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INFORMATION CATEGORY Unclassified	
<i>D. Goldberg</i>	2/20/64
Authorized Classifier	Date

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**EVALUATION OF
AN ELECTRON BEAM
WELDING PROCESS
FOR CONTROL DRUMS
MASTER**

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SUMMARY

A welding technique has been developed for the production of control drum assemblies. These parts required the joining of end caps to tubes with a minimum of distortion, weld build-up and heat input.

Hi-voltage electron beam welding was employed for joining the 6061-T6 aluminum parts. Special joint configurations were developed to eliminate a tendency for the development of weld cracks. Weld repair techniques were also developed which prove the feasibility of using pre-placed filler metals.

INTRODUCTION

Fabrication of the control drum requires the joining, by welding, of approximately 4" diameter, .050" wall 6061-T-6 aluminum tubing to end caps of the same material. The end caps have a complex shape with various size holes and slots. Severe limitations exist on weld build-up, weld width, allowable distortion and finishing after welding. In addition, the desired weld joint location results in considerable variation in material backup thickness. These considerations make the use of the electron beam welding process attractive.

The following report defines the development tests required to produce an acceptable procedure for joining end caps to tubing for control drum manufacture. Tests defined here were directed towards producing acceptable weld joints by the hi-voltage electron beam welding process. The equipment used was a 150 KV Hamilton-Zeiss unit and all test and production welds noted were produced by Electron Beam Techniques, Inc., Plainville, Connecticut, under the direction of WANL Process Engineering.

WELD PROCEDURE DEVELOPMENT

Conventional welding of 6061 aluminum requires the use of filler material such as 4043 or 5356 to prevent cracking during solidification due to hot shortness. This was recognized as a possible problem in hi-voltage electron beam welding where no filler is added. However, the high welding speed and very limited heat affected zone typical of this electron beam process are an aid in the prevention of cracking.

Butt welds were produced in .063" thick 6061-T6 aluminum to evaluate feasibility and basic weld properties. At a welding speed of 50" per minute, with other parameters adjusted for slightly in excess of 100% penetration, sound, ductile welds were produced. Table I shows the tensile data obtained. In addition, 90° longitudinal bend tests were

conducted and a minimum bend radius of 1T achieved. Metallographic specimens (see Figures 1 and 2) showed no internal cracks or porosity and little or no discernable heat affected zone.

TABLE I
 Tensile Properties of E.B. Welded
6061-T6 Aluminum Alloy, .063" Sheet

Test Temperature	Room Temperature
Ultimate Tensile Strength	33,700 psi
Yield Strength (0.2% Offset)	21,400 psi
Elongation, % in 1/2 inch	12.5
Elongation, % in 2 inch	3

The success in producing butt welds without filler metal addition was encouraging and simulated control drum weld joints were then made. The basic joint cross section was as follows:

The first samples were welded at, 50 IPM, the speed which gave good results in the butt welding. The results, however, were poor as root cracking was general and large root to face cracks occurred in the area of weld power tail-off (see Figure 3). Welding speed was then increased in an effort to eliminate the cracking that had occurred. Table II lists typical weld parameters and the results obtained.

TABLE II

Sample Number	Welding Speed	Voltage	Current	Remarks
4	52"/min.	80 KV	7.5 ma	Root and tail-off area cracks
5	75"/min.	80 KV	9.0 ma	Root cracking
6	156"/min.	90 KV	10.0 ma	Minor root cracking
7	197"/min.	90 KV	11.25 ma	Minor root cracking

It was decided from this information that future welds would be made at 156 inches per minute. At this speed no tail-off cracks occurred but very minor, although unacceptable, root cracks were present (see Figure 4).

Since butt welds had not been a problem and cracking was occurring in the area of the weld which was bottoming in the end cap, the joint configuration was modified to more closely approximate a butt weld. This new design was as follows:

Four welds were made with this configuration at the following settings:

Weld Speed	156 IPM
Voltage	85 KV
Current	8.5 ma

Metallographic analysis indicated that penetration was obtained through the thickness of the tube wall with only limited drop through into the underbead groove. All cracking was eliminated and the welds satisfied all requirements of this joint. Typical sections are shown in Figures 5 and 6. Further modification was necessary to reduce the

depth of the underbead groove into the end cap. The design, which was incorporated into the final engineering drawing, employed a bevel (.020" x 45°) on the I.D. of the tube wall. This served to decrease weld penetration to .030"(and thus heat input) in addition to the reduction in the depth of the underbead groove. The following sketch shows this design:

Sample welds produced for qualification were sectioned at various points and once again proved satisfactory. A typical cross-section is shown in Figure 7. The conditions used to produce this weld (and production parts) was as follows:

Weld Speed	156"/min. (one revolution in 5 sec.)
Voltage	80 KV
Current	7.5 Milli amperes

The plan for assembly of the control drum called for the use of magna-forming to attach one end cap to the tube prior to welding. Deformation of the tube into a groove in the end cap was necessary to produce the magna-formed mechanical joint. This required a modification of the joint design. A typical cross-section through a qualification weld for this joint is shown in Figure 8. Once again sound, defect free welds were produced.

In actual production inconsistent forming resulted in erratic weld fit-up. This was a severe problem for this hi-voltage electron beam welding where the small weld size makes fit-up requirements very critical. The assembly procedure was modified to eliminate the magna-forming operation. The weld joint design is now similar on both end caps.

WANL process specification PS 294524 was prepared from the information obtained in this development work to assure a reliable process for the welding of control drum assemblies. This specification is attached as Appendix I.

PRE-WELD CLEANING

Early in the development of the welding procedures it became apparent that to consistently achieve welds free of blow holes and internal porosity, a careful pre-cleaning and de-oxidizing treatment was required. Figure 9 shows porosity that occurred occasionally on sample welds which had not been pre-cleaned. This was particularly true as weld speed was increased. The following cleaning procedure was adopted for all test items and production hardware:

Swab with 20% by volume Oakite 33 for 2-3 min.

Cold water rinse

Hold in 1 lb/gallon solution of Oakite 34 M for 2 min.

Cold water rinse + hot water rinse

REPAIR WELDING

Some weld cracking and burn through did occur as a result of the weld fit-up problem associated with the magna-forming. Techniques were developed for repair welding as required on the control drums. In some cases re-fusing with the electron beam at the original settings was adequate. In other cases a more elaborate procedure, including pre-placement of filler material, was required.

In this case a groove .020" wide by .032" deep was cut around the full circumference in the center of the weld to be repaired. Two layers of .020" diameter 4043 aluminum

filler wire were placed in the groove and mechanically upset to the original level of the base material. A tack pass was then made at low energy and .020" transverse beam oscillation. The beam was then focused successively at the interfaces of the filler alloy and the base metal. The weld conditions were:

	<u>Tack Pass</u>	<u>Weld Passes</u>
Weld Speed	88 IPM (.020" beam oscillation)	88 IPM
Voltage	80 KV	80 KV
Current	3 ma	9 ma

Complete fusion was obtained with no cracking or observable weld porosity. It was necessary to reduce the speed and use the tack pass on this repair weld to facilitate the complete fusion. The upsetting of the filler into the groove was also necessary. Without the intimate contact between filler and base metal the filler would melt and ball-up before fusion with the base metal took place.

The technique described for repair welding indicates the possible application of pre-placed filler where weld cracking is a problem and electron beam welding equipment with filler wire feed is not available.

CONCLUSIONS

1. Butt welding is feasible in relatively thin gage 6061-T6 aluminum by high voltage electron beam welding equipment without filler metal additions.
2. Root cracking could not be completely eliminated in the 6061-T6 aluminum when the electron beam weld fusion zone bottomed in solid material.
3. Increased welding speed was necessary to avoid tail-off and other weld cracking. In this case 156 inches/min. was required.
4. Careful cleaning and de-oxidizing was required to obtain consistent weld results. This was particularly true when weld speeds were very high.
5. Repair welding techniques were developed and used employing pre-placed 4043 filler material.

50X

FIGURE 1

200X

FIGURE 2

FIGURES 1 & 2 - Butt Weld in .060 inch 6061-T6 Aluminum
Hi-Voltage Electron Beam Welded Without Filler Wire

50X

**FIGURE 3 - Cracking That Occurred at 50 in/min.
Weld Speed-Weld Power Tail-Off Area**

100X

**FIGURE 4 - Root Cracking in Weld Produced
at 156 in/min Weld Speed**

50X

FIGURE 5

50X

FIGURE 6

Typical Tube to End Cap Sample Weld With Underbead Groove

50X

FIGURE 7 - Qualification Sample on Production Weld Joint

50X

FIGURE 8 - Qualification Sample on Magnaformed Weld Joint

50X

FIGURE 9

Weld Porosity Where Pre-Cleaning Was Not Employed

APPENDIX I

PROCESS SPECIFICATION WANL 294524-2

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PROCESS SPECIFICATION WANL 294524 Revision No. 2
(Not for Publication)

October 7, 1963

FABRICATION OF CONTROL DRUM

1. SCOPE

This specification covers those welded joints in the control drum assembly that require special control to assure proper reliability, designated as follows:

<u>Designation</u>	<u>Description</u>
294524-1	End cap-to-cylinder joint

2. GENERAL REQUIREMENTS

2.1 COMPLIANCE: No change shall be made from these procedures without first obtaining approval of the purchaser.

2.2 APPLICABLE DOCUMENTS: The documents referenced herein shall be the issue in effect on the date of invitation for bids, and shall form a part of this specification to the extent specified herein.

P S WANL 294520
MIL-STD-271

2.3 CLEANING: This assembly shall conform to P S 294520-2. It is of prime importance that all loose material that might be carried into the final clean-assembly operation be removed from parts before assembly operations that form crevices.

2.4 SAMPLES: All samples are the property of WANL and shall be kept by the vendor for a period of two years following termination of vendor's contract, after which they may be destroyed. Samples must be identified to the contract and applicable joint.

2.5 QUALIFICATION: When a qualification test is required, a WANL representative may witness any part of the qualification including the

Printed in U.S.A.

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testing, and shall be given 48 hours notice of the vendor's intention to perform the qualification. After the qualification, the test samples may be reviewed by WANL at the vendor or at WANL.

3. ACCEPTANCE

- 3.1 Where items on a fabrication drawing are not produced from a detail drawing (as noted in the Bill of Materials for the fabrication drawing), they shall be inspected visually for conformance to the drawing requirements applicable to that sub-assembly and subjected to a penetrant examination per MIL-STD-271, Type IV, over any finished surfaces that will not be accessible in the final inspection of the part.
- 3.2 Acceptance of the completed joint shall be based on the acceptance criteria set forth for each joint in the attached procedure sheets or the appropriate specification shown on drawing.
- 3.3 Where WANL approval of a production (or repair) process requires that a demonstration or test joint be made prior to production, the following is to apply.
 - 3.3.1 The joint shall be made on the same piece of equipment that will be used in production using the production tooling. A description of the required test joint or demonstration piece will be found in the individual procedure.
 - 3.3.2 WANL may witness and approve through appropriate testing or the vendor may submit a report (five copies) of the test which shall include as a minimum:
 - a. A statement indicating successful compliance with all visual and nondestructive test requirements (these tests shall be completed prior to destructive testing.)
 - b. All quantitative data including joint dimensions (such as penetration, fillet, size, crown, etc.) individually tabulated for each test.
 - c. Description of the metallographic findings, including a statement as to the presence or absence of any cracks, porosity, undercut or other conditions whether these exceed the limits or not.
 - d. Statement that the process will meet the requirements of this specification and recommendation for approval. This statement shall be approved by the vendor personnel responsible for control of the process during production.

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- 3.4 WANL approval on an approved WANL form must be received prior to production or repair.

October 7, 1963

1. JOINT DESCRIPTION: End cap-to-cylinder joint2. MATERIALS:

Filler: None

Base Material:

Form - Tube; 0.050" wall

Root thickness at Joint -
0.030" $\pm$ 0.005"

Grade - 6061 Al. alloy

Condition - T6

Base Material:

Form - Plug

Joint overlap - 0.050" thick
cylinder lapped over
joint. Magnaformed. (See
section 3.2)

Grade - 6061 Al. alloy

Condition - T6

3. WELD PREPARATION:

3.1 Cleaning - Prior to welding parts shall be cleaned in the weld area as follows:

- a) Degrease using vapor degreaser or solvent wipe technique.
- b) Place in 20% volume solution of Oakite 33 operated at 120°F and hold for 1 minute. (Alternate: Swab 2-3 minutes in room temperature bath.)
- c) Rinse in clear running water.
- d) Place in 1 lb/gal solution of Oakite 34M operated at room temperature, hold for 1 minute.
- e) Rinse in cold water followed by hot water (approximately 150°F.)

Parts must be welded within 48 hours of oxide removal unless they have been suitably bagged in an inert gas (nitrogen or argon).

3.2 Magnaforming - This process may be used in assembly for attaching the cylinder to the nozzle end cap prior to welding. Where it is used the following apply:

- a. The nozzle end cap must be grooved to allow for proper set down of the cylinder.
- b. Samples must be prepared and sectioned to illustrate the forming achieved for the selected combination of coil, field shaper and machine settings. Whenever the coil or field shaper are changed or machine settings modified more than $\pm 5\%$, additional samples must be produced.
- c. After forming, the end of the cylinder must be in contact with the weld face of the end cap. In addition, the ID of the cylinder must be a maximum of 0.005 inches from the end cap shoulder in the area of the weld.
- d. Dimensional tolerance of holes in the end cap shall be retained.

4. PROCESS:

Equipment: High voltage (150 KV) electron beam welder of the Hamilton-Zeiss type equipment with a binocular microscope for locating the electron beam. The equipment shall be capable of controlling the welding variables within the following tolerances:

Kilovolts	± 2
Current	± 0.25 millamperes
Speed (SFM)	± 2 ipm

5. POST WELD TREATMENT - None

6. PROCEDURE QUALIFICATION:

A separate procedure for each end shall be qualified on simulated production parts which have acceptable welding diameters and preparation and contain all slots, holes, and proper joint configurations. The use of simulated parts for qualification is permissible provided:

- a. In production assembly, the dome end cap and the drum are welded prior to assembly of the beryllium shaft into the part.
- b. When magnaforming is to be used, qualification welds for the nozzle end shall be made on parts in which the cylinder has been so formed to the end cap.
- c. Cleaning and oxide removal has been accomplished using the process defined in section 3.1 of this procedure.

At least one sample for each end shall be made as noted above and shall be visually inspected, nondestructively tested, and, if acceptable, micro sectioned.

Where any parameter of the recorded welding cycle changes more than that specified in section 4, a requalification sample shall be welded and submitted as above.

7. QUALITY REQUIREMENTS INCLUDING ACCEPTANCE STANDARDS:

Visual: The crown shall not exceed the height of the metering ring on the dome end or 0.005" on the nozzle end when measured from the nominal outer diameter of the tube. The surface of each weld shall not exhibit a sink in excess of 0.005" from the adjacent work piece surfaces; or 0.002" of undercut adjacent to the tube; or 0.010" of undercut to the plug. Localized undercut or weld sink up to 0.25" in length and 0.010" deep shall be acceptable.

Nondestructive Testing: Type II non-water washable dye penetrant shall be applied to the exposed surface of the weld per MIL-STD-271. Reject all linear indications. Linear is defined as an indication having one dimension more than 4 times the minimum dimension. All other indications are circular. Reject circular indications over 0.032". The joint shall be rejected if it exhibits more than five indications regardless of size on either weld. The interpretation of this inspection shall be limited to the weld zone and 1/16" either side.

NOTE: Care must be taken to mask holes in end caps to prevent dye penetrant or developer entering the interior of the cylinder.

Destructive Testing: (Procedure Qualification only) - The weld cross section shall be examined at 4 points 90° apart. (One point shall include the beginning of tail off). Examination of cross section at 25X mag. shall show the weld to be free of cracks and penetration to be at least to the root of the joint preparation.

8. PERSONNEL QUALIFICATION:

It is the responsibility of the manufacturer to demonstrate familiarity of their personnel with the set up and operating procedures for the equipment. This can be done by monitoring a production set up. No qualification test is required.

9. REPAIR PROCEDURE:

Excessive bead height may be removed using a shield to prevent damage to the workpiece. The shield shall be covered with grease or a tacky substance to catch any chips. The part shall be protected with clean polyethylene except at the repair location.