Process Specification for the Laser Welding of Battery Assemblies

Engineering Directorate

Structural Engineering Division

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Process Specification for the Laser Welding of Battery Assemblies

Prepared by:	Signature on File	9/24/2019
	Clinton S. Denny Quality and Flight Equipment Division/NT4	Date
Reviewed by:	Signature on File	9/19/2019
	Sarah Luna Materials and Processes Branch/ES4	Date
Approved by:	Signature on File	01/21/2020
	Brian Mayeaux Materials and Processes Branch/ES4	Date

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1.0 SCOPE

This process specification provides the requirements that govern the Laser Welding (LW) of battery tabs to batteries, battery tabs, or other associated electronic components. Welding equipment includes both Gas Laser (CO2) and Solid-State Laser (Nd:YAG, Diode, Fiber) beam generators in both pulsed and continuous wave. Procedural and quality assurance requirements are given. All work instructions and Weld Procedure Specifications (WPSs) used during welding shall satisfy the requirements of this process specification and its applicable documents.

2.0 APPLICABILITY

This process specification applies to the LW of battery assemblies and associated electronic flight and non-flight hardware fabricated under the control of the NASA/Johnson Space Center (JSC). Battery assemblies are considered to be nonstructural with no load carrying capacity and shall be either potted, taped, shrink wrapped, or installed in a rigid containment to preclude stressing the tabs and lead wires.

3.0 USAGE

This process specification shall be called out on the engineering drawing by a drawing note with the following general format:

WELD AND INSPECT PER NASA/JSC PRC-0016

3.1 DESIGN REQUIREMENTS

a) The design of welded joints shall conform to the applicable hardware design handbooks contained in the JSC Library (library.sp.jsc.nasa.gov).

b) All engineering drawings shall depict welded joints using the applicable symbols described in AWS A2.4.

c) As required, all engineering drawings shall specify the minimum number and maximum number of laser welded spots required for each connection. In any case, there shall be no less than two weld spots per connection, unless a single spot is a spiral weld.

d) As applicable, all engineering drawings shall specify the maximum electrical resistivity allowed for each connection. Where resistivity is not specified, measurements shall not exceed 1.0 mΩ.

e) When welding occurs onto battery cells, the parts list shall contain the battery manufacturer, size, model/type no., and voltage rating.

f) The parts list shall contain the tab or contact material, specification, thickness, width, metallurgical condition (e.g., ¼ hard, ½ hard, etc.) and surface finish as applicable.

g) The parts list shall contain component leads (i.e., diode leads) gage, material, and metallurgical condition (e.g., metallurgical, surface finish, etc.) and surface finish as applicable.

h) Stranded wire shall not be laser welded.

3.2 LASER SAFETY

3.2.1 Safety Requirements

ANSI 2136.1 describes the minimum safety requirements for laser users.

3.2.2 Classification of Lasers

ANSI 2136.1 divides lasers into four broad categories based on their potential hazards.

Class 1 Laser Product: Considered to be incapable of producing damaging radiation levels during operation, and exempt from any control measures.

Class 1M Laser Product: Considered to be incapable of producing hazardous exposure conditions during normal operation unless the beam is viewed with collecting optics (e.g., telescope)and is exempt from any control measures other than to prevent potentially hazardous optically aided viewing.

Class 2 Laser Product: Emits in the visible portion of the spectrum (400 nm to 700 nm) and eye protection is normally afforded by the aversion response.

Class 2M Laser Product: Emits in the visible portion of the spectrum (400 nm to 700 nm) and eye protection is normally afforded by the aversion response for unaided viewing. However, Class 2M is potentially hazardous if viewed with collecting optics (e.g., telescope).

Class 3R Laser Product: Has reduced control requirements and is potentially hazardous under some direct and specular reflection viewing conditions if the eye is appropriately focused and stable, but

the probability of an actual injury is small. This laser will not pose either a fire hazard or diffuse reflection hazard.

Class 3B Laser Product: May be hazardous under direct and specular reflection viewing conditions, but is normally not a fire hazard, diffuse reflection hazard, nor a laser generated air contaminant (LGAC) production hazard.

Class 4 Laser Product: Is a hazard to the eye or skin from the direct beam, may pose a fire hazard or diffuse reflection hazard, and may also produce LGAC and hazardous plasma radiation.

3.3 WORK INSTRUCTIONS

Work instructions shall be generated for implementing this process specification. The work instructions shall contain sufficient detail to ensure that the manufacturing process produces consistent, repeatable products that comply with this specification. At JSC, these work instructions are approved as Detailed Process Instructions (DPIs) or Work Authorization Documents (WADs) that describe in a detailed, step-by-step format the required procedures, equipment, and materials to be used for conducting a given process.

If this manufacturing process is to be performed by an outside vendor, work instruction development shall be the responsibility of the vendor. The responsible engineering organization shall ensure that the work instructions meet the requirements of this process specification.

3.4 DEFINITIONS

Carbon Dioxide Laser (CO2) - A gas laser that use carbon dioxide as the lasing medium.

Continuous Wave - A laser beam that is produced continuously rather than a series of pulses.

Diode Laser - A type of laser in which the active medium is a semiconductor with polished end facets forming mirror surfaces.

Essential Variable - An identified variable in the welding process that must be controlled to ensure repeatable weld quality.

Fiber Laser - A solid-state laser design in which the active medium is a doped optical fiber.

Missed Weld - Any weld that has been specified on the drawings but has been overlooked by the welding operator shall be identified and welded to meet the drawing requirements.

Nd:YAG - Neodymium-doped yttrium aluminum garnet crystal which is utilized as the lasing material in a common type of solid-state laser.

Open Weld - An open weld is one in which a weld has been attempted but no bonding has occurred.

Pulsed Laser - A laser which emits light as a pulse or a series of pulses rather than continuously.

Unique Weld Type - Those weld joint configurations that differ from one another in any of the following respects:

1. Battery anode and/or cathode cross sectional thickness (±10%),
2. Anode and/or cathode material, metallurgical condition, and surface finish,
3. Jumper tab cross sectional thickness (±10%),
4. Jumper tab material or metallurgical condition.
5. Component lead/wire material, metallurgical condition, and surface finish,
6. Component lead material/wire cross sectional diameter (±10%).

4.0 REFERENCES

The standards listed below shall be considered a part of this specification to the extent specified herein. Unless otherwise indicated, the revision that is in effect on the date of invitation for bids or the date of request for proposals shall apply.

a. American National Standards Institute

ANSI 2136.1	*Safe Use* of *Lasers*

b. American Welding Society (AWS) Standards

ANSI/AWS A2.4	*Standard Symbols* for *Welding, Brazing and Nondestructive Testing*
ANSI/AWS A3.0	*Standard Welding Terms and Definitions*
ANSI/AWS C7.2	*Recommended Practices for Laser Beam Welding, Cutting, and Allied*

c. NASA/JSC Documents

JPG 1700.1G	*NASA/JSC Requirements Handbook for Safety, Health and Environmental Protection*
EM-007.1	*Preparation and Revision* of *Process Specifications*
Tl-0000-04	*Training For Welders and Welding Operators for Laser Beam Welding*

5.0 MATERIAL AND EQUIPMENT REQUIREMENTS

All materials used in the welding of electronically related flight hardware shall meet the requirements of an applicable JSC material specification unless otherwise specified. If a JSC material specification is not available, an applicable commercial specification or a manufacturer's specification shall be used.

5.1 EQUIPMENT

The equipment used to produce the welds should consist of a self-contained Class 1 eye-safe enclosure including a laser generator, beam delivery and optical hardware, and a motion control system and fixturing hardware. In the event that a Class 2, 3 or 4 laser is to be used, the user shall ensure that the required controls and personnel training are performed in accordance with ANSI Z136.1.

5.1.1 Laser Generator

The laser generator shall be capable of meeting all of the essential variable requirements listed in Table 1, 1-4.

5.1.2 Beam Delivery and Optical Hardware

The beam delivery hardware shall safely and consistently convey the laser beam from the laser generator to the workpiece.

5.1.4 Motion Control System & Fixture Hardware

The motion control system shall safely and consistently control the speed and path of the part or laser beam while the fixturing hardware safely and consistently position and locate the workpiece.

5.1.5 Welding Equipment Qualification

The welding equipment shall be qualified as a system that includes at a minimum, a laser generator, laser beam delivery hardware and motion control system & fixturing. Qualification of a Welding Procedure Specification also qualifies the system. Otherwise, qualification of a system shall be per 6.1.4.

6.0 PROCESS REQUIREMENTS

All weldments shall be fabricated according to the requirements of this process specification. The requirements of the applicable codes and standards listed in Section
4.0 shall be met as specified by this PRC based on the design and intended function of the hardware. Certain paragraphs of this process specification are abbreviated re-statements taken from the applicable standards and are included here for the clarification. The remaining paragraphs of this process specification may represent requirements imposed in addition to the basic requirements of the applicable codes and standards.

All laser welding shall be performed using Welding Procedure Specifications (WPS) that have been qualified in accordance with the requirements of Section 6.1.4.

6.1 WELD QUALIFICATION

A Welding Procedure Specification (WPS) shall be qualified for each unique weld type to be produced by conforming to the requirements below, before the production welds are made. An existing qualified WPS for one unique weld type may be used for a new engineering drawing provided the resistivity determined during qualification meet the requirements of the new drawing as applicable, and it is demonstrated that the essential weld variables will be met. Demonstration shall constitute all the requirements of Section 6.1.2 except that no additional documentation is required (existing Procedure Qualification Record (PQR) and WPS records shall be acceptable documentation).

6.1.1 Qualification of WPS

The actual welding variables, methods, practices, specific tooling requirements, and test results used during WPS qualification shall be recorded on a PQR. Refer to section 6.1.4 for the requirements needed for the qualification of a welding procedure.

6.1.2 Requalification of WPS

Requalification of the WPS shall be required when any of the following conditions exist:

a) The weld system has been placed on a different external power source except when the power supply has a means for internal power regulation,
b) A WPS is proposed to be used on a weld system or systems other than that used for the initial qualification,
c) Major maintenance has been performed on the weld system which shall include but not limited to the replacement of components.
d) Preproduction weld samples do not meet requirements and no assignable cause for the failure can be determined.

Requalification may be performed with less total test sample requirements than that required for an initial qualification for a unique weld type. For requalification, 5 total weld samples shall be produced and submitted as a lot. All 5 samples shall be subjected to visual inspection and conductivity and destructive peel testing and shall meet the applicable requirements specified herein. No requalification specimens from the 5 submitted shall fail any of the requirements as stated herein. Requalification results shall be documented on a PQR with a specific notation made indicating "requalification". If the requalification activities result in any welding parameter deviations that exceed the range specified in Table 1 for that parameter, then the level of testing in 6.1.4 shall be required.

6.1.3 Essential Variables

All essential variables shall be addressed and identified on a qualified WPS and the supporting PQR. These essential variables are listed in Table 1 below. Other variables determined to be essential to maintaining the quality of the process output may be required to be controlled, as determined by the Materials and Processes (M&P) organization.

TABLE 1: ESSENTIAL WELDING VARIABLES

NUMBER	ESSENTIAL VARIABLES	VARIABLE RANGE
	Laser Generator	
1	Power Range change	±5%
2	Pulse Energy change	±5%
3	Pulse Length change	±5%
4	Pulse Rate change	±5%
	Laser Beam Delivery Hardware	
5	Lens Focal Length change	±5%
6	Focal Point Setting change	±5%
7	Unfocused Beam Diameter change	±10%
8	Beam Manipulation Method	NONE
9	Other Beam Delivery Parameters	±10%
	Motion Control System & **Fixturing**	
10	Surface Speed change	±5%
11	Single to Multiple Passes	NONE
12	Angle of Beam Axis change	±5%
13	Change from Qualified Welding Position	NONE
14	Nozzle Gas Type change	NONE
15	Auxiliary Shielding Gas Type change	NONE
16	Flow Rate or Pressure of Process Gas change	±10%
17	Change in Purge Atmosphere from One Gas to any Other	NONE
18	Change from Atmosphere to Purge Environment & Vice Versa	None
	Materials	
19	Battery Anode/Cathode Material change	NONE
20	Battery Anode/Cathode Material Thickness change	±10%
21	Battery Anode/Cathode Metallurgical Condition change, e.g. ½ Hard,¼ Hard, Wrought, Cast, etc.	NONE
22	Battery Anode/Cathode Surface Finish change, e.g. Cold Finished, Hot Finished, Plated, etc.	NONE
23	Jumper Tab Material change	NONE
24	Jumper Tab Material Thickness change	±10%
25	Jumper Tab Metallurgical Condition change, e.g. ½ Hard, ¼ Hard, etc.	NONE
26	Jumper Tab Surface Finish change, e.g. Cold Finished, Hot Finished, Plated, etc.	NONE

	Joint Design	
27	Change in Joint Design from that Qualified	NONE
28	Change in Joint Gap Beyond the Tolerance Qualified	NONE

6.1.4 Qualification Samples

6.1.4.1 General

The manufacturing organization is responsible for qualifying the welding process. Actual cathode and anode ends for the same make, size, and model/type battery used in the design shall be obtained for use as qualification and preproduction control samples. Actual batteries may be also used for qualification and/or preproduction control samples. Wire/leads of the same material and construction as component leads, or actual components used in the design, shall also be supplied when appropriate.

6.1.4.2 Qualification Materials

For each unique type of weld to be performed, a minimum of sixteen (16) sample welded connections shall be produced for an initial procedure qualification and submitted as a lot. Weld control settings shall not be varied nor shall any maintenance be performed on the equipment during the production of the qualification samples. The number of weld spots on each qualification sample connection shall not exceed the maximum number required per the engineering drawing or if not specified shall be no greater than 2 spots per connection or that planned for production work. The qualification sample set shall be acceptable to all of the following 4 levels of quality control for successful qualification: 1) visual inspection, 2) conductivity (resistivity) testing, 3) destructive peel testing, and 4) metallurgical examination.

6.1.4.3 Visual Inspection and Electrical Conductivity Testing

All weld specimens shall be visually inspected per 7.3 and tested for electrical conductivity (resistivity). The resistivity of each connection shall meet the drawing requirements or if not specified by the drawing, shall measure less than 1.0 mQ. If any of the individual samples from those submitted fail to pass the visual or resistivity requirements, an additional sample shall be allowed to be welded and submitted to replace it, one time only. If more than 2 samples from the original lot fail the visual or resistivity requirements further weld parameter development or process analysis to determine the cause for the rejection(s) is required prior to submitting another lot of samples for testing to the requirements of this specification.

6.1.4.4 Destructive Peel Testing

Fifteen (15) of the sixteen (16) weld samples shall be peel tested. The edges of a laser welded sample connection shall be gripped and pulled apart to failure. The welded connection (lap joint) shall be pulled in tension at an approximate 90° angle to the plane of the faying joint surfaces. See Figure 1. The length of the grip sections on the samples shall be long enough to preclude any interference of the gripping hardware with the welded connection. For a procedure qualification or pre-production verification sample set to be considered acceptable, the result of the peel test must be a plug pull- out in a minimum of 75% of the total number of individual spots in the sample set for connections with 4 or more spots, 85% for connections with 3 spots only, and 100% for connections with 2 or less spots. If any of the individual samples from the 15 peel tests fail to result in at least 2 plug pull-outs from the total number of weld spots on the individual connection, 2 additional welded sample connections may be welded and submitted for inspection and testing as part of the initial sample set, one time only.

These 2 samples shall then be factored into the above acceptance criteria. If more than 2 samples from the original lot fail the peel test as described above, further weld parameter development or process analysis to determine the cause for the failure(s) is required prior to submitting another 16 samples for testing to the requirements of this specification. If the minimum plug pull-out requirement for the total number of individual spots in the sample set (i.e., 75%, 85%, or 100% for the respective condition) cannot be met as described above, further weld parameter development or process analysis to determine the cause for the failure is required prior to submitting another lot of samples for testing to the requirements of this specification.

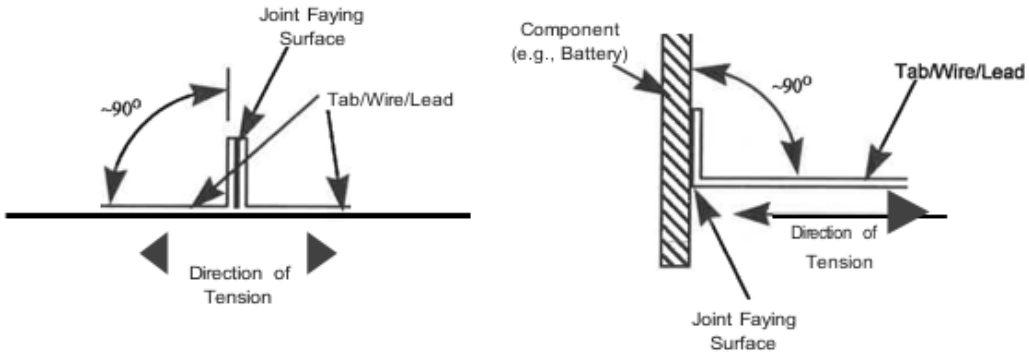

Figure 1 - Peel Test Examples

6.1.4.5 Metallurgical Examination

One (1) of the 16 samples submitted shall be cross-sectioned, mounted, polished,

and etched for metallurgical examination. For samples involving a wire or component leads, one each weld spot on the connection will be cross sectioned transverse to the wire diameter and longitudinal to the wire diameter **axis** and for Series Welded samples, cross sections of both weld spots produced by one weld cycle shall be taken. See Figure 2.

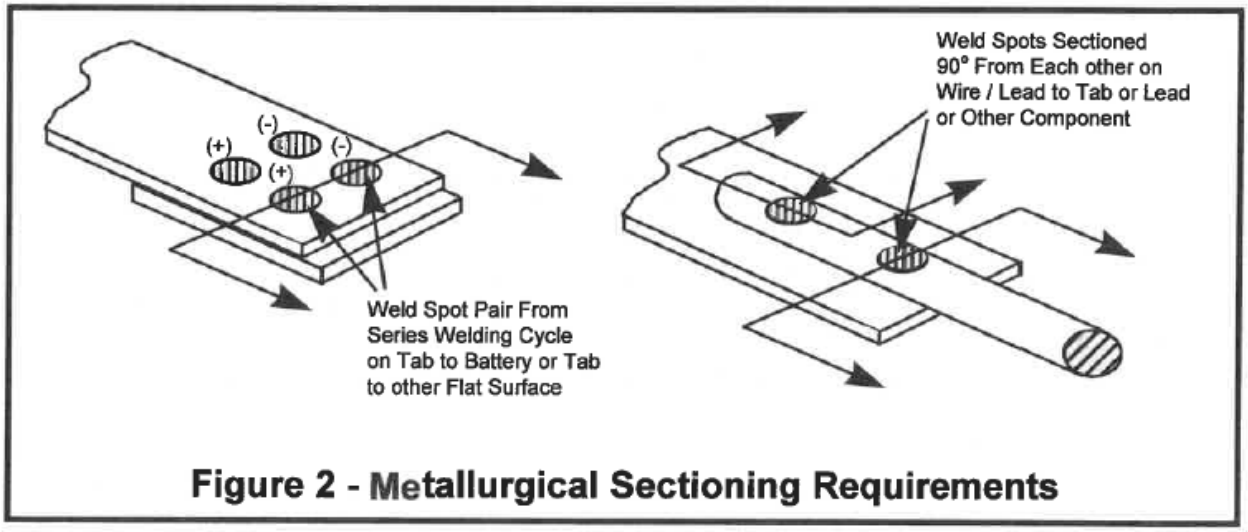

Figure 2 - Metallurgical Sectioning Requirements

The welds shall be free of cracks or voids open to any exterior surface. Pores and voids contained within the weld zone but not open to an exterior surface, and are not determined to have sharp notch like characteristics, shall be acceptable. When examining welds intended for battery cells, any anomaly which is determined to be a potential for breaching or degrading the battery housing and therefore potentially causing a leak, shall be cause for rejection. In addition, a metallurgical fusion bond shall be visible at each weld spot interface. If this criteria cannot be met, further weld parameter development or process analysis to determine the cause for the rejectable condition, is required prior to submitting another lot of samples for testing to the requirements of this specification. Photomicrographs shall be taken of the prepared samples and retained with the PQR.

7.0 PROCESS VERIFICATION

Process verification shall consist of visual examination and destructive testing, when required, as described further in sections 7.1 to 7.3. In addition, at the appropriate time during the fabrication activities, the manufacturing activity shall assure the following items:

a) The operator is certified for the specific welding operation,
b) A valid WPS exists,
c) The essential variable ranges for the WPS are being adhered to.

7.1 PREPRODUCTION WELDING SYSTEM VERIFICATION TEST

Prior to the start of a production run, a minimum of 1 pre-production weld sample for each unique type of weld shall be prepared using the appropriate qualified WPS. Actual batteries and component leads or simulated ones, as described in section 6.1.4.1, shall be used for this preproduction weld sample. The sample shall be visually inspected, in accordance with Section 7.3, and peel tested, in accordance with Section
6.1.4.4. The pre-production sample shall be made and tested before the welding of the production welds and under the following conditions:

a) At the start of a production shift or the change of production shifts,
b) Following a delay in welding of more than 4 hours and where the welding system was required to be powered down during this period,
c) Where a different operator was assigned to the workstation to continue a job.

Different WPSs may be alternated within a production welding session provided that a pre-production weld sample is produced and visually inspected per 7.3 and peel tested in accordance 6.1.4.4.

7.2 WELD VERIFICATION

Prior to encapsulation, potting, or any process which would preclude inspection of the welds, all welds and workmanship shall be inspected for conformance to the requirements of this standard and the engineering drawing. If a nonconformance is identified it shall be documented appropriately and/or be dispositioned by a Materials Review Board (MRB). If the welds of a completed welded module or assembly cannot be inspected after the assembly is complete, the module or assembly must be inspected at selected points during assembly to assure inspection of each weld in the module.

7.3 VISUAL INSPECTION

All welds shall be inspected visually at a magnification of 30X. The welds shall conform to the following visual inspection criteria:

a. Cracks - None Allowed.
b. Incomplete fusion - None Allowed.
c. Porosity (Individual Size) - 0.25 T or 0.030" whichever is less.
d. Porosity (Spacing) - 8 times the size of the larger adjacent discontinuity.
e. Undercut (maximum depth) - 0.070 T or 0.030" whichever is less.
f. Craters (maximum depth) - 0.020 T or 0.030" whichever is less.
g. Coloration - Black is unacceptable.
h. Open Weld - Unacceptable.

7.4 WELD REPAIRS AND REWORK

Any weld that has been indicated as having a defect (with the exception of an Open Weld or a Missed Weld) as listed in 7.3, or as not meeting the requirements specified on the drawing, may be rewelded no more than 1 time at the same location where the original weld was attempted. An Open or Missed Weld shall be reworked to provide an initial weld per the engineering drawing. If a reweld attempt is unsuccessful, a discrepancy report shall be generated and shall require dispositioning by the responsible engineering organization. Two unsuccessful reweld attempts shall require dispositioning by the Material Review Board (MRB). The level of documentation of repair welds shall, at a minimum, be consistent with that required for the original production weld. All rewelds shall be performed using the WPS used for the original weld or a specific qualified WPS for that repair and shall meet all of the requirements of the original drawing and any additional requirements that are documented in the WPS.

8.0 PROCESS DOCUMENTATION REQUIREMENTS

The WPS, PQR, and Weld Operator Performance Qualification (WOPQ) shall be prepared and retained as a permanent record and made available upon request to the NASA/JSC M&P organization for review. These procedures must contain, at a minimum, all of the essential welding parameters, an identification of the welding equipment, and include any pertinent tooling information. One copy of the WPS shall be maintained in the vicinity of the welding station and shall be readily accessible by the welders, inspectors, supervision, and/or engineering.

8.1 WELDING PROCEDURE SPECIFICATION

A WPS is a qualified written working procedure that must be developed before beginning production for each unique weld type to be produced. Qualification support documentation in the form of a PQR shall be maintained on file to show proof of process/procedure capability using the WPS. The WPS shall be traceable by means of serialized nomenclature and shall show traceability to the applicable PQR(s). The WPS used for production welding shall meet the requirements of this process specification and shall be certified by the responsible M&P organization at the operating facility, prior to use in production. Appendix A is an example of a WPS however, any format is considered acceptable provided all the information and data necessary to successfully perform the welding activity is available and displayed clearly.

8.2 PROCEDURE QUALIFICATION RECORD

A PQR is documentation to support the welding procedure specification to show proof of process/procedure capability. A PQR shall be unique and traceable, by means of serialized nomenclature. The PQR shall be process specific and specific to a unique

weld type. Data required in the PQR shall include detailed descriptions of the test coupon configurations and joint designs, all pertinent material specifications, all pertinent essential process variables used, all destructive and nondestructive test results from the qualification sample set, and all required certifications from the approving organization. The PQR shall be approved by the responsible M&P organization at the operating facility. Appendix B is an example of a PQR however, any format is considered acceptable provided all the information and data necessary to accurately document the process is made available and displayed clearly.

8.3 WELDING OPERATOR PERFORMANCE QUALIFICATION

A WOPQ is documentation that shows that a welder has been tested in accordance with this PRC and shown competent to produce a sound weld for a specific welding process/base material/equipment combination. Appendix C is an example of a WOPQ, however, any format is considered acceptable provided all the information and data necessary to accurately document the operator's performance qualification is made available and displayed clearly.

8.4 DEVIATIONS AND WAIVERS

Any deviations or waivers regarding the use of this process specification shall be requested in writing by the outside vendor. This request shall be directed to the NASA/JSC M&P organization with the appropriate justification and rationale. A written response will be provided upon such a request.

9.0 TRAINING AND CERTIFICATION OF PERSONNEL

9.1 TRAINING

At JSC, if welding operator training is considered necessary prior to qualification/requalification of existing JSC welding operator personnel or the initial qualification of new hires, it shall be conducted in accordance with TI-0000-04. For an outside JSC vendor, welding operator training (when necessary) should consist of practice using the facility welding equipment with a specific WPS to demonstrate proficiency, under the supervision of a qualified/certified welding operator or designated training personnel. Specific development of an appropriate training program shall be the responsibility of the vendor. LW is a potentially hazardous joining process because of the high energies involved. Training shall include adequate exposure to all welding equipment manufacturer's instructions and applicable industry standards relating to safety and where applicable, to the specific hazards related to batteries. All JSC organizations and their contractors who engage in handling batteries shall be trained in all approved guidelines and procedures for working with and handling batteries. Safety related documents listed in Section 4.0 of this PRC form a part of these safety precautions and notes to the extent specified herein.

9.2 WELDING OPERATOR QUALIFICATION

Laser welding of battery and related electronic assemblies shall be performed by a welding operator qualified and certified in accordance with NASA/JSC PRC-0016. Sufficiently detailed records shall be maintained by the manufacturing organization executing the process(es). These records shall be made available to the NASA/JSC M&P organization upon request. Minimum requirements for qualification/certification shall be demonstrated by either of the following:

a) The operator must have successfully performed a PQR qualification or requalification to a written WPS per this specification, or
b) The operator must have been judged competent in the process and use of the equipment, by the responsible M&P engineering representative, by successfully demonstrating the application of a qualified WPS. This shall include demonstration to the qualifier (certifying representative), laser welding machine operation, schedule/parameter selection, workpiece setup and final weld results.

APPENDIX A

Welding Procedure Specification (WPS)

NASA / Johnson Space Center
Welding Procedure Specification (WPS) / Laser Welding (LW)

WPS # :_____ Revision:_____ PQR # :_____ Date in Effect :_____

Laser Equipment Identification

Owner / Location :_____
Manufacturer / Model :_____
Laser Type :_____
Serial Number :_____
Wave Length :_____
Power Rating (watts) :_____

Materials

Battery

Manufacturer :_____
Type / Size :_____
Material Type / Metallurgical Condition :_____
_____
Anode Thickness (± 10%) :_____
Cathode Thickness (± 10%) :_____
Surface Condition :_____

Connecting Components / Component Materials

Manufacturer :_____
Type / Temper :_____
Heat Number :_____
Thickness / Width (± 10%) :_____
Surface Condition :_____
Component Lead Material :_____
Component Lead Gage :_____

Gas Shielding

Gas Type / Composition :_____
Gas Flow Rate / Pressure (± 10%) :_____
Prepurge Time :_____
Post Purge Time :_____
Gas Nozzle Diameter :_____
Other :_____

Variables

Power Range (± 5%) :_____
Pulsed or Continuous :_____
Pulse Rate (± 5%) :_____
Pulse Energy (± 5%) :_____
Pulse Length (± 5%) :_____
Pulse Width :_____
Lens Focal Length (± 5%) :_____
Focal Point Setting (± 5%) :_____
Unfocused Beam Diameter (± 10%) :_____
Weld Beam Angle (± 5%):_____
Lens to Workpiece Distance :_____
Delivery Optics :_____
Travel Speed :_____
Axis :_____
Nozzle to Workpiece Distance :_____
Ramp Up & Down Time :_____
Other :_____
_____

Joint Design

We certify that the statements in this data sheet are correct and the test welds were welded and tested in accordance with PRC-0016.

By:_____ Date:_____

By:_____ Date:_____

Page 1 of 1

APPENDIX B

Procedure Qualification Record (PQR)

NASA / Johnson Space Center

Procedure Qualification Record (PQR) / Laser Welding (LW)

Procedure Qualification Record # : _____ Date : _____ Initial Qualification : _____ Requalification : _____

Laser Equipment Identification

Owner / Location : _____
Manufacturer / Model : _____
Laser Type : _____
Serial Number : _____
Wave Length : _____
Power Rating (watts) : _____

Materials

Battery

Manufacturer : _____
Type / Size : _____
Material Type / Metallurgical Condition : _____
_____
Anode Thickness : _____
Cathode Thickness : _____
Surface Condition : _____

Connecting Components / Component Materials

Manufacturer : _____
Type / Temper : _____
Heat Number : _____
Thickness / Width : _____
Surface Condition : _____
Component Lead Material : _____
Component Lead Gage : _____

Gas Shielding

Gas Type / Composition : _____
Gas Flow Rate / Pressure : _____
Prepurge Time : _____
Post Purge Time : _____
Gas Nozzle Diameter : _____
Other : _____

Variables

Power Range : _____
Pulsed or Continuous : _____
Pulse Rate : _____
Pulse Energy : _____
Pulse Length : _____
Pulse Width : _____
Lens Focal Length : _____
Focal Point Setting : _____
Unfocused Beam Diameter : _____
Weld Beam Angle : _____
Lens to Workpiece Distance : _____
Delivery Optics : _____
Travel Speed : _____
Axis : _____
Nozzle to Workpiece Distance : _____
Ramp Up & Down Time : _____
Other : _____
_____

Joint Design

We certify that the statements and photomicrographs in this data sheet are correct and the test welds were welded and tested in accordance with PRC-0016. The photomicrographs shall form a part of this PQR to the extent specified in the current revision of PRC-0016.

By: _____ Date: _____

By: _____ Date: _____

Page 1 of 3

NASA / Johnson Space Center

Procedure Qualification Record (PQR) / Laser Welding (LW)

Procedure Qualification Record # : _____ Date : _____ Initial Qualification : _____ Requalification : _____

Inspection and Testing Results

Sample Number	Cathode, Anode Or Bus Bar	Visual Inspection	Resistivity (m-ohms)	Peel Test # Nugget Pull-Outs	Peel Test UTS (lbs.)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					
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We certify that the statements and photomicrographs in this data sheet are correct and the test welds were welded and tested in accordance with PRC-0016. The photomicrographs shall form a part of this PQR to the extent specified in the current revision of PRC-0016.

By: _____ Date: _____ By: _____ Date: _____

Page 2 of 3

NASA / Johnson Space Center

Procedure Qualification Record (PQR) / Laser Welding (LW)

Procedure Qualification Record # : _____ Date : _____ Initial Qualification : _____ Requalification : _____

Metallurgical Testing Results

We certify that the statements and photomicrographs in this data sheet are correct and the test welds were welded and tested in accordance with PRC-0016. The photomicrographs shall form a part of this PQR to the extent specified in the current revision of PRC-0016.

By: _____ Date: _____ By: _____ Date: _____

Page 3 of #

Appendix C

Weld Operator Qualification Record (WPQR)

Laser Welding (LW)

Welding Operator Performance Qualification

Welding Operator: _____ Date: _____

Company: _____

WPS: _____

Weld Machine: _____

Materials: _____

_____

Qualification Demonstration

Welding Machine Operation: _____

Schedule Parameter Selection: _____

Workpiece Setup: _____

Weld Cycle Execution: _____

Weld Sample Inspection –

Visual: _____

Peel Test: _____

Anode / Cathode : Number of Plug Pull Outs / Total: _____

Other Materials : Number of Plug Pull Outs / Total: _____

LW Operator Qualification Test Results: _____

I certify that the Laser Welding Operator Performance Qualification was conducted in accordance With the requirements of the current revision of JSC, PRC-0016.

Qualifier: _____ Approved By: _____