LEVEL III QMS

Title: Electrical Discharge Machining for Suppliers

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Department: SUPPLY CHAIN MANAGEMENT

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ADDITIONAL APPROVALS

Justin Liguori; Joy Plecker

REVISION/CHANGE RECORD

<table>
<thead>
<tr>
<th>Version</th>
<th>Description</th>
</tr>
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<tr>
<td>1.0</td>
<td>New</td>
</tr>
<tr>
<td>2.0</td>
<td>Updated Section 3.4.2.1 microstructure magnification to 400x and 3.4.3.1 to include hydrogen embrittlement relief. Added Process Procedure template, added Table 1 Material Groupings, Exemptions Section 1.1, 3.4.2.3 instructions for measuring HAZ, 3.4.2.4, and 3.4.3.3.</td>
</tr>
<tr>
<td>3.0</td>
<td>Updated approvals section and corrected numbering format.</td>
</tr>
<tr>
<td>4.0</td>
<td>Re-ordered section 3.3 and 3.4 to match SPX-00008468 (internal EDM procedure). Minor editorial changes to clarify intent.</td>
</tr>
</tbody>
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1 PURPOSE

This document provides processing and acceptance requirements for electrical discharge machining (EDM) when applied to the manufacturing of SpaceX parts. EDM is a controlled process that requires SpaceX qualification and approval as described herein. Approved suppliers are listed in the SpaceX ASL.

1.1 Exemptions

1.1.1 Parts with EDM surfaces that are subsequently machined to remove 0.005” material or more are exempt from the requirements of this specification.

1.1.2 Parts made out of the following materials are considered insensitive to recast and are exempt from recast characterization and removal requirements provided that surface finish requirements are met: Nickel 200 and 201; Monel 400; Copper C10100 and C11000.

1.1.3 Except when required on the engineering drawing or purchase orders, recast layer removal from lockwire holes is not required.

1.1.4 In certain applications, the recast layer may be left on part surfaces if an engineering evaluation shows that they are not of consequence to the required performance of the part. The cognizant SpaceX engineer will provide additional guidance in these special cases.

2 DEFINITIONS

ASL – Approved Suppliers List. Available at www.spacex.com/legal

Electrical Discharge Machining (EDM) – The process of metal removal by electrical spark discharge between an electrode and the work piece in the presence of a dielectric fluid that allows formation of the spark. Once the spark is created between the electrode and the part, the metal removal takes place by melting and vaporization. A recast layer will remain on the work piece surface after the EDM operation is complete.

Recast Layer – A layer of material created by localized melting of the work piece material that solidifies before being removed and has different physical and mechanical properties than the base material. The recast layer is attached to the base metal and may contain cracks. The heat affected zone (HAZ) from underneath the recast layer is not considered part of the recast layer.

Heat Affected Zone (HAZ) – The layer beneath the recast layer that exhibits a different microstructure (grain size, precipitate size, precipitate morphology or precipitate distribution) than the base material.

Process Procedure Operation Sheet, Shop Router or Work Instructions – A document that contains at least all applicable parameters in accordance with this specification and is routed throughout the entire machining process.

Adequate Lighting – Uniform lighting with white light intensity of greater than 1000 LUX or greater than 93 Foot Candles at the part. No shadows or bright spots shall be present when examining the parts.

Lot/Batch – All parts set up under the same conditions and submitted for acceptance at one time.
3 REQUIREMENTS

3.1 Equipment

3.1.1 EDM Machine

The EDM machine and supporting equipment shall be capable of controlling the control factors listed in 3.3.2.

3.1.2 Dielectric Fluid

EDM fluids and associated maintenance intervals shall be selected such that part surfaces after EDM are conforming to the cleanliness requirements in 4.2.

3.1.3 Jigs and Fixtures

Shall be of material which leaves no visible residue on parts when evaluated by visual examination under adequate lighting with no magnification.

Shall not leave metallic contaminants such as copper, zinc, lead, iron or aluminum on the parts. These materials may react with spacecraft propellants.

3.2 Cleanliness

3.2.1 Visible contaminants (when observed by inspection using visual examination under adequate lighting with no magnification) such as surface oxides, grease and oils shall be removed from part surfaces prior to electrical discharge machining.

3.2.2 Parts shall be 100% visually examined prior to EDM processing.

3.3 Processing

3.3.1 Process Procedure

Each part shall be EDM processed using a documented process procedure. Processing parameters are not expressly defined in this specification since they are dependent upon the requirements of the product. The factors listed in 3.3.2 shall be controlled as application to the specific process and equipment used. Documented process procedures for EDM processing shall include, as a minimum, the applicable control factors in 3.3.2. In addition, the procedure shall include revision control.

3.3.2 Required control factors shall include, but not be limited to, the following:

- Size of the spark gap
- Voltage and/or amperage
- Frequency of electrical pulse
- Feed rate
- Dielectric Type
- Dielectric Pressure
- Flow of dielectric fluid, including fluid cleanliness and freedom from recycled particulates
- Dielectric fluid conductivity limits for water based dielectric fluid
On time
Off time
Sensitivity
Wire or Electrode (material, shape, coating etc.)
Type and method of flushing

3.3.3 Rework

If EDM part dimensions do not meet requirements, rework is permitted to the original approved process procedure.

3.3.4 Recast/HAZ Removal Requirements

3.3.4.1 Recast Removal Requirement

The recast layer shall be 100% removed from fracture critical and fatigue critical surfaces. Surfaces shall be identified on the drawing or work order. If no surfaces are identified on a drawing labeled “fracture critical” it shall be assumed that all surfaces are fracture critical. Acceptable removal methods include mechanical removal and etch processes. The work order shall define the process steps and removal depth. Material removal requirements shall be based upon the depth of the recast layer as determined in 5.1.1 or 5.1.2.

Recast layer severely impacts corrosion resistance of stainless steels, especially those containing less than 18% chromium (such as 15-5PH). The recast layer should be removed from all stainless steel parts/surfaces that are exposed to the environment, regardless of whether or not they are labeled as fracture critical. Recast removal verification may be accomplished by corrosion testing after passivation. In these cases, metallographic characterization is not required, however, passivation verification shall be performed per AMS 2700, Class 2, using Test method 101 (humidity) or 104 (salt spray). Samples for testing shall be a production part or processed from the same material, using the identical parameters as production parts.

Chemical or electrochemical removal methods shall be controlled per the requirements of one of the following specifications or internally developed and qualified procedures.

- NASA-PRC-5010 Process Pickling Etching Descaling Metals. (Alternate chemical bath compositions are permissible provided that the process is qualified and controlled)
- ASTM B912 Standard Specification for Passivation of Stainless Steels Using Electropolishing
- ASTM B600 Standard Guide for Descaling and Cleaning Titanium and Titanium Alloys
- SPX-00039008 Nickel Alloy Electropolishing

3.3.4.2 HAZ Removal Requirement

EDM of bearing and wear surfaces (bearings, bearing races, gears), and hardened high strength steels >180 ksi or HRC 40 also require removal of the heat affected zone (HAZ). Applications that require removal of the HAZ will be specified on the engineering drawing.

3.3.4.3 Additional Requirements for Chemical Removal of Recast on Steel
Hydrogen embrittlement relief per AMS 2759/9 is required when the following materials are chemically etched to remove recast. This requirement does not apply if heat treatment is performed after EDM:

- Carbon, low-alloy, and martensitic stainless steel heat treated to a minimum strength of 160 ksi or heat treated to a minimum hardness of 40 HRC or equivalent.
- Threaded fasteners made from carbon, low-alloy, or martensitic stainless steels heat treated to a minimum strength of 150 ksi or 34 HRC.
- Precipitation hardening steels heat treated to a minimum strength of 180 ksi or heat treated to a minimum hardness of 40 HRC (reference the engineering drawing or AMS 2759/3 for minimum hardness).

3.3.4.4 Additional Requirements for Chemical Removal of Recast on Titanium

Process verification coupons to verify freedom from hydrogen embrittlement are required when titanium parts are processed with nitric acid/hydrofluoric acid solutions.

Tensile coupons are required when the Nitric Acid 7% -- HF Acid 3% solution is used. The coupons shall be made of the same lot of material as the production parts. Coupons for EDM layer descaling process hydrogen verification shall have their gage section cut by the EDM process. Coupons for NDE etch process hydrogen verification shall be conventionally machined (unless the part is EDM machined). Tensile coupons made by the EDM process shall be rectangular sheet type (Figure 1 of ASTM E8) and shall have the same thickness as the minimum section of the part or 0.300 inches, whichever is less. The preferred coupon for conventionally machined parts is the ASTM E8 cylindrical-type and shall have a diameter less than the minimum section of the part or 0.500 inches diameter, whichever is less. Tensile coupons shall be tested to ASTM E8, except that coupon shall be chilled to 32°F immediately before testing. Hydrogen verification tensile test coupons made of 6-4 titanium shall have an elongation greater or equal to 10.0% and a reduction of area greater or equal to 25%.

Tensile coupons are not required when a solution with 10:1 or greater ratio of nitric acid to hydrofluoric acid is used. Instead a total hydrogen pickup test may be performed on a daily or lot basis. The coupon for this test shall be processed, at the minimum, the maximum time the coupon is immersed in the acid solution. The coupon is not required to be from the same lot of titanium, but it does have to be the same alloy and heat treatment. The details of this test and the calibration of the equipment shall be documented in the facility work instructions for the process.

4 INSPECTION REQUIREMENTS

Visual requirements only apply to surfaces that have line-of-sight for inspection. EDM entrance and exit edges shall not be visually inspected unless specifically required by the engineering drawing. Surfaces to be finish machined, chemically etched or thermally treated after EDM processing may exceed specified visual criteria provided the inspection criteria in this section are met after the final manufacturing operation. This is applicable only to processors who perform the post EDM processing.
4.1 Surface Finish

EDM surfaces shall be free from pits, craters and selectively-etched or eroded areas as determined by visual examination under adequate lighting with no magnification at a maximum 24” viewing distance.

4.2 Cleanliness

EDM part surfaces shall be free from contaminants such as surface oxides, grease and oils when observed by inspection using visual examination under adequate lighting with no magnification.

4.2.1 Discoloration (oxidation) and Arcing

EDM surfaces shall not exhibit discoloration indicative of overheating due to localized arcing. No evidence of uncontrolled localized arcing shall be acceptable on finished EDM processed parts.

4.3 Dimensions

The dimensions of EDM drilled features shall conform to the engineering drawing requirements after recast/HAZ removal (when required). Unless otherwise specified, offset circles (variable diameters) in a hole shall be rejected.

5 QUALIFICATION REQUIREMENTS

5.1 Microstructure Requirements

5.1.1 Recast Layer Depth Determination

Characterization of recast layer thickness is required when EDM is used to produce finished surfaces that require recast removal (see 3.3.3).

At a minimum, characterization shall be performed on samples made using the most aggressive processing parameters (highest power) allowed for a given material/part. Samples shall be of the same material or representative material as allowed in Table 1. Materials not listed in Table 1 require individual qualification using the unique substrate.

A representative sample or samples shall be cut, polished, etched, and the face of the EDM-cut surface shall be examined at a magnification of a minimum of 400x in accordance with ASTM E3. Deviations to this approach may be approved by the cognizant SpaceX personnel.

The thickness of the recast layer shall be determined by measuring the thickest section from at least three views at a minimum of 400x. The recast layer shall include recast particles that are attached, including any oxide layer, to the base metal. Recast particles that are not attached are not considered part of the recast layer.
Table 1 Material Groupings For EDM Process Procedure and Recast Removal Process Qualifications

<table>
<thead>
<tr>
<th>Test Sample</th>
<th>4140 or 4340 (200-220 ksi)</th>
<th>302 Stainless (full hard)</th>
<th>304 Stainless (Annealed)</th>
<th>17-4 or 15-5 H900</th>
<th>Custom 465 (All)</th>
<th>A286 (Aged)</th>
<th>Nickel Alloy 718 (Aged)</th>
<th>7075-T6</th>
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<tr>
<td>Alloy Steels (≤200 ksi)</td>
<td>304/304L (All)</td>
<td>304/304L (Annealed)</td>
<td>13-8Mo (All)</td>
<td>Custom 465 H900</td>
<td>A286 (All)</td>
<td>Nickel Alloy 625</td>
<td>7075 (All)</td>
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<tr>
<td>Carbon Steels (≤200 ksi)</td>
<td>316/316L (All)</td>
<td>316/316L (Annealed)</td>
<td>15-5 PH (All)</td>
<td>Custom 455 (All)</td>
<td>13-8Mo (All)</td>
<td>Nickel Alloy 625</td>
<td>Monel 400</td>
<td>7050 (All)</td>
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<tr>
<td>301 (All)</td>
<td>301 (Annealed)</td>
<td>Custom 455 (All)</td>
<td>13-8Mo (All)</td>
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<td>Monel K500 (All)</td>
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<tr>
<td>302 (All)</td>
<td>302 (Annealed)</td>
<td>17-4 (All)</td>
<td>15-5 PH (All)</td>
<td>Monel 400</td>
<td>2219 (All)</td>
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<td></td>
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<td></td>
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<td>Monel K500</td>
<td>2195 (All)</td>
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<td>3XXX (All)</td>
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</table>

5.1.2 HAZ Depth Determination

When removal of HAZ is required, the HAZ depth may be measured by the following methods:

- Microhardness traverse of a test specimen sectioned perpendicular to the EDM surface and prepared in accordance with ASTM E3. Hardness shall be determined in accordance with ASTM E384 starting 0.001 inch from the EDM edge and traversing inward in increments of 0.001 inch to the 0.005” depth. The HAZ depth shall be the distance from the surface to the location where the hardness difference is less than 20 points HV from the core.

- The chord method of ARP1820 may be used to determine depth of thin HAZ.

- HAZ removal may be qualified by a comparative measurement of the surface and core hardness. Hardness of the surface shall be measured after recast/HAZ removal on the HR15N or HR15T scale. A second measurement shall be taken at a depth not less than .010” below the surface. A difference of more than 1 point HR15N/HRT is unacceptable. Materials with a core hardness <100 HRB shall be tested using the HR15T scale.

5.1.3 Alternate Recast/HAZ Removal Qualification

In lieu of measuring recast and HAZ thickness in the as EDM processed condition to determine removal amount, the recast removal process may be qualified to show that no recast and when required, HAZ, remains on the final part after. Samples shall be prepared after EDM and all removal processes. No evidence of recast is permitted when inspected per the methods of 5.1.1. When HAZ removal is required, verification of removal shall be per 5.1.2. Validation of removal is required whenever EDM parameters or removal methods change.
5.1.4 Recast Layer Removal Process Qualification

When chemical removal is utilized, only vendors on the Approved Supplier List (ASL) shall be used. The chemical recast removal process shall not produce intergranular attack, pitting, alloy depletion or other deleterious effects. Qualification of chemical processes is defined in the specifications listed in section 3.3.4.1.

The recast removal process, and HAZ removal when required, shall be qualified using representative samples of the same material. No evidence of recast is permitted when inspected per the methods of 5.1.1. When HAZ removal is required, verification of removal shall be per 5.1.2. Documentation providing evidence of sufficient removal shall be maintained and made available upon request.

5.2 Classification of Tests

5.2.1 Acceptance Tests

The Visual and Dimensional requirements of Section 4 are classified as acceptance tests and shall be performed on 100% of parts produced.

5.2.2 Periodic Tests

Microstructure requirements (5.1) and recast removal process qualification (5.1.4) are classified as periodic tests and shall be performed prior to the initial shipment of EDM parts or when a change in equipment, material and/or processing occurs. An actual part or a representative test sample of the same material and dimensions may be used for this destructive evaluation.

5.3 Approval

5.3.1 An EDM process procedure (3.3.1) and recast removal process qualification reports (5.1.4) shall be maintained and made available upon request. An EDM Process Procedure template is provided in Figure 1 as an optional form for the process procedure to be documented.

5.3.2 The processor shall make no significant change to equipment, materials, processes or control factors without requalifying the recast removal process (5.1.4). A significant change is one which could affect the quality of the EDM part.

The processor of EDM parts shall provide with each shipment a report stating that the parts have been manufactured using EDM, tested in accordance with specified requirements, and that they conform to the acceptance test requirements. This report shall include the purchase order number, lot number, SPX-00040560, part number, and quantity.
# Appendix A – EDM Process Procedure Template

## EDM Process Procedure

<table>
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<tr>
<th>Part Number and Revision</th>
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<tr>
<td>Material</td>
<td>Hardness or Condition</td>
<td>Machine #</td>
<td>Wire Type</td>
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<td>Customer Specification and Revision</td>
<td>Fluid</td>
<td>Recast layer removal required?</td>
<td>HAZ removal required?</td>
<td>Quality approval</td>
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<table>
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<td>1</td>
<td>SIZE OF SPARK GAP</td>
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<td>2</td>
<td>VOLTAGE</td>
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<td>FREQUENCY (OF ELECTRICAL PULSE)</td>
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<td>4</td>
<td>FEED RATE</td>
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<td>DIELECTRIC PRESSURE</td>
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<td>DIELECTRIC FLUID CONDUCTIVITY LIMIT</td>
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Figure 1 EDM Process Procedure template provided as an optional form for the process procedure to be documented.