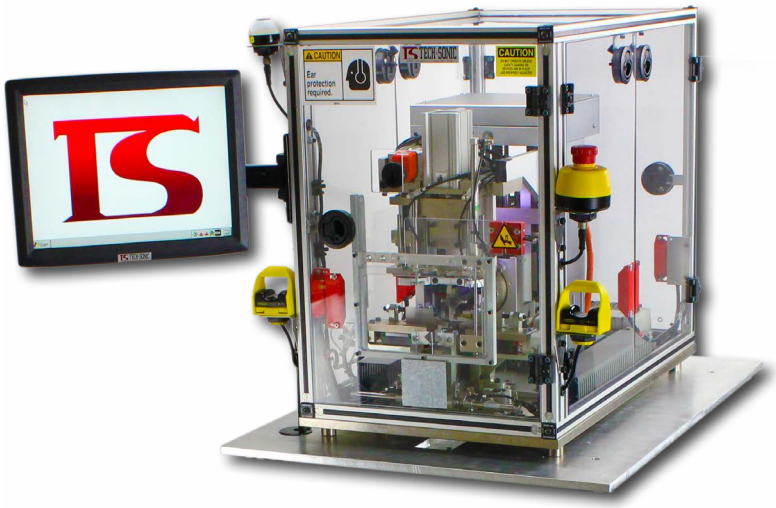
Digital Servo Ring Terminator

US-3020SRT

U.S. Patent Pending

The World's First Servo Ultrasonic Ring Terminal Welder



Proven Automotive Wire Harness Industry Solution

TECH-SONIC has been providing Multi-National support for over two decades

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	6.5 bars / 94 psi; Air Filter built-in; requires 6mm OD Hose
Weld Force	~3,000 Newton maximum
Weldhead	113 kg / 40.6 x 76.2 x 58.4 cm 250 lb / 16 x 30 x 23 inches
Controller Cabinet	41 kg / 22.9W x 61D x 50.8H cm 90 lb / 9W x 24D x 20H inches
Visual Display	17 inch LCD display and mouse
Additional Options	Wire Cutter Barcode Scanner

Welding Capabilities

Cross Section Area	Up to 28mm²
Heavy Duty Upgrade	Over 60mm² Cu Over 95mm² Al
Wire Type	Copper (Cu) Aluminum (Al)

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 Wire Detection Under 3% CSA

- Capable of detecting a single missing wire at 0.35mm²
- Retracted wire from weld area detection, or added insulation into the weld area within 3% total CSA

Load Cell Force Feedback

- Single micron resolution
- Consistent measurement and ultrasonic output produce high cPk values
- Measurement of pre-weld and post-weld height
- 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

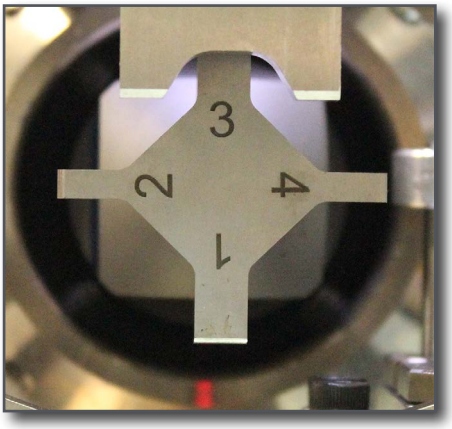
TECH-SONIC
ULTRASONIC METAL WELDING

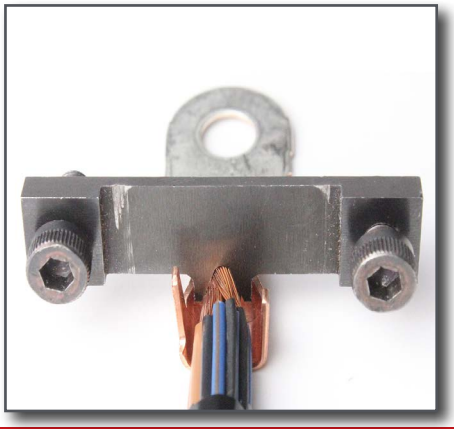
TECH-SONIC

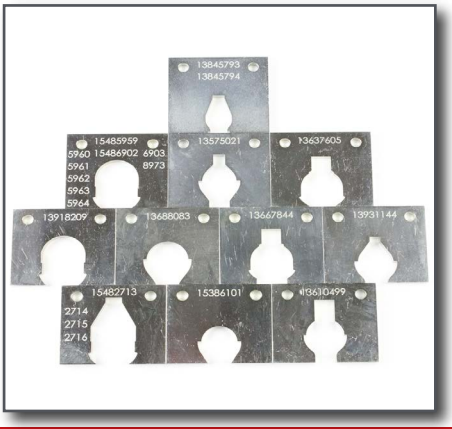
ULTRASONIC METAL WELDING

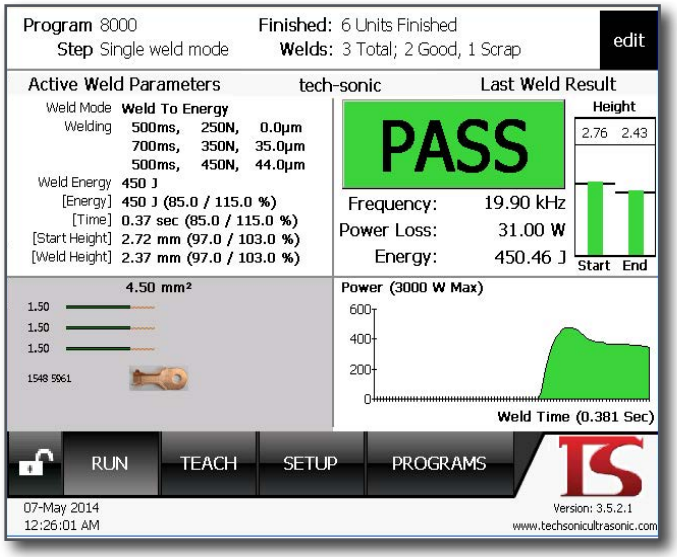
Special Features

- RIGHT: Four-sided horn
- BOTTOM: Wire strand gatherer (Patent Pending)
- BOTTOM RIGHT: Interchangable terminal nests for specific welding applications









This picture shows the "run" mode weld screen featuring Multi-step welding, real time weld data, and an accurate diagram of current wire-to-terminal configuration providing the user full transparency of the welding process.

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

United States, Headquarters
Columbus, Ohio
info@techsonicultrasonic.com

China (Shenzhen)
Nanshan, Shenzhen, Guangdong
tsc@techsonic.com.cn

Mexico
Ciudad Juarez, Chihuahua
rosendo@techsonicultrasonic.com

Thailand
Bang Na, Bangkok
atthapol.c@techsonicultrasonic.com

Philippines
Basak, Lapu-Lapu City
dante.d@techsonicultrasonic.com

China (Suzhou)
Industrial Park, Suzhou
tsc@techsonic.com.cn

Germany
Obertshausen, Germany
k.bauer@techsonicultrasonic.com

India
Janakpuri, New Delhi
sushant@techsonicultrasonic.com

Website
www.tech-sonic.us

Address
2710 Sawbury Blvd.
Columbus, OH 43235 USA

Phone
+1-614-792-3117

Email
info@techsonicultrasonic.com

CE

PROUDLY MADE IN COLUMBUS, OHIO USA

TECH-SONIC
ULTRASONIC METAL WELDING

Servo vs. Pneumatic Ultrasonic Wire Terminator Comparison

TECH-SONIC US-3020SRT Digital Servo Wire Termination Machine

- 3.0 kW power supply, 20 kHz frequency
- Max welding 28mm² copper wire to terminal
- 3,000 Newton max clamping force
- 220 V power supply

Servo Features

- Servo motor with belt drive to control weld head motion
- Dynamic Force and Amplitude Control™ with Multi-Step Welding
  - 20+ possible weld steps
  - Uses optimum welding parameters by changing force and amplitude during weld cycle
- 3% missing volume of CSA detection capability
  - Single missing 0.35mm² wire detection
- Fast cycle times as product of pre-weld home position at lower level than full open position
- Cost savings over time in comparison to pneumatic units (see attached Doc. # A10011)
- Increased weld consistency and higher Cpk values with precision control of servo
- Soft touch landing on weld materials creating less stress on wire strands
- Automatic height calibration
- Meets all requirements of USCAR-38

Pneumatic Features

- Pneumatic cylinders control weld head motion
- Fixed weld force and amplitude and only single step welding
  - Not able to change force and amplitude during welding
- Can not detect single missing 0.35mm² wires in common wire bundles
- Weld head must return to full open position each weld cycle extending cycle times
- Inconsistent welding due to inconsistency of air supply, contamination, moisture, etc.
  - Frequent weld failures as a result
- Aggressive landing controlled by pneumatic cylinder
- Pin gauge height calibration, can lead to user errors and faulty calibration

TECH-SONIC US-3020SRT Servo Spot Welder Video Links

YouTube

US-3020SRT Servo Ring Terminator Demo

US-3020SRT Missing Wire Detection Demo

Vzaar (International Safe Link)

US-3020SRT Servo Ring Terminator Demo (Alt)

US-3020SRT Missing Wire Detection Demo (Alt)

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

The new line of TECH-SONIC servo-controlled 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 servo-controlled ultrasonic wire termination machine, model US-3020SRT, provides a whole new ultrasonic metal welding capability beyond conventional ultrasonic metal welds. It provides precise, reliable, and repeatable welds for small and delicate parts without damage. It produces single point ground terminals and it can accommodate a variety of terminals by changing terminal nest hardware. It uses a microprocessor-controlled ultrasonic welder and servo-controlled spot welding hardware that can weld multiple wires onto a single terminal and provide a stress free joint.

Combining servo control and load cell feedback technology, the US-3020SRT is a 100% digitally controllable process as opposed to less accurate analog processes. It features Dynamic Force and Amplitude Control™ through multi-step welding with real force monitoring during welding, meaning it can vary the ultrasonic amplitude and applied force during the weld process to produce optimum weld conditions. This allows it the capability to weld delicate parts without cracking or damage occurring and reducing the overall stress applied to wires and parts.

The US-3020SRT also features industry-leading missing wire and strand detection. A typical pneumatic termination machine can only detect missing wires if they are greater than 5% of the total cross section of wires. The US-3020SRT can detect missing wires less than 3% of the total cross section, and single 0.35mm² wires, the smallest wires used in automotive wire bundles which are commonly retracted from the weld area without the user's awareness. The US-3020SRT has proven capable of detecting retracted wires as well. Many automobile manufacturers require the wire harness producers to detect less than 3% of missing wires and have determined that the limitations of the pneumatic process prevent them from providing consistently acceptable part quality.

The US-3020SRT provides ring termination solutions for cross sections from 0.50mm² to 28mm² using the same set of tooling. Many pneumatic welders require larger, bulkier tooling and higher ultrasonic power (over 5 kW) to overcome energy losses. The additional power causes excess stress on the tooling resulting in a shorter life cycle. The US-3020SRT uses a 3 kW generator and can extend the life cycle of tooling with precise control of weld parameters.

The US-3020SRT provides ample storage of user-defined wire termination 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 can provide 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 Termination Testing Report

Model: US-3020SRT Servo Ultrasonic Ring Termination

Wire Termination Analysis of Consistency and Detection of Weld Failures

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

www.tech-sonic.us
info@techsonicultrasonic.com
+1-614-792-3117
2710 Sawbury Blvd.
Columbus, OH 43235, USA

Introduction

The purpose of this research is to test TECH-SONIC's US-3020SRT digital servo-controlled ring terminator's ability to detect wire bundle defects. Defects included in this research are missing strands, and retracted wires. These defects can occur during stripping of the wire, wire placement, and overall operator error. If defects such as these go undetected, it can result in electrical failure within the system due to high resistance and low tensile strength. Detection of these defects using standard pneumatic-controlled ring termination machines is relatively difficult because of the need to set windows where non-defected welds end up being discarded at a high rate. The US-3020SRT's ability to detect defects is being tested along with the capability of being able to prevent non-defective welds from being discarded.

Testing Procedure

The welds were performed on TECH-SONIC's US-3020SRT servo ring termination machine. Wire bundle cross section areas that were tested are: 5.20mm², 5.35mm², 5.95mm², 6.10mm², 6.40mm², 7.90mm², 9.05mm², 9.20mm², 10.60mm², and 16.60mm². Details of each bundle configuration are outlined in the table below. All sample bundles were tested first without any defects in trials of six. The second set of trials had defects and were also tested in trials of six. Defects included missing strands and missing 0.35mm² wire(s). Welding parameters and tolerance windows were unique depending on the cross-section area of the bundle. End height tolerance windows were turned on so welds could be rejected upon detection of a missing strand or wire. Weld steps, weld time, force, amplitude, energy, start height, end height, and triggered alarms were recorded for all trials. Following detection testing, a process capability study was performed on each bundle configuration using minimum (100 samples), nominal (30 samples), and maximum (100 samples) weld parameters. CPK values were calculated from the pull tests; further details are outlined in the data section of this report.

Wire Bundle CSA	Wire Bundle Configuration
5.20mm²	2 (0.35mm²) x 6 (0.50mm²) x 2 (0.75mm²)
5.35mm²	1 (0.35mm²) x 2 (0.5mm²) x 1 (1.50mm²) x 1 (2.50mm²)
5.95mm²	2 x (0.35mm²) x 6 (0.50mm²) x 3 (0.75mm²)
6.10mm²	1 (0.35mm²) x 2 (0.5mm²) x 1 (0.75mm²) x 1 (1.50mm²) x 1 (2.50mm²)
6.40mm²	4 (0.35mm²) x 1 (0.50mm²) x 2 (0.75mm²) x 3 (1.00mm²)
7.90mm²	4 (0.35mm²) x 1 (0.50mm²) x 4 (0.75mm²) x 3 (1.00mm²)
9.05mm²	3 (0.35mm²) x 2 (0.50mm²) x 1 (1.00mm²) x 1 (6.00mm²)
9.20mm²	2 (0.35mm²) x 6 (0.50mm²) x 2 (.075mm²) x 1 (4.00mm²)
10.60mm²	6 (0.35mm²) x 3 (0.50mm²) x 1 (1.00mm²) x 1 (6.00mm²)
16.60mm²	6 (0.35mm²) x 3 (0.50mm²) x 1 (1.00mm²) x 2 (6.00mm²)

No Defects

The no defects group was the control group for this experiment. It represented terminal ring welds without defect, meaning they had no missing strands or wires. A Process Capability Study was completed, welds were pull tested from the smallest wire furthest from the horn located on the bottom, and by the largest wire closest to the horn located on the top of the bundle. Pull tests were done using on all samples tested under minimum, nominal, and maximum weld parameters. The CPK value was calculated for the pull test among other results outlined in the data section of this report.

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 bundle configuration. The actual CSA is the sum of the individual strands CSA, as opposed to just adding nominal wire CSA to get to nominal weld CSA. The strands were removed from the same wires each trial. Missing strands detection was tested for values around 3%.

Missing Wires

Retracted wires were tested by retracting the smallest wire furthest from the horn located on the bottom of the wire bundle. In this experiment, 5 trials included the retraction of one or more 0.35mm^2 wires from a bundle. To calculate percent missing CSA, the percent missing was based on the actual CSA of the wire bundle configuration. Missing wire detection was calculated for missing CSA values around 3%.

Results

5.20mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	150	300	0	240
2	300	365	35	

End Height Tolerance %	
102.00%	98.50%
101.50%	98.00%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.700	2.430	0.293	240.290
Maximum	2.740	2.480	0.317	240.990
Average	2.723	2.470	0.304	240.585
Std. Dev.	0.01633	0.02530	0.00821	0.30072

Alarms
0 / 6

5 Missing Strands from 0.75mm² -- 3.00%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.590	2.320	2.870	240.200
Maximum	2.670	2.410	0.307	240.990
Average	2.627	2.370	0.299	240.617
Std. Dev.	0.02875	0.03464	0.00695	0.33381

Alarms
6 / 6

Process Capability Study -- Pull Test							
Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	230.00	2.93	2.58	0.33
2	350.00	300.00	33.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	0.75	Top

Pull Value	
Minimum	90.00
Maximum	98.00
Average	93.31
Std. Dev.	1.7735
Avg. - 3xSD	87.9895
Pull Spec.	55
Cpk	7.200

Pull Value	
Minimum	154.00
Maximum	176.00
Average	161.97
Std. Dev.	5.7057
Avg. - 3xSD	144.8530
Pull Spec.	120
Cpk	2.452

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	240.00	2.91	2.53	0.31
2	355.00	300.00	35.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	0.75	Top

Pull Value	
Minimum	86.00
Maximum	98.00
Average	91.07
Std. Dev.	2.7283
Avg. - 3xSD	82.8817
Pull Spec.	55
Cpk	4.406

Pull Value	
Minimum	164.00
Maximum	192.00
Average	176.20
Std. Dev.	7.4990
Avg. - 3xSD	153.7031
Pull Spec.	120
Cpk	2.498

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	250.00	2.86	2.47	0.30
2	380.00	500.00	37.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	0.75	Top

Pull Value	
Minimum	88.00
Maximum	98.00
Average	91.67
Std. Dev.	1.8966
Avg. - 3xSD	85.9802
Pull Spec.	55
Cpk	6.445

Pull Value	
Minimum	168.00
Maximum	188.00
Average	176.47
Std. Dev.	4.6220
Avg. - 3xSD	162.6041
Pull Spec.	120
Cpk	4.073

5.35mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	300	300	0	330
2	500	315	36	

End Height Tolerance %	
101.5%	99%
101%	98.5%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.780	2.430	0.332	330.170
Maximum	2.850	2.490	0.360	330.820
Average	2.814	2.454	0.346	330.490
Std. Dev.	0.02881	0.02881	0.01108	0.24839

Alarms
0 / 6

3 Missing Strands from 2.5mm² -- 2.81%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.710	2.110	0.351	330.030
Maximum	2.810	2.390	0.396	330.420
Average	2.753	2.297	0.370	321.267
Std. Dev.	0.03327	0.10652	0.01464	22.01012

Alarms
6 / 6

Process Capability Study -- Pull Test

Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	230.00	2.93	2.58	0.33
2	350.00	300.00	33.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	0.75	Top

Pull Value	
Minimum	90.00
Maximum	98.00
Average	93.31
Std. Dev.	1.7735
Avg. - 3xSD	87.9895
Pull Spec.	55
Cpk	7.200

Pull Value	
Minimum	154.00
Maximum	176.00
Average	161.97
Std. Dev.	5.7057
Avg. - 3xSD	144.8530
Pull Spec.	120
Cpk	2.452

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	240.00	2.91	2.53	0.31
2	355.00	300.00	35.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	0.75	Top

Pull Value	
Minimum	86.00
Maximum	98.00
Average	91.07
Std. Dev.	2.7283
Avg. - 3xSD	82.8817
Pull Spec.	55
Cpk	4.406

Pull Value	
Minimum	164.00
Maximum	192.00
Average	176.20
Std. Dev.	7.4990
Avg. - 3xSD	153.7031
Pull Spec.	120
Cpk	2.498

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	250.00	2.86	2.47	0.30
2	380.00	500.00	37.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	0.75	Top

Pull Value	
Minimum	88.00
Maximum	98.00
Average	91.67
Std. Dev.	1.8966
Avg. - 3xSD	85.9802
Pull Spec.	55
Cpk	6.445

Pull Value	
Minimum	168.00
Maximum	188.00
Average	176.47
Std. Dev.	4.6220
Avg. - 3xSD	162.6041
Pull Spec.	120
Cpk	4.073

5.95mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	300	300	0	250
2	300	420	35	

End Height Tolerance %	
101.50%	99.00%
101.00%	98.50%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.950	2.690	0.315	250.160
Maximum	2.980	2.700	0.344	250.880
Average	2.962	2.690	0.322	250.402
Std. Dev.	0.00983	0.01095	0.01106	0.26619

Alarms
0 / 6

5 Missing Strands from 0.75mm² -- 3.33%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.880	2.570	0.314	250.220
Maximum	2.930	2.630	0.327	250.850
Average	2.903	2.602	0.323	250.543
Std. Dev.	0.02251	0.02401	0.00471	0.28005

Alarms
6 / 6

Process Capability Study -- Pull Test							
Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	250.00	3.14	2.76	0.33
2	400.00	300.00	33.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	0.75	Top

Pull Value	
Minimum	89.00
Maximum	98.00
Average	93.64
Std. Dev.	2.0963
Avg. - 3xSD	87.3512
Pull Spec.	55
Cpk	6.144

Pull Value	
Minimum	157.00
Maximum	185.00
Average	172.64
Std. Dev.	7.6204
Avg. - 3xSD	149.7787
Pull Spec.	120
Cpk	2.303

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	260.00	3.08	2.73	0.32
2	420.00	300.00	35.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	0.75	Top

Pull Value	
Minimum	89.00
Maximum	101.00
Average	92.97
Std. Dev.	3.0567
Avg. - 3xSD	83.7964
Pull Spec.	55
Cpk	4.140

Pull Value	
Minimum	175.00
Maximum	191.00
Average	182.67
Std. Dev.	4.9919
Avg. - 3xSD	167.6908
Pull Spec.	120
Cpk	4.185

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	270.00	3.10	2.64	0.31
2	440.00	300.00	37.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	0.75	Top

Pull Value	
Minimum	85.00
Maximum	99.00
Average	92.62
Std. Dev.	2.8025
Avg. - 3xSD	84.2124
Pull Spec.	55
Cpk	4.475

Pull Value	
Minimum	167.00
Maximum	193.00
Average	180.67
Std. Dev.	5.2629
Avg. - 3xSD	164.8813
Pull Spec.	120
Cpk	3.843

6.10mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	300	300	0	370
2	345	500	36	

End Height Tolerance %	
101.5%	99%
101%	98.5%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.990	2.630	0.402	370.300
Maximum	3.080	2.680	0.433	370.000
Average	3.020	2.663	0.419	370.115
Std. Dev.	0.03162	0.02160	0.01082	0.13172

Alarms
0 / 6

4 Missing Strands from 2.5mm² -- 3.27%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.930	2.560	0.405	370.000
Maximum	2.970	2.600	0.427	370.130
Average	2.958	2.580	0.419	370.022
Std. Dev.	0.01472	0.01673	0.00845	0.05307

Alarms
6 / 6

Process Capability Study -- Pull Test							
Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	350.00	3.09	2.69	0.48
2	330.00	500.00	34.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	2.50	Top

Pull Value	
Minimum	80.00
Maximum	98.00
Average	89.96
Std. Dev.	3.1811
Avg. - 3xSD	80.4166
Pull Spec.	55
Cpk	3.663

Pull Value	
Minimum	402.00
Maximum	470.00
Average	434.03
Std. Dev.	19.0520
Avg. - 3xSD	376.8740
Pull Spec.	275
Cpk	2.782

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	365.00	3.03	2.63	0.43
2	345.00	500.00	36.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	2.50	Top

Pull Value	
Minimum	83.00
Maximum	96.00
Average	90.43
Std. Dev.	2.7251
Avg. - 3xSD	82.2579
Pull Spec.	55
Cpk	4.334

Pull Value	
Minimum	409.00
Maximum	468.00
Average	441.17
Std. Dev.	17.0639
Avg. - 3xSD	389.9748
Pull Spec.	275
Cpk	3.246

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	300.00	300.00	0.00	380.00	3.10	2.55	0.42
2	360.00	500.00	38.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	2.50	Top

Pull Value	
Minimum	81.00
Maximum	99.00
Average	90.59
Std. Dev.	2.9885
Avg. - 3xSD	81.6245
Pull Spec.	55
Cpk	3.970

Pull Value	
Minimum	404.00
Maximum	474.00
Average	436.86
Std. Dev.	18.1926
Avg. - 3xSD	382.2822
Pull Spec.	275
Cpk	2.966

6.40mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	300	500	0	210
2	500	735	38	

End Height Tolerance %	
102.50%	98.00%
102.00%	97.50%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.310	2.060	0.169	210.670
Maximum	2.350	2.090	0.183	211.750
Average	2.330	2.075	0.173	211.135
Std. Dev.	0.01897	0.01049	0.00506	0.39389

Alarms
0 / 6

5 Missing Strands from 1.00mm² -- 4.10%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.230	2.000	0.170	210.400
Maximum	2.280	2.030	0.176	211.660
Average	2.253	2.013	0.173	210.983
Std. Dev.	0.01633	0.01033	0.00259	0.61171

Alarms
6 / 6

Process Capability Study -- Pull Test

Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	200.00	2.31	2.06	0.18
2	700.00	500.00	36.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	1.00	Top

Pull Value	
Minimum	87.00
Maximum	97.00
Average	91.57
Std. Dev.	2.3667
Avg. - 3xSD	84.4700
Pull Spec.	55
Cpk	5.151

Pull Value	
Minimum	201.00
Maximum	218.00
Average	207.75
Std. Dev.	4.3167
Avg. - 3xSD	194.7999
Pull Spec.	170
Cpk	2.915

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	210.00	2.34	2.07	0.16
2	700.00	500.00	38.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	1.00	Top

Pull Value	
Minimum	86.00
Maximum	102.00
Average	90.43
Std. Dev.	2.8969
Avg. - 3xSD	81.7427
Pull Spec.	55
Cpk	4.077

Pull Value	
Minimum	200.00
Maximum	218.00
Average	209.50
Std. Dev.	5.7521
Avg. - 3xSD	192.2438
Pull Spec.	170
Cpk	2.289

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	220.00	2.33	2.04	0.16
2	770.00	500.00	40.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	1.00	Top

Pull Value	
Minimum	84.00
Maximum	94.00
Average	89.14
Std. Dev.	2.3139
Avg. - 3xSD	82.1984
Pull Spec.	55
Cpk	4.918

Pull Value	
Minimum	202.00
Maximum	222.00
Average	211.04
Std. Dev.	4.8105
Avg. - 3xSD	196.6088
Pull Spec.	170
Cpk	2.844

7.90mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	150	500	0	240
2	500	840	38	

End Height Tolerance %	
102.00%	98.50%
101.50%	98.00%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.650	2.340	0.176	240.300
Maximum	2.700	2.400	0.181	241.290
Average	2.670	2.372	0.179	240.840
Std. Dev.	0.02098	0.02229	0.00172	0.45175

Alarms
0 / 6

1 Missing 0.35mm² wire -- 4.14%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.550	2.180	0.176	240.060
Maximum	2.630	2.300	0.180	241.400
Average	2.587	2.233	0.178	240.668
Std. Dev.	0.03204	0.04457	0.00163	0.55937

Alarms
6 / 6

Process Capability Study -- Pull Test							
Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	200.00	2.31	2.06	0.18
2	700.00	500.00	36.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	1.00	Top

Pull Value	
Minimum	88.00
Maximum	95.00
Average	90.20
Std. Dev.	1.2060
Avg. - 3xSD	86.5819
Pull Spec.	55
Cpk	9.729

Pull Value	
Minimum	204.00
Maximum	218.00
Average	209.58
Std. Dev.	2.7384
Avg. - 3xSD	201.3649
Pull Spec.	170
Cpk	4.818

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	210.00	2.34	2.07	0.16
2	735.00	500.00	38.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	1.00	Top

Pull Value	
Minimum	89.00
Maximum	94.00
Average	91.03
Std. Dev.	1.6709
Avg. - 3xSD	86.0206
Pull Spec.	55
Cpk	7.188

Pull Value	
Minimum	207.00
Maximum	217.00
Average	211.33
Std. Dev.	2.9750
Avg. - 3xSD	202.4084
Pull Spec.	170
Cpk	4.631

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	220.00	2.33	2.04	0.16
2	770.00	500.00	40.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	1.00	Top

Pull Value	
Minimum	88.00
Maximum	98.00
Average	91.10
Std. Dev.	1.9618
Avg. - 3xSD	85.2147
Pull Spec.	55
Cpk	6.134

Pull Value	
Minimum	205.00
Maximum	217.00
Average	210.32
Std. Dev.	2.6813
Avg. - 3xSD	202.2760
Pull Spec.	170
Cpk	5.012

9.05mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	300	500	0	525
2	500	470	38	

End Height Tolerance %	
101.12%	98.81%
101.29%	97.99%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.800	2.480	0.369	525.050
Maximum	2.930	2.530	0.414	525.950
Average	2.852	2.512	0.389	525.460
Std. Dev.	0.04535	0.01941	0.01494	0.34188

Alarms
0 / 6

1 Missing 0.35mm² wire -- 3.86%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.780	2.410	0.366	525.040
Maximum	2.850	2.460	0.391	525.930
Average	2.815	2.430	0.381	525.513
Std. Dev.	0.02881	0.02098	0.00948	0.38004

Alarms
6 / 6

Process Capability Study -- Pull Test							
Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	500.00	2.85	2.50	0.46
2	450.00	500.00	26.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	6.00	Top

Pull Value	
Minimum	88.00
Maximum	93.00
Average	89.53
Std. Dev.	1.1760
Avg. - 3xSD	86.0021
Pull Spec.	55
Cpk	9.788

Pull Value	
Minimum	1005.00
Maximum	1189.00
Average	1084.33
Std. Dev.	40.1686
Avg. - 3xSD	963.8242
Pull Spec.	435
Cpk	5.388

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	525.00	2.81	2.49	0.46
2	470.00	500.00	38.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	6.00	Top

Pull Value	
Minimum	88.00
Maximum	93.00
Average	89.43
Std. Dev.	0.9353
Avg. - 3xSD	86.6276
Pull Spec.	55
Cpk	12.272

Pull Value	
Minimum	1101.00
Maximum	1169.00
Average	1134.37
Std. Dev.	20.6790
Avg. - 3xSD	1072.3298
Pull Spec.	435
Cpk	11.273

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	550.00	2.81	2.46	0.43
2	490.00	500.00	40.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	6.00	Top

Pull Value	
Minimum	88.00
Maximum	92.00
Average	89.34
Std. Dev.	0.9663
Avg. - 3xSD	86.4411
Pull Spec.	55
Cpk	11.846

Pull Value	
Minimum	1031.00
Maximum	1187.00
Average	1121.17
Std. Dev.	28.5119
Avg. - 3xSD	1035.6342
Pull Spec.	435
Cpk	8.022

9.20mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	300	500	0	450
2	500	420	38	

End Height Tolerance %	
103.00%	98.00%
102.00%	97.00%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.820	2.460	0.336	450.050
Maximum	2.890	2.520	0.365	451.090
Average	2.853	2.502	0.354	450.427
Std. Dev.	0.02582	0.02229	0.01029	0.38790

Alarms
0 / 6

1 Missing 0.35mm² wire -- 3.80%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	2.700	2.160	0.341	450.540
Maximum	2.800	2.450	0.387	451.230
Average	2.751	2.356	0.360	450.811
Std. Dev.	0.04357	0.12443	0.02140	0.29181

Alarms
6 / 6

Process Capability Study -- Pull Test							
Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	450.00	2.86	2.52	0.39
2	400.00	500.00	36.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	4.00	Top

Pull Value	
Minimum	82.00
Maximum	99.00
Average	89.10
Std. Dev.	2.2984
Avg. - 3xSD	82.2047
Pull Spec.	55
Cpk	4.945

Pull Value	
Minimum	673.00
Maximum	874.00
Average	781.47
Std. Dev.	50.6023
Avg. - 3xSD	629.6630
Pull Spec.	375
Cpk	2.678

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	470.00	2.74	2.42	0.36
2	420.00	500.00	38.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	4.00	Top

Pull Value	
Minimum	85.00
Maximum	92.00
Average	89.17
Std. Dev.	1.8585
Avg. - 3xSD	83.5912
Pull Spec.	55
Cpk	6.128

Pull Value	
Minimum	647.00
Maximum	880.00
Average	755.70
Std. Dev.	50.9599
Avg. - 3xSD	602.8204
Pull Spec.	375
Cpk	2.490

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	300.00	0.00	490.00	2.74	2.42	0.36
2	440.00	500.00	40.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	4.00	Top

Pull Value	
Minimum	81.00
Maximum	95.00
Average	87.44
Std. Dev.	3.0528
Avg. - 3xSD	78.2816
Pull Spec.	55
Cpk	3.542

Pull Value	
Minimum	690.00
Maximum	883.00
Average	787.83
Std. Dev.	49.1604
Avg. - 3xSD	640.3487
Pull Spec.	375
Cpk	2.799

10.60mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	150	500	0	525
2	500	1260	38	

End Height Tolerance %	
104.00%	98.00%
102.00%	96.00%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	3.090	2.550	0.356	525.100
Maximum	3.160	2.640	0.404	525.840
Average	3.128	2.617	0.385	525.480
Std. Dev.	0.02317	0.03327	0.01782	0.29523

Alarms
0 / 6

1 Missing 0.35mm² wire -- 3.30%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	3.010	2.410	0.363	525.360
Maximum	3.120	2.540	0.424	525.740
Average	3.058	2.487	0.393	525.520
Std. Dev.	0.04070	0.04761	0.02136	0.18254

Alarms
6 / 6

Process Capability Study -- Pull Test							
Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	150.00	0.00	500.00	3.31	2.66	0.34
2	1200.00	500.00	36.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	6.00	Top

Pull Value	
Minimum	86.00
Maximum	94.00
Average	89.57
Std. Dev.	1.5522
Avg. - 3xSD	84.9135
Pull Spec.	55
Cpk	7.424

Pull Value	
Minimum	1090.00
Maximum	1280.00
Average	1168.92
Std. Dev.	46.7045
Avg. - 3xSD	1028.8066
Pull Spec.	435
Cpk	5.238

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	150.00	0.00	525.00	3.20	2.54	0.33
2	1260.00	500.00	38.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	6.00	Top

Pull Value	
Minimum	87.00
Maximum	96.00
Average	89.70
Std. Dev.	1.7449
Avg. - 3xSD	84.4652
Pull Spec.	55
Cpk	6.629

Pull Value	
Minimum	1097.00
Maximum	1278.00
Average	1181.80
Std. Dev.	50.1937
Avg. - 3xSD	1031.2189
Pull Spec.	435
Cpk	4.959

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	150.00	0.00	550.00	3.17	2.49	0.33
2	1320.00	500.00	40.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	6.00	Top

Pull Value	
Minimum	87.00
Maximum	96.00
Average	91.38
Std. Dev.	2.1404
Avg. - 3xSD	84.9587
Pull Spec.	55
Cpk	5.666

Pull Value	
Minimum	1051.00
Maximum	1268.00
Average	1159.15
Std. Dev.	39.0512
Avg. - 3xSD	1041.9964
Pull Spec.	435
Cpk	6.181

16.60mm² Combination

Weld Parameters				
Step	**Time (ms)**	**Force (N)**	**Amp. (µm)**	**Energy (J)**
1	150	500	0	735
2	500	1450	40	

End Height Tolerance %	
104.00%	98.00%
102.00%	96.00%

No Defects				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	3.930	3.330	0.427	433.860
Maximum	4.010	3.430	0.442	736.000
Average	3.983	3.385	0.433	685.400
Std. Dev.	0.03502	0.04087	0.00534	123.22952

Alarms
0 / 6

2 Missing 0.35mm² wires-- 4.21%				
	Start Height (mm)	**End Height (mm)**	**Time**	**Energy**
Minimum	3.830	3.200	0.422	735.250
Maximum	3.870	3.300	0.443	736.230
Average	3.852	3.253	0.431	735.858
Std. Dev.	0.01329	0.03204	0.00866	0.37134

Alarms
6 / 6

Process Capability Study -- Pull Test							
Minimum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	150.00	0.00	700.00	4.07	3.32	0.51
2	1400.00	500.00	38.00				

Pull 1	Wire Size (mm)	Position
Smallest	0.35	Bottom

Pull 2	Wire Size (mm)	Position
Largest	6.00	Top

Pull Value	
Minimum	87.00
Maximum	99.00
Average	93.27
Std. Dev.	2.8950
Avg. - 3xSD	84.5851
Pull Spec.	55
Cpk	4.406

Pull Value	
Minimum	1007.00
Maximum	1218.00
Average	1108.96
Std. Dev.	55.3649
Avg. - 3xSD	942.8653
Pull Spec.	435
Cpk	4.058

Nominal Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	150.00	0.00	735.00	4.07	3.28	0.50
2	1450.00	500.00	40.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	6.00	Top

Pull Value	
Minimum	87.00
Maximum	98.00
Average	92.00
Std. Dev.	2.4212
Avg. - 3xSD	84.7365
Pull Spec.	55
Cpk	5.094

Pull Value	
Minimum	1047.00
Maximum	1199.00
Average	1113.80
Std. Dev.	38.8821
Avg. - 3xSD	997.1536
Pull Spec.	435
Cpk	5.819

Maximum Weld Parameters							
Step	**Force (N)**	**Time (ms)**	**Amp. (µm)**	**Energy (J)**	**Start Height (mm)**	**End Height (mm)**	**Time (ms)**
1	500.00	150.00	0.00	770.00	4.08	3.24	0.47
2	1500.00	500.00	42.00				

Pull 1	**Wire Size (mm)**	**Position**
Smallest	0.35	Bottom

Pull 2	**Wire Size (mm)**	**Position**
Largest	6.00	Top

Pull Value	
Minimum	88.00
Maximum	99.00
Average	93.76
Std. Dev.	2.4582
Avg. - 3xSD	86.3854
Pull Spec.	55
Cpk	5.256

Pull Value	
Minimum	1027.00
Maximum	1183.00
Average	1113.78
Std. Dev.	30.1014
Avg. - 3xSD	1023.4759
Pull Spec.	435
Cpk	7.517

Discussion

The US-3020SRT showed the ability to consistently detect missing strands for all five wire bundle combinations (5.2mm², 5.35mm², 5.95mm², 6.10mm², 6.40mm²) at a range from 2.81% missing CSA to 4.10% missing CSA. The machine performed at 100% reliability, meaning that all welds nearest to 3% missing CSA triggered an alarm and the missing strands were detected. Welds were rejected at end height as the machine was able to detect a smaller CSA than calculated in the taught parameters. Additionally, the control group with no defect achieved 100% reliability without triggering an alarm meaning no welds were falsely rejected. All welds were defected in order to achieve as close to 3% missing CSA as possible.

The machine also showed a successful detection of retracted wires for all five wire bundle combinations (7.90mm², 9.05mm², 9.20mm², 10.60mm², 16.60mm²) at a range from 3.3% missing CSA to 4.21% missing CSA. The smallest wire for each combination was retracted (0.35mm² in all cases except for the 16.60mm² combination where two 0.35mm² wires were retracted), so the machine will be successful in detecting larger wires in each combination retraction at levels less than or equal to the ones tested. The machine performed at 100% reliability, meaning that all retracted wires nearest to 3% missing CSA triggered an alarm and the missing wire was detected. Welds were rejected at end height, meaning that the machine detected a smaller CSA for the bundle than previously taught in teach mode. Additionally, the control groups with no retracted wires achieved 100% reliability without triggering an alarm and no welds were falsely rejected. All welds were defected in order to achieve as close to 3% missing CSA as possible.

Following detection testing, a process capability study was done on each wire bundle combination under three different sets of parameters: minimum, nominal, and maximum. Weld step time remained constant for each set of parameters while force, amplitude, and energy all slightly increased from minimum-nominal-maximum. 100 samples were tested for the minimum and maximum parameters, while 30 samples were tested for the nominal weld parameters. After completion of sample creation, each sample was pull tested two separate times. The first pull test was executed using the smallest wire (0.35mm²) furthest away from the horn located on the bottom of the bundle. The second pull test was done using the largest wire in the combination closest to the horn located on top of the bundle. All pull test values (min, max, and avg.) fall well above the required specification for all 30 sets of capability study parameters ((minimum, nominal, maximum) x (10 separate wire bundle combinations)). Additionally, CPK values were calculated after each pull test, and all 60 of them are greater than the specified value of 2.

The parameters for each wire bundle combination were based on previous testing done with bundles of similar CSA. The first steps 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 acts to compress the wires and prevent start height fluctuations.

Conclusion

The testing procedure outlined allows for consistent testing of missing strands, and retracted wires in servo ring termination. The US-3020SRT showed the ability to detect +/- 3% missing strands at 100% reliability on wire bundle combinations of 5.2mm², 5.35mm², 5.95mm², 6.10mm², and 6.40mm² with varying amount of total wires. It also showed the ability to detect retracted wires at 100% reliability on wire bundle combinations of 7.90mm², 9.05mm², 9.20mm², 10.60mm², and 16.60mm². In addition to detecting these defects, the servo ring termination machine rejected zero welds without defects.

The pull tests CPK values for all of the combinations were above a value of 2.289, exceeding the targeted CPK value of 2.

TECH-SONIC, Inc.
2710 Sawbury Blvd.
Columbus, OH 43235
USA

+1-614-792-3117

www.tech-sonic.us
info@techsonicultrasonic.com

Company Representative:

Frank Myers
Sales & Marketing Manager
frank.m@techsonicultrasonic.com