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**EVALUATION OF RESISTANCE
(CAPACITOR DISCHARGE)
WELDING FOR ATTACHING
INSTRUMENTATION**

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INTRODUCTION

Sheathed instrumentation leads must be supported against vibration during shipment and operation. This is accomplished by fastening them with straps to a structural component. For the NRX-A-1 Reactor these straps were applied during the assembly operation. For structures made from weldable materials, such as the 6061 aluminum alloy core barrel (or the 2219 aluminum alloy core barrels to be used in subsequent reactors), the straps can be fastened by welding. However because welding is accomplished during assembly these welds must:

1. Be produced by a process that can be accommodated in the assembly area.
2. Result in minimum metallurgical and dimensional disturbance of the structural component since the structural components are finished to close tolerances and are heat treated to produce optimum strength.

Resistance welding was selected over arc welding because the process is completely mechanized and metallurgical or dimensional effects can be both minimized and controlled. Further, by series* welding and the application of a capacitor discharge power source which reduces the time of heating to below 1×10^{-3} seconds the amount of energy released into the finished structure could be held to a minimum. In spite of aluminum's high diffusivity, the volume of metal that sensed any heat could be reduced.

Since capacitor discharge equipment stores energy, it is characteristically small in size and will operate from a 110V appliance outlet. Therefore, capacitor discharge equipment could be readily introduced into the reactor assembly area. Because of the short welding cycle, electrodes are not water cooled. They are massive enough to provide their own heat sink and heat is dissipated while the operator relocates the electrodes for the next weld.

* In series welding the electrodes are both placed on one side of the work so that the current path is along the member being welded rather than through it. This tends to reduce the heating of the work piece except in the area of the spot.

SCOPE

This report described the evaluation of a capacitor discharge welding process for fastening instrumentation leads with straps to the core barrel and documents the qualification of the capacitor discharge equipment of MIL-W-6858 Class B.

EQUIPMENT AND METHOD

UNITEK PS 1045, 200 watt-second capacitor discharge welding (Figure 1). This unit plugs into a standard appliance socket. Charge level is indicated on the panel meter. Re-charging occurs in about one second. The hand piece and probe fasten to jacks in the front panel. The hand piece was fastened to the negative jack for these tests except where noted.

UNITEK HP 3030, 500 (maximum) watt-second probe and hand piece set (Figure 2). Force is variable from 0-25 pounds through an adjustable spring. Current will not flow until a preset pressure is reached. Pressure is adjusted by a knob on the top of the hand piece which compresses a spring. A pointer on the spring on the side of the hand piece indicates the pressure. However, a more accurate setting can be produced by counting the turns of the adjusting knob and this method was used throughout the tests. A calibration curve of pressure versus turns is shown in Figure 3.

RWMA-Class 2 electrodes were used in both the probe and hand piece.

To make a weld the ground probe is placed firmly on the work piece. The welding electrode is then forced against the work piece until the preset pressure in the spring balances the force on the electrode and the capacitors are discharged. For convenience the probe was clamped to the barrel during actual operation.

Tensile tests were carried out on a 500 pound Unitron tester set at 40 pounds full scale deflection on a 14 inch chart recorder.

MATERIAL

Base Metal: .063" 6061 (R_p 25 approximate) aluminum.

Note: for set up purposes 6061 T4 material was used which approximated the condition of the barrel.

Strap Material: .006" 1100-0 aluminum strip 5/8" wide.

PROCEDURE

This program encompassed two objectives. The first objective required the development of a practical resistance welding procedure. The second required that sufficient tests be made to determine the consistency of operation of the machine at or near the desired operating range as required in MIL-W-6858 Paragraph 5.1.

DEVELOPMENT OF A PRACTICAL RESISTANCE WELDING PROCEDURE

In the development of a procedure for fastening straps, the basic variables of electrode configuration, pressure and amperage were considered. Additionally, early tensile-shear tests indicated that the very flexible foil preferentially transmitted load to a single weld in a given row of welds, therefore consideration was given to the establishment of a pattern so that as many welds as possible could work in concert at potential load points.

Amperage:

Initial tests indicated that there was no reason not to use the maximum current available. In fact the mass of the core barrel indicated that maximum amperage would be required. Further, since heating is a function of I^2RT it appeared desirable to retain the natural oxide at the faying surfaces to increase resistance^(R). Time^(T) cannot be altered on

capacitor discharge equipment while current⁽¹⁾ was at a maximum.

Electrode Configuration:

The electrode is furnished with a flat tip approximately .125" in diameter. Initial trials indicated that spot strength could vary depending on whether the tip was placed flat on the work piece or whether it was tilted so that current flowed through sharp corner of the flat surface.

To increase reliability, by allowing for some variation in the angle at which the operator sets the tip, the corners of the tip were chamfered and a more conventional spherical configuration generated. A sphere with a 3/8" diameter eliminated any visible effect of sharp corners even though the electrode was 45° from normal. Sharper radii (approximately 1/8", which provided a hemisphere) unnecessarily concentrated the current and produced undersized nuggets. This channeling of current into a small diameter under the tip increased electrode sticking and also indentation since the base material was overheated under the tip of the electrode.

Pressure:

Using the maximum current (195-200 watt-seconds) and a spherical tip configuration with a radius of 3/8 - 1/2" pressure was varied to determine at what maximum spot strength could be expected. As noted previously, it appeared more convenient and more accurate to count turns of the adjusting knob (from its extreme position fixed by a preset stop) than to read the gage on the side of the hand piece.

As a first step a pressure calibration chart was made (Figure 3).

A series of welds was made at increased pressure. Pressure effects resistance in an inverse ratio. However, at very low pressures electrode sticking and expulsion may be encountered. Welds made at pressures from 0-2 turns exhibited excessive electrode sticking. Welds made at pressures over 3-1/2 turns exhibited severe indentation and at 4-1/2 turns resistance was so low that nuggets were not formed.

A second series of welds were produced using pressures from 2 to 3-1/2 turns. Five welds per specimen were used and three specimens were made at each setting and tested in tensile shear. The results are as follows:

TABLE I - Effect of Pressure on Weld Strength
and Electrode Performance

Turns	Strength Each Specimen, lbs.	Average Strength, lbs	Comments on Electrode Performance
2	27.7 24.6 32.3	28.2	Moderate electrode sticking on each weld
2-1/2	32.3 27.8 28.5	29.5	Slight electrode sticking on 3rd or 4th weld of each piece.
3	27.4 27.5 27.3	27.4	Electrode produced 8 or 10 welds before sticking
3-1/2	21.1 25.9 22.1	23.0	No observed sticking

From the above, 2-1/2 turns was selected. Later, a change in the setting of the micro switch in the hand piece resulted in an increase to 3 turns although the pressure stayed approximately the same. Figure 3 has been corrected to reflect this change.

Pattern:

With the selected settings for the variables a series of test specimens were prepared utilizing actual straps and loading these straps normal to the core barrel. Figure 4 illustrates this specimen. Each specimen involved two joints so that each value represents the failure strength of the weakest of a pair of straps.

Initial tests indicated that the end welds of each row controlled the failure because the cross wire bent in test and placed the greatest strain at this point (Figure 4). For this reason a pattern of spots was run down the side of each joint.

The service loading is primarily tensile so the total area of spots is important. For this reason at least one reinforcing row was used. A third row was also tested but was apparently too far out of the bending field to be effective. Also spots were spaced as closely together as possible. By moving the first row of spots a short distance from the instrument lead the tensile load was converted, somewhat, to shear. Further, the spots were aligned mechanically to prevent one spot from taking all of the initial load and failing prematurely.

From the above discussion it is apparent that spots were closely spaced so that the shunting of current through existing spots had to be considered. To minimize shunting, the following welding sequence was adopted. It was designed to assure maximum nugget size in the critical corner areas and still provide at least one strong weld midway across the strap.

Weld No. 1:	corner
Weld No. 2:	opposite corner
Weld No. 3:	midway along first seam
Welds No. 4 & 5:	divide the remaining halves of the first seam
Welds No. 6, 7, 8 & 9:	start the second and place these welds midway between those in the front row
Welds No. 10, 11 & 12:	place along edge approaching corner weld
Welds No. 13, 14 & 15:	place along edge approaching opposite corner weld
Welds No. 16 & 17:	place at rear corners of tab
Welds No. 18, 19, 20, 21, 22, 23 & 24:	place between existing spots in first and second rows (overlap is to be avoided if possible)

DETERMINATION OF CONSISTENCY OF OPERATION USING DEVELOPED PROCEDURE

Since welding was to be performed under MIL-W-6858, the consistency of operation of the equipment had to be verified (Section 5) and a welding process certified (Section 6). The use of .006" material prevents the use of MIL-W-6858 Table I values in qualification. Further, for this particular application, interactions of spots appeared to be more important than the performance of a given spot, since the close spacing undoubtedly led to a progressive degradation of values through shunting. Therefore, tests of full scale strap assemblies were used to simultaneously evaluate the equipment and the procedure. This was accomplished under MIL-W-6858 Section 1.2.2.1 Special Conditions.

Three test specimens, including that shown in Figure 4, were produced. The performance of these specimens represents the strength of 288 welds. Each failure represents the least strong of a pair of assemblies.

A minimum breaking strength, 20 pounds per strap, was established as a reasonable criteria for this application. Earlier observations indicated that failures at high strengths were contingent upon alignment between the cross wires rather than weld strength. At about 25 pounds failure occurred through the strap away from the welds. Thus values above 20 pounds did not provide useful information regarding the weld except to indicate that the welds were at or above minimum requirements. The following values were achieved on three consecutive specimens:

1. 22 pounds
2. 24 pounds
3. 26 pounds (specimen shown in Figure 4)

DISCUSSION

During the preparation and testing of the specimens, the need for care in placing the electrodes (particularly the hand held probe) squarely on the surface of the work piece was observed. If the probe was tilted and if extra force was not applied the high current overheated the edge. This initiated an arc and vaporized all metal in the area damaging the probe as well as the work piece.

For this reason, during production, welding, the probe was clamped on the core barrel at locations where an inadvertent expulsion would not damage the barrel. The surfaces of the dome end tabs and of the spacers are two areas used for grounding when producing tab-barrel welds and tab-spacer welds respectively.

In spite of this precaution, an expulsion occurred during the welding of NRX-A-1 and involved the pressure-regulated hand piece. This occurred, apparently, when the electrode was inadvertently set on a kinked portion of the tab. The kink supported the electrode long enough to fire the welder. However as current flowed the kink collapsed permitting an arc to be initiated. Part of the tab and a small portion of the outer surface of barrel were affected.

Electrode sticking was noted after about 10-15 spots. Therefore, the electrode was cleaned after spot Number 10 and again when the tab was finished (or at any time the operator noted a tendency to stick). Fine emery cloth was used and the electrode was checked with a radius gage to assure retention of the configuration.

A series of metallographic specimens were prepared and indicated that the base metal is little effected (Figure 5). This is an advantage since a large fused zone in the heat treated (solution treated and aged) barrel might have a significant effect on the strength of the barre.

CONCLUSIONS

1. A capacitor discharge resistance welding procedure using 195-200 watt-seconds 2-1/2 - 3 turns of pressure and a carefully planned sequence results in a technique providing instrumentation straps which will support at least 20 pounds.
2. The UNITEK PS 1045 welder used for these tests met a special set of equipment qualification requirements based on, and compatible with, MIL-W-6858.

RECOMMENDATIONS

Since all tests were run at the upper limit of the UNITEK PS 1045 equipment (200 watt-seconds) the UNITEK 1028D control with the 500 watt-second UNITEK 1024B power supply should be considered. This larger unit provides a capability for welding materials or thicknesses that demand greater power than the application reported herein. For example, the welding of stainless steel straps or strain gages.

FIGURE I

200 Watt-Second Capacitor Discharge Resistance (Spot) Welder
(without probe and hand piece)

FIGURE II

500 Watt-Second, Handpiece

FIGURE III - Calibration Curve for Handpiece

Values determined by forcing handpiece against weigh-pan of a calibrated spring balance and noting microswitch relay click. These values represent force after adjustment and repair of microswitch.

FIGURE IV

Test Specimen Used to Evaluate Welds and Weld Patterns

Failure occurred at 26 lbs. force and is typical. Gripping wires are shown. Note bending at edge of strap and preferential corner failure. Typical pattern illustrated on the undamaged tab. Note that four such patterns are tested simultaneously.

- STRAP

- BASE METAL

FIGURE V

Photomicrograph of Weld

Photomicrograph of weld shows tenacity of 2 spots subsequent to tensile test referred to in Figure IV.