690	1.453	1.834	0.630
Average	1.756	1.447	2.680	1.443	1.832	0.617
Std. Dev.	0.02472	0.00577	0.01000	0.01060	0.00153	0.01528

Alarms		
Start Height	End Height	Total
27 / 30	3 / 30	30 / 30

1 Missing Strand -- 1.3% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.750	1.450	2.690	1.450	1.820	0.580
Maximum	1.820	1.510	2.800	1.521	1.860	0.720
Average	1.782	1.481	2.738	1.488	1.845	0.634
Std. Dev.	0.01710	0.01621	0.03353	0.02437	0.01013	0.04144

Alarms		
Start Height	End Height	Total
18 / 30	2 / 30	20 / 30

25% Retraction of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.670	1.460	2.690	1.455	1.842	0.640
Maximum	1.810	1.460	2.700	1.462	1.850	0.680
Average	1.750	1.460	2.697	1.458	1.847	0.657
Std. Dev.	0.03248	0.00000	0.00577	0.00361	0.00436	0.02082

Alarms		
Start Height	End Height	Total
27 / 30	3 / 30	30 / 30

25% Added Insulation of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.880					
Maximum	2.210					
Average	2.036					
Std. Dev.	0.08465					

Alarms		
Start Height	End Height	Total
30 / 30	0 / 30	30 / 30

2.70mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (µm)	Energy (J)	Width (mm)
1	250	700	0	260	1.89
2	100	250	19		
3	150	400	25		
4	100	20	0		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
2.0 - 2.16	1.69 - 1.79	3.35

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	2.027	1.693	3.200	1.702	1.870	0.510	72.000
Maximum	2.156	1.786	3.380	1.824	1.910	0.610	91.000
Average	2.095	1.724	3.259	1.751	1.893	0.545	85.980
Std. Dev.	0.03080	0.01520	0.02899	0.02087	0.00672	0.01714	3.07804

Alarms		
Start Height	End Height	Total
0 / 100	0 / 100	0 / 100

2 Missing Strands -- 2.97% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.951	1.645	3.110	1.668	1.890	0.540
Maximum	2.087	1.689	3.190	1.729	1.905	0.590
Average	2.028	1.670	3.155	1.703	1.896	0.564
Std. Dev.	0.03237	0.01202	0.02284	0.01688	0.00457	0.01651

Alarms		
Start Height	End Height	Total
26 / 30	4 / 30	30 / 30

1 Missing Strand -- 2.03% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.996	1.641	3.100	1.881	1.881	0.550
Maximum	2.103	1.734	3.280	1.902	1.902	0.770
Average	2.054	1.693	3.200	1.893	1.893	0.613
Std. Dev.	0.02807	0.01926	0.03610	0.00537	0.00537	0.07026

Alarms		
Start Height	End Height	Total
1 / 30	11 / 30	12 / 30

15% Retraction of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.976	1.639	3.100	1.676	1.872	0.530
Maximum	2.106	1.690	3.190	1.744	1.907	0.710
Average	2.043	1.668	3.153	1.716	1.887	0.597
Std. Dev.	0.03330	0.01586	0.03040	0.01932	0.00902	0.04472

Alarms		
Start Height	End Height	Total
4 / 30	26 / 30	30 / 30

25% Added Insulation of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.175					
Maximum	2.273					
Average	2.221					
Std. Dev.	0.03207					

Alarms		
Start Height	End Height	Total
30 / 30	0 / 30	30 / 30

3.50mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (µm)	Energy (J)	Width (mm)
1	50	700	0	320	2.35
2	150	400	20		
3	150	500	26.7		
4	50	20	0		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
2.17425 - 2.2969	1.8816 - 1.9776	3.39

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	2.150	1.890	4.430	1.888	2.345	0.530	78.000
Maximum	2.250	1.960	4.600	1.955	2.353	0.560	90.000
Average	2.188	1.919	4.511	1.921	2.349	0.543	84.071
Std. Dev.	0.02740	0.02107	0.05025	0.02129	0.00279	0.00945	2.94302

Alarms		
Start Height	End Height	Total
0 / 30	0 / 30	0 / 30

2 Missing Strands -- 2.86% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.120	1.862	4.370	1.869	2.340	0.540
Maximum	2.244	1.888	4.440	1.890	2.460	0.580
Average	2.162	1.879	4.415	1.880	2.357	0.563
Std. Dev.	0.02562	0.00964	0.02382	0.00692	0.03440	0.01104

Alarms		
Start Height	End Height	Total
24 / 30	6 / 30	30 / 30

1 Missing Strand -- 1.43% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.228	1.836	4.310	1.839	2.340	0.550
Maximum	2.384	1.942	4.560	1.944	2.374	0.800
Average	2.296	1.908	4.485	1.908	2.351	0.632
Std. Dev.	0.03581	0.02659	0.06270	0.02418	0.00542	0.06154

Alarms		
Start Height	End Height	Total
10 / 30	4 / 30	14 / 30

15% Retraction of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.128	1.769	4.250	1.788	1.813	0.580
Maximum	2.408	1.876	4.500	2.410	2.413	0.620
Average	2.201	1.828	4.385	1.849	2.390	0.597
Std. Dev.	0.05626	0.02624	0.06331	0.09978	0.10039	0.01010

Alarms		
Start Height	End Height	Total
18 / 30	12 / 30	30 / 30

25% Added Insulation of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	0.580					
Maximum	0.620					
Average	0.597					
Std. Dev.	0.01010					

Alarms		
Start Height	End Height	Total
30 / 30	0 / 30	30 / 30

3.75mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (µm)	Energy (J)	Width (mm)
1	250	900	0	400	2.3
2	100	700	25.7		
3	100	900	22		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
2.1825 - 2.34	1.8236 - 1.9552	1.8879

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	2.194	1.830	4.210	1.845	2.298	0.700	135.000
Maximum	2.303	1.900	4.370	1.918	2.322	0.780	164.000
Average	2.253	1.863	4.286	1.889	2.308	0.733	150.533
Std. Dev.	0.02699	0.01865	0.04304	0.02092	0.00687	0.02120	6.27383

Alarms		
Start Height	End Height	Total
0 / 30	0 / 30	0 / 30

3 Missing Strands -- 2.88% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.915	1.684	3.870	1.677	2.299	0.710
Maximum	2.225	1.716	3.950	1.705	2.310	0.740
Average	2.105	1.700	3.910	1.691	2.305	0.725
Std. Dev.	0.06067	0.02263	0.05657	0.01980	0.00778	0.02121

Alarms		
Start Height	End Height	Total
28 / 30	2 / 30	30 / 30

2 Missing Strands -- 1.97% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.943	1.614	3.710	1.598	2.288	0.690
Maximum	2.210	1.738	4.000	1.741	2.310	0.750
Average	2.106	1.704	3.915	1.699	2.299	0.725
Std. Dev.	0.07505	0.05976	0.13723	0.06759	0.00913	0.02646

Alarms		
Start Height	End Height	Total
26 / 30	4 / 30	30 / 30

1 Missing Strand -- 0.97% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.121	1.701	3.910	1.817	2.235	0.720
Maximum	2.305	1.857	4.270	1.861	2.340	0.770
Average	2.213	1.798	4.135	1.837	2.292	0.743
Std. Dev.	0.04056	0.04682	0.10755	0.01625	0.03012	0.01832

Alarms		
Start Height	End Height	Total
9 / 30	13 / 30	21 / 30

25% Retraction of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	1.963	1.597	3.670	1.612	2.289	0.690
Maximum	2.312	1.819	4.180	1.814	2.312	0.750
Average	2.154	1.733	3.986	1.746	2.301	0.722
Std. Dev.	0.08745	0.08816	0.20311	0.08061	0.00781	0.02279

Alarms		
Start Height	End Height	Total
21 / 30	9 / 30	30 / 30

25% Added Insulation of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.344					
Maximum	2.914					
Average	2.536					
Std. Dev.	0.12484					

Alarms		
Start Height	End Height	Total
30 / 30	0 / 30	30 / 30

3.80mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (µm)	Energy (J)	Width (mm)
1	100	750	0	325	2.4
2	200	500	20		
3	200	650	25		
4	100	20	0		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
2.301 - 2.4308	1.9109 - 2.0291	4.15

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	2.310	1.950	4.680	1.946	2.381	0.570	80.000
Maximum	2.410	2.010	4.820	2.005	2.407	0.630	92.000
Average	2.351	1.972	4.735	1.972	2.398	0.595	86.867
Std. Dev.	0.02708	0.01555	0.03501	0.01554	0.00577	0.01224	2.55604

Alarms		
Start Height	End Height	Total
0 / 30	0 / 30	0 / 30

3 Missing Strands -- 3.2% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.230	1.760	4.220	1.758	2.388	0.590
Maximum	2.350	1.930	4.620	1.926	2.404	0.620
Average	2.290	1.888	4.531	1.887	2.397	0.599
Std. Dev.	0.02859	0.05286	0.12663	0.05302	0.00531	0.01054

Alarms		
Start Height	End Height	Total
21 / 30	9 / 30	30 / 30

2 Missing Strands -- 2.23% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.180	1.840	4.420	1.841	1.900	0.560
Maximum	2.420	1.910	4.590	2.376	2.403	0.590
Average	2.317	1.888	4.530	1.911	2.369	0.575
Std. Dev.	0.04143	0.01832	0.04401	0.11071	0.11056	0.00827

Alarms		
Start Height	End Height	Total
10 / 30	20 / 30	30 / 30

15% Retraction of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.250	1.840	4.410	1.840	2.380	0.570
Maximum	2.390	1.940	4.660	1.940	2.408	0.600
Average	2.332	1.881	4.516	1.884	2.396	0.588
Std. Dev.	0.03377	0.02522	0.06130	0.02336	0.00675	0.00850

Alarms		
Start Height	End Height	Total
5 / 30	24 / 30	29 / 30

25% Added Insulation of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.460					
Maximum	2.650					
Average	2.524					
Std. Dev.	0.05393					

Alarms		
Start Height	End Height	Total
30 / 30	0 / 30	30 / 30

4.00mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (µm)	Energy (J)	Width (mm)
1	50	400	0	350	2.25
2	250	450	24		
3	250	500	20		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
2.5 - 2.7	2.12 - 2.27	1.97

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	2.500	2.120	4.770	2.120	2.250	0.690	215.000
Maximum	2.620	2.190	4.930	2.210	2.280	0.890	234.000
Average	2.543	2.157	4.855	2.166	2.264	0.724	223.367
Std. Dev.	0.02897	0.01780	0.04216	0.01958	0.00928	0.03501	4.79571

Alarms		
Start Height	End Height	Total
0 / 30	0 / 30	0 / 30

4 Missing Strands -- 3.125% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.420	2.070	4.650	2.070	2.250	0.710
Maximum	2.530	2.110	4.750	2.120	2.280	0.770
Average	2.472	2.093	4.706	2.093	2.261	0.737
Std. Dev.	0.02653	0.01704	0.04036	0.01799	0.00900	0.02289

Alarms		
Start Height	End Height	Total
23 / 30	7 / 30	30 / 30

3 Missing Strands -- 2.34% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.390	2.060	4.960	2.060	2.380	0.690
Maximum	2.540	2.090	5.020	2.080	2.390	0.750
Average	2.451	2.074	4.977	2.073	2.381	0.718
Std. Dev.	0.04152	0.00976	0.02360	0.00951	0.00378	0.01775

Alarms		
Start Height	End Height	Total
23 / 30	1 / 30	29 / 30

5.85mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (µm)	Energy (J)	Width (mm)
1	200	620	0	500	2.9
2	50	670	33		
3	200	720	26.7		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
2.9 - 3.15	2.35 - 2.45	3.08

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	2.947	2.358	6.840	2.373	2.880	0.570	75.000
Maximum	3.120	2.428	7.040	2.420	2.918	0.650	91.000
Average	3.001	2.387	6.920	2.402	2.895	0.601	83.400
Std. Dev.	0.03837	0.01786	0.05051	0.01306	0.00971	0.01676	4.27180

Alarms		
Start Height	End Height	Total
0 / 30	0 / 30	0 / 30

3 Missing Strands -- 2.78% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.805	2.310	6.700	2.311	2.880	0.570
Maximum	2.963	2.335	6.770	2.342	2.891	0.600
Average	2.866	2.324	6.740	2.327	2.887	0.592
Std. Dev.	0.03771	0.01080	0.03082	0.01119	0.00497	0.01304

Alarms		
Start Height	End Height	Total
25 / 30	5 / 30	30 / 30

2 Missing Strands -- 1.85% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.826	2.301	6.670	2.327	2.882	0.570
Maximum	2.997	2.364	6.850	2.382	2.902	0.620
Average	2.900	2.342	6.792	2.360	2.891	0.595
Std. Dev.	0.04350	0.01874	0.05398	0.01341	0.00650	0.01613

Alarms		
Start Height	End Height	Total
17 / 30	7 / 30	24 / 30

15% Retraction of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	2.846	2.280	6.610	2.295	2.870	0.600
Maximum	3.031	2.349	6.810	2.377	2.895	0.650
Average	2.918	2.326	6.741	2.348	2.886	0.616
Std. Dev.	0.04692	0.01988	0.05600	0.01778	0.00662	0.01320

Alarms		
Start Height	End Height	Total
13 / 30	17 / 30	30 / 30

25% Added Insulation of Single Wire						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	3.148	2.421	7.020	2.417	2.894	0.630
Maximum	3.306	2.421	7.020	2.417	2.894	0.630
Average	3.212	2.421	7.020	2.417	2.894	0.630
Std. Dev.	0.03875					

Alarms		
Start Height	End Height	Total
29 / 30	0 / 30	29 / 30

6.25mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (μm)	Energy (J)	Width (mm)
1	150	350	0	570	2.9
2	200	500	18		
3	200	600	24		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
3.19 - 3.40	2.58 - 2.72	1.847

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	3.150	2.620	7.600	2.620	2.900	0.900	107.000
Maximum	3.300	2.690	7.800	2.700	2.920	1.030	129.000
Average	3.230	2.653	7.695	2.657	2.913	0.941	116.933
Std. Dev.	0.04060	0.01643	0.04644	0.01826	0.00828	0.02726	6.66402

Alarms		
Start Height	End Height	Total
0 / 30	0 / 30	0 / 30

6 Missing Strands -- 3.0% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	3.100	2.510	7.260	2.520	2.900	0.870
Maximum	3.230	2.580	7.470	2.590	2.920	1.010
Average	3.164	2.548	7.383	2.551	2.908	0.926
Std. Dev.	0.04087	0.02137	0.05770	0.02021	0.00754	0.03777

Alarms		
Start Height	End Height	Total
18 / 30	12 / 30	30 / 30

5 Missing Strands -- 2.5% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	3.130	2.580	7.490	2.580	2.900	0.890
Maximum	3.310	2.620	7.590	2.610	2.920	0.950
Average	3.196	2.597	7.528	2.592	2.910	0.921
Std. Dev.	0.04687	0.01371	0.03664	0.01030	0.00426	0.01730

Alarms		
Start Height	End Height	Total
18 / 30	12 / 30	30 / 30

4 Missing Strands -- 2.0% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	3.060	2.610	7.560	2.620	2.870	0.910
Maximum	3.170	2.680	7.780	2.680	2.900	0.990
Average	3.124	2.639	7.655	2.655	2.891	0.942
Std. Dev.	0.03421	0.02378	0.06995	0.02307	0.00848	0.01954

Alarms		
Start Height	End Height	Total
11 / 30	11 / 30	22 / 30

14.0mm²

Weld Parameters					
Step	Time (ms)	Force (N)	Amp. (μm)	Energy (J)	Width (mm)
1	500	490	0	650	4.35
2	800	490	16		

Tolerances		
Start Height (mm)	End Height (mm)	Pull Test Cpk
4.14 - 4.42	3.51 - 3.55	3.77

No Defects							
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)	Pull Test (N)
Minimum	4.210	3.570	15.520	3.616	4.355	0.900	479.000
Maximum	4.310	3.650	15.880	3.699	4.382	1.050	553.000
Average	4.250	3.620	15.740	3.631	4.369	0.960	515.000
Std. Dev.	0.03067	0.02532	0.11323	0.02606	0.00843	0.04131	20.67780

Alarms		
Start Height	End Height	Total
0 / 15	0 / 15	0 / 15

6 Missing Strands -- 3.0% CSA						
	Start Height (mm)	End Height (mm)	CSA (mm ²)	Measured End Height (mm)	Measured Width (mm)	Time (s)
Minimum	4.100	3.490	15.160	3.505	4.363	0.970
Maximum	4.180	3.500	15.220	3.530	4.366	0.970
Average	4.140	3.495	15.190	3.518	4.365	0.970
Std. Dev.	0.02463	0.00707	0.04243	0.01768	0.00212	--

Alarms		
Start Height	End Height	Total
13 / 15	2 / 15	15 / 15

Discussion

The US-3020WS2 showed the ability to detect 3% missing strands for all splice combinations tested. The machine performed at 100% reliability, meaning all welds with 3% (or nearest to 3% CSA) missing strands were rejected. Welds were either rejected on start height or end height. Additionally, the no defect group was run at 100% reliability without any welds being falsely rejected.

The US-3020WS2's detection of missing strands significantly below 3% was not as reliable. The welder showed the ability to reject some welds, but not all. For it to reject all welds significantly below 3%, the tolerance windows would have to be tightened to the point where welds without defects would be rejected. Since percent missing strands is based on CSA of wire combination, larger combinations will have more missing strands compared to smaller combinations at the same missing strands percent level, allowing for more reliable detection.

The machine also showed successful detection of retracted wires and added insulation to weld area. The smallest wire for each splice was retracted, so the machine will be successful in detecting larger wires in each splice at retraction levels less than or equal to levels tested. The same can be applied for added insulation. Added insulation results were unique in the fact that they rejected welds exclusively on start heights. This was consistent with previous findings that added insulation does not affect end height because it is melted and pushed to the side during welding. The level of retraction and added insulation for the largest splice were slightly larger than the other splices. This is attributed to the large tolerance windows used in order to prevent welds without defects being falsely rejected. Larger tolerance windows were needed because these splices had the most wires which contributes to a wider range of start and end heights.

In general, larger amount of wires in a splice make it more difficult to detect defects because wires can lie differently prior to initiating the welding cycle from weld to weld, and be slightly moved again as anvils move to weld position resulting in a wider range of start and end heights. The team reduced these inconsistencies by utilizing the servo's ability to adjust vertical and horizontal anvils pre-weld home positions. Pre-weld home positioning allows users to control the anvil's position for each splice configuration. Normally, anvils move from full open to weld position then back to full open position once welding is complete. Servo control allows for anvils to move from pre-weld home position to weld position then back to pre-weld home position once welding is complete. The horizontal and vertical anvil pre-weld home positions were set slightly larger than the desired width and start height. This prevented inconsistencies of how operators place wires. Additionally, it also prevented vertical and horizontal anvils from needing to move from full open to weld position and operator movement of wires during this time. It has also been shown to prevent side splices because it is nearly impossible for wires to fall to the side given the limited space.

The parameters for each splice combination were based on previous testing done with wire combinations with similar CSA. The first step's force was set relatively high with no amplitude being applied. Previous research showed that using high force with no amplitude initially, allowed for more consistent start heights. It acted to compress the wires and prevent start height fluctuation.

Data from each group (no defects, missing strands, retracted wires, and added insulation) for each wire combination show similarities between groups. The standard deviations for start and end

heights for each group are similar values, specifically no defects and missing strands. Differences in retracted wire and added insulation can be contributed to our testing method, which was consistent, but not as consistent as testing of missing strands. Similar standard deviations means that whether a splice has a defect or not a user can expect the same start and end height consistencies. Additionally, comparing start height and end height standard deviations to each other shows that end height is significantly more consistent. This follows trends found in previous studies.

Conclusion

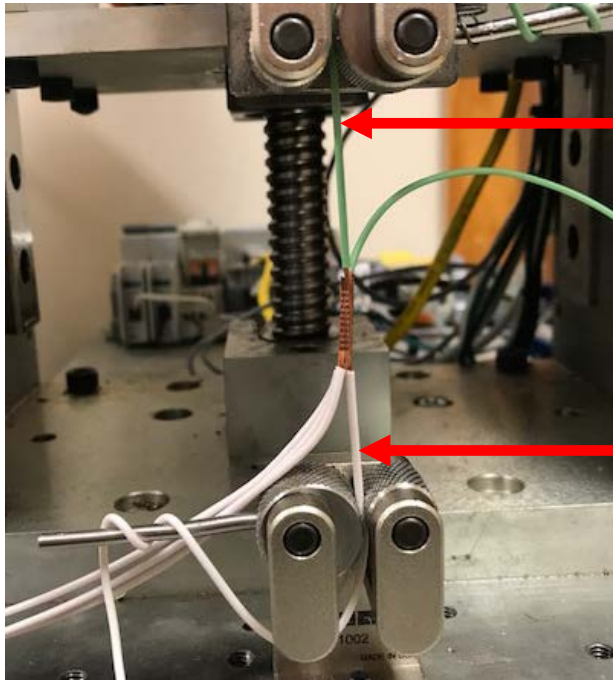
The testing procedure outlined allows for consistent testing of missing strands, retracted wires, and added insulation defects in wire splicing. The US-3020WS2 showed the ability to detect under 3% missing strands (or nearest to that value in combinations where one strand was greater than 3%) at 100% reliability on wire combinations with varying amount of total wires. It also showed the ability to detect retracted wires and added insulation. In addition to detecting these defects, the wire splicer rejected zero welds without defects.

The pull tests CPK values for all the combinations were above a value of 1.75, exceeding the targeted CPK value of 1.67.

Future Work

Additional testing needs to be done on the US-3020WS2 in order to identify all benefits that servo-control brings to the wire splicing industry. Specifically, more research should be conducted on process optimization utilizing the US-3020WS2's ability to change force and amplitude during welding, which is an ongoing internal study. It has been hypothesized that starting with a low force and high amplitude initially then switching to a high force and low amplitude towards the end of welding will significantly reduce sliding friction between horn and top workpiece, reducing horn wear and post-weld horn-to-workpiece adhesion. Additionally, this will reduce weld time necessary to complete the weld and expand 3kW wire splicer weld size range.

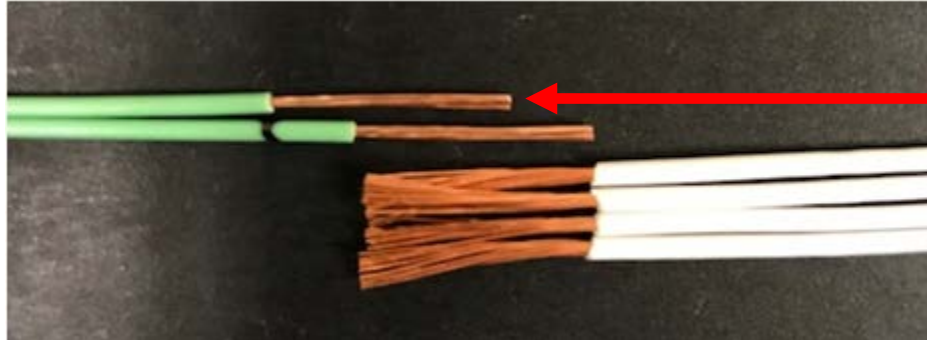
Appendix



Smallest and furthest from horn wire

Vertically in line across splice wire

Figure 1: Pull test Configuration



Smallest and furthest from horn wire

Figure 2: Retracted wire configuration

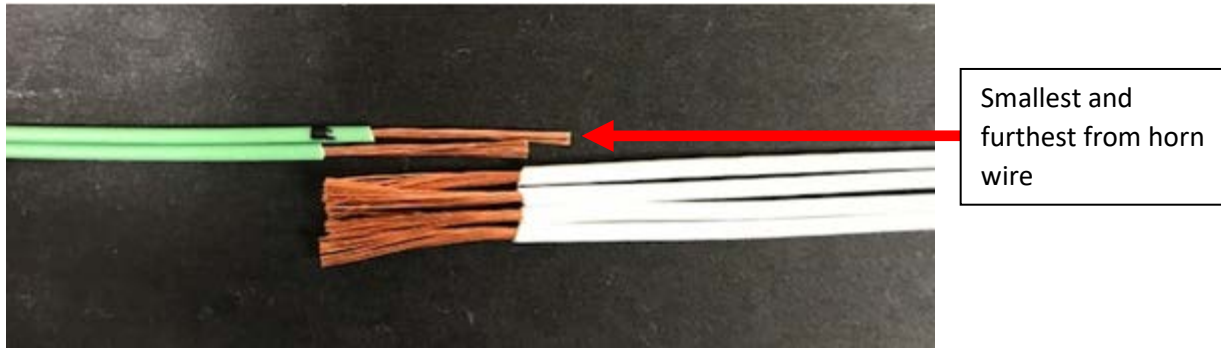


Figure 3: Added insulation configuration.

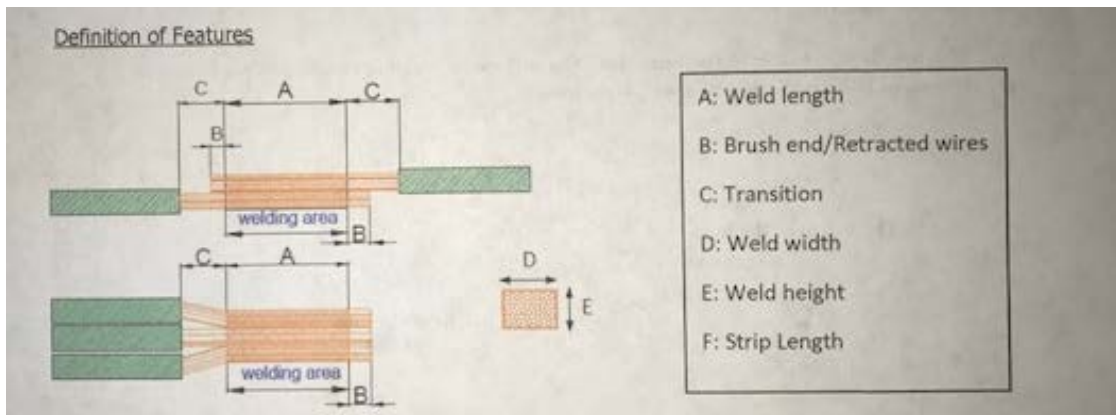


Figure 4: Definition of wire splice features.

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