shall be pressurized hydrostatically until failure occurs. The procedure qualification is acceptable if failure occurs in the base metal.

**QW-286.3** A test coupon at least 10 in. (250 mm) long shall be made per Figure QW-462.7.2. This test coupon shall be cut transverse to the length of the weld into ten pieces, each approximately 1 in. (25 mm) long. Four transverse weld specimens and four longitudinal weld cross section specimens shall be cut and prepared as detailed in Figure QW-462.7.2. The specimens shall be metallographically examined for compliance with the requirements of QW-196.

**QW-287 VARIATION OF SETTINGS FOR ELECTRIC RESISTANCE WELDING**

Settings for preheating cycles, electrode pressure, welding current, welding time cycle, or postheating cycles may be varied by ±5% from the values recorded on the PQR, or by ±10% when only one of the above settings is changed.

(19) **QW-288 TUBE-TO-TUBESHEET QUALIFICATION ESSENTIAL VARIABLES**

Essential variables applicable to tube-to-tubesheet welding procedure qualifications in accordance with QW-193 are listed in Table QW-288.1 for all welding processes except explosion welding and Table QW-288.2 for explosion welding. Essential procedure qualification variables applicable for each welding process listed in QW-250 shall also be observed in addition to the variables of QW-288. A change in the welding process used shall require requalification.

---

### Table QW-288.1

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Brief of Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>QW-407</td>
<td>.1 φ PWHT</td>
</tr>
<tr>
<td>PWHT</td>
<td></td>
</tr>
<tr>
<td>QW-409</td>
<td>.4 φ Polarity</td>
</tr>
<tr>
<td>Electrical Characteristics</td>
<td>.10 + Amperage</td>
</tr>
<tr>
<td>QW-410</td>
<td>.5 φ Method of cleaning</td>
</tr>
<tr>
<td>Technique</td>
<td>.37 Single to multiple pass</td>
</tr>
<tr>
<td></td>
<td>.81 + Tube expansion</td>
</tr>
</tbody>
</table>

Legend:
- **+** Addition
- **-** Deletion
- **×** Amperage
- **<** Decrease or less than
- **φ** Change


---

### Table QW-288.2

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Brief of Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>QW-403</td>
<td>φ Tube thickness</td>
</tr>
<tr>
<td>Base Metals</td>
<td></td>
</tr>
<tr>
<td>QW-410</td>
<td>.82 φ Pressure application</td>
</tr>
<tr>
<td>Technique</td>
<td>.83 φ Explosive</td>
</tr>
<tr>
<td></td>
<td>.84 φ Distance charge to tubesheet</td>
</tr>
<tr>
<td></td>
<td>.85 φ Specified clearance</td>
</tr>
</tbody>
</table>

Legend:
- **φ** Change

---

(19) **QW-289 LOW-ENERGY CAPACITOR DISCHARGE WELDING**

The following requirements apply to low-energy capacitor discharge welding:

(a) The energy output shall be limited to 125 W-sec.

(b) A Welding Procedure Specification describing the capacitor discharge equipment, the combination of materials to be joined, and the technique of application shall be prepared; qualification of the welding procedure is not required.
(c) If specific qualification test requirements are not specified by the applicable Code Section, welders and welding operators shall be qualified with one of the following methods:

(1) a demonstration mockup per the requirements of QW-193.2, except that for welding operators
   -a) the hole pattern does not need to be duplicated
   -b) the type or model of equipment is an essential variable
(2) a groove-weld qualification per the requirements of QW-303.1

### Table QW-388

**Essential Variables for Tube-to-Tubesheet Performance Qualification**

(Welders; All Welding Processes)

<table>
<thead>
<tr>
<th>Paragraph</th>
<th>Brief of Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>QW-402</td>
<td>.31 ≤ Ligament size</td>
</tr>
<tr>
<td>Joints</td>
<td>.32 φ Joint configuration</td>
</tr>
<tr>
<td>QW-403</td>
<td>.16 φ Tube diameter</td>
</tr>
<tr>
<td>Base Metals</td>
<td>.32 φ Tube thickness</td>
</tr>
<tr>
<td>QW-404</td>
<td>.50 ± Preplaced filler metal</td>
</tr>
<tr>
<td>Filler Metals</td>
<td>.10 Amperage</td>
</tr>
</tbody>
</table>

Legend:
- φ Change
- ± Addition or deletion
- ≤ Less than or equal to

**QW-389  CAPACITOR DISCHARGE WELDING OPERATOR QUALIFICATION**

Welding operators using low-energy capacitor discharge welding in accordance with QW-289 are not required to be qualified.
**QW-402.14** An increase or decrease of more than 10% in the spacing of the welds when they are within two diameters of each other.

**QW-402.15** A change in the size or shape of the projection in projection welding.

**QW-402.16** A decrease in the distance between the approximate weld interface and the final surface of the production corrosion-resistant or hard-facing weld metal overlay below the minimum thickness qualified as shown in Figures QW-462.5(a) through QW-462.5(e). There is no limit on the maximum thickness for corrosion-resistant or hard-facing weld metal overlay that may be used in production.

**QW-402.17** An increase in induction spray fuse hard-facing deposited on the process coupon.

**QW-402.18** For lap joints,

(a) a decrease of more than 1 edge of the material

(b) an increase in the number of layers of material

(c) a change in surface preparation or finish from that qualified

**QW-402.19** A change in the nominal diameter or nominal thickness for tubular cross sections, or an increase in the total cross section area beyond that qualified for all non-tubular cross sections.

**QW-402.20** A change in the joint configuration.

**QW-402.21** A change in the method used to minimize internal flash.

**QW-402.22** A change in the end preparation method.

**QW-402.23** For test coupons less than 1 1/4 in. (38 mm) thick, the addition of a cooling medium (water, flowing gas, etc.) to the back side of the weld. Qualification on test coupons less than 1 1/2 in. (38 mm) thick with a cooling medium on the back side of the weld qualifies base metal thickness equal to or greater than the test coupon thickness with and without coolant.

**QW-402.24** Qualification with a cooling medium (water, flowing gas, etc.) on the root side of a test coupon weld that is welded from one side qualifies all thicknesses of base metal with cooling medium down to the thickness of the test coupon at the root or 1/2 in. (13 mm), whichever is less.

**QW-402.25** A change from lap joint to groove welding, and vice versa.

**QW-402.26** A reduction of more than 5 deg in the edge preparation bevel angle for groove welds.

**QW-402.27** A change in material of fixed backing anvils (when used). A change in backing anvil design that affects the weld cooling rate (e.g., a change from air-cooled to water-cooled, and vice versa). This variable is not applicable to tube-to-tubesheet or double-sided welds with overlapping fusion zones, or welds completed using self-reaction pins.

**QW-402.28** A change in joint design from that qualified, including edge preparation geometry (e.g., a change from square butt edge to beveled edge), reductions in the smallest joint path radius to less than the shoulder radius, or joint paths crossing themselves or another HAZ.

**QW-402.29** A change in joint spacing greater than 1/10 of the qualification test coupon thickness. For WPSS qualified using per Table QW-240.25, the maximum allowable joint spacing is more in the specified tube wall thickness than the greater specified tube wall thickness.

**QW-402.30** Increase in the depth of the groove type welding; an increase or decrease in the weld groove by more than 5 deg.

**QW-403** BASE METALS

**QW-403.1** A change from a base metal listed under Table QW-403.1 to another. When the difference made is, even each of

**QW-403.2** The maximum thickness qualified is the thickness of the test coupon.

**QW-403.3**

(a) For full penetration single-sided welds without backing where the verification of penetration can be made, an increase of more than 20% in base metal thickness when the test coupon thickness is less than equal to 1 in. (25 mm), and more than 10% in base metal thickness when the test coupon thickness is greater than 1 in. (25 mm).

(b) For all other welds, an increase of more than 10% in base metal thickness when the test coupon thickness is less than or equal to 1 in. (25 mm), and more than 5% in base metal thickness when the test coupon thickness is greater than 1 in. (25 mm).

**QW-403.4** Welding procedure qualifications shall be made using a base metal of the same type or grade as another base metal listed in the same group (see Table QW/QB-422) as the base metal to be used in production.
QW-403.19 A change to another base material type or grade (type or grade are materials of the same nominal chemical analysis and mechanical property range, even though of different product form), or to any other base metal type or grade. When joints are made between two different types or grades of base metal, a procedure qualification must be made for the applicable combinations of materials, even though procedure qualification tests have been made for each of the two base metal materials welded to itself.

QW-403.21 The addition or deletion of a coating, plating or cladding, or a change in the nominal chemical analysis or thickness range of a change in type of coating as s

QW-403.22 A change in the exceeding 10% of the thickness or qualed.

QW-403.23 A change in base metal range qualified in Table QW

QW-403.24 A change in the specification, type, or grade of the base metal. When joints are to be made between two different base metals, a procedure qualification must be made for the applicable combination even though procedure qualifications have been made for each of the two base metals welded to themselves.

QW-403.25 Welding procedure qualifications shall be made using a base metal of the same P-Number and Group Number as the base metal to be temper bead welded. When joints are to be made between base metals from two different P-Number and Group Number combinations, a temper bead procedure qualification must be made for each base metal P-Number and Group Number combination to be used in production; this may be done in separate test coupons or in combination on a single test coupon. When base metals of different P-Number and Group Number combinations are tested in the same coupon, the welding variables utilized and test results on each member of the coupon shall be documented independently but may be reported on the same qualification record. Where temper bead welding is to be applied to only one member of a joint (e.g., on the P-No. 1 member of a joint between P-No. 1 and P-No. 8 metals) or where cladding is being applied or repaired using temper bead techniques, qualification in accordance with QW-290 is required only for the portion of the WPS that applies to welding on the member to be temper bead welded.

QW-403.26 An increase in the base metal carbon equivalent using the following equation:

\[
CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}
\]

QW-403.27 The maximum thickness qualified is the thickness of the test coupon, T, or it is unlimited if the test coupon is 1 1/2 in. (38 mm) thick or thicker. However, where T is 7/4 in. (6 mm) or less, the maximum thickness qualified is 2T. This limitation applies to fillet welds as well as to groove welds.

QW-403.28 A change to another base metal type, grade, or UNS number.

QW-403.29 A change in the surface finish as defined by the material specification or established surface roughness range as measured in accordance with ASME B46.1-2006.

QW-403.30 A change in base metal thickness greater than 20%

(a) of the test coupon thickness for fixed-pin and retraction-pin rotating tooling below the minimum and maximum thickness or thickness trai

QW-403.31 0.100 in. (2.5 mm) to increase it to 1/2 T. For tube or tubing material is par A-Number or in the nominal composition of the tubesheet cladding or c

QW-403.32 0.100 in. (2.5 mm)

QW-403.33 0.100 in. (2.5 mm)

QW-403.34 a wall thickness of tube wall thickness shall not be less than 1/2 T. For tubes or tube sheet material is par A-Number or the nominal composition of the tube sheet cladding or c

QW-403.35 A decrease in the thickness or change in nominal specified chemical analysis of weld metal buttressing beyond that qualified. (Buttering or surfacing is the deposition of weld metal on one or both faces of the joint prior to preparation of the joint for final electron beam welding.)

QW-404 FILLER METALS

QW-404.1 An increase of greater than 10% in the cross-sectional area of the filler metal added (excluding buttering) or in the wire-feed speed beyond that qualified.

QW-404.2 A decrease in the thickness or change in nominal specified chemical analysis of weld metal buttressing beyond that qualified. (Buttering or surfacing is the deposition of weld metal on one or both faces of the joint prior to preparation of the joint for final electron beam welding.)

QW-404.3 A change in the size of the filler metal.