664405

DP-996

AEC RESEARCH AND DEVELOPMENT REPORT

ATTACHING RIBS TO ZIRCALOY FUEL ASSEMBLIES BY ELECTRON BEAM WELDING

A. S. FERRARA and F. F. GLASGOW

DU PONT
REG. U. S. PAT. OFF.

Savannah River Laboratory

Aiken, South Carolina

Printed in USA. Price $2.00

Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia

M-3 HOUSING TUBE - RIB WELDING

Fab Lab Tube No: ______________ Date: ______________

Tube Vendor: ______________ Operators: ______________

Vendor's No: ______________ ______________

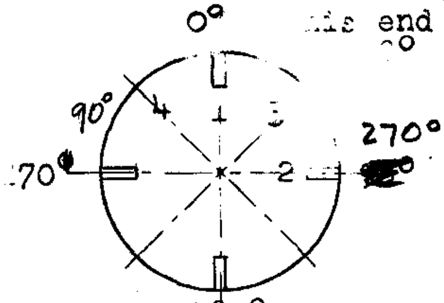
Mandrel: Insert A-12 Lbs.

Withdrawn E-9 Lbs.

SAMPLE DATA SHEET - NUMBERS REFER TO STEPS IN PROCEDURE.

Rib	Weld Parameters Range		Speed	Left Slot		Right Slot		Diff. in Rt&Lt ¢	Avg. Rib ¢ "X"	Beam Setting	
	KV	Ma.	"/M	Rib Edges	Rib ¢	Rib Edges	Rib ¢			"X"+	"X"-
0°				B-31	B-32	B-28	B-29	B-34	B-33	C-5	C-5
				C-6	C-6	C-7	C-7	C-8c			
180°				SAME	AS	FOR	0°				
90°				SAME	AS	FOR	0°				
270°				SAME	AS	FOR	0°				

ial No. on
is end at
0



Tube viewed from
RT [redacted] end.

Post Welding Measurements:

Axis	6" Fr.Lt.End	6" Fr.Rt.End	Cen.of Tube
1			
2			
3			
4			

Rib Spacing: Go No Go

1. "Go" Gage ______ ______
2. "No Go" Gage ______ ______

PROCEDURE FOR WELDING RIBS IN M-3 HOUSING TUBES USING THE ELECTRON BEAM WELDING FACILITY

This procedure is divided into the following sections.

A. Loading Tube on Mandrel

B. Positioning Tube in E.B. Weld Cabinet

C. Welding Ribs in Tube

D. Removing Tube from E.B. Weld Cabinet.

E. Stripping Tube from Mandrel

A. Loading Tube on Mandrel

General - Cleanliness in this whole operation is extremely important since the tube cannot be cleaned after welding. Clean rubber or nylon glove liners are to be worn when handling bare tube or mandrel. For safety reasons the heavy mandrel should be handled with clean rubber gloves rather than nylon gloves. Avoid pinching hazards and lift properly to avoid backstrain.

1. Place the mandrel on the table between the wooden Vee blocks with the front end (end with 1" threaded hole) about 12 inches back from the 3" channels.

2. ~~Insert~~ VERIFY that the 4 cam bars ARE IN THE ~~[illegible]~~ "down" position (flat side toward spring).

3. Insert the 4 leaf springs.
   Springs are inserted from front end of mandrel and pulled through to the rear using a special tool, until they extend 1/2" beyond mandrel.

4. Place Zircaloy housing tube on the table between the 3" channels and push it into the stripper die as far as it will go.

5. Swing the 3 channel latches into place and secure.

6. Screw the short 1" dia. x 6-inch~~es~~-long adapter into the mandrel.
   Important: Screw adapter into mandrel fully (1-3/4") to prevent stripping of aluminum threads.

7. Slide the 11-foot-long rod through the tube and screw it onto the other end of the 1" adapter.

   Important: To save wear and possible stripping of the threads in the aluminum mandrel, <u>do not reverse</u> steps 6 & 7.

8. Connect screw eye, shackle and Dillon force gage to the other end of the <u>11</u>-foot rod.

9. Attach hook from winch to other screw eye on force gage and take up slack in cable.

10. Close wooden guard covers over cable.

11. Rotate winch and draw mandrel into tube.

    Caution: Be extra careful as mandrel enters tube and as mandrel emerges from tube and enters die. - Some guiding may be required. - Slots in mandrel must be in line with center of 1/32" wide transverse slots in tube.

    Safety: Avoid pinching fingers.

12. Observe force gage - Record maximum force required during insertion. If force exceeds 700 pounds - stop and consult supervisor.

13. Draw mandrel through tube and allow the front end of mandrel to extend beyond the end of the tube until the distance between the tube end and the slot for tungsten test block equals 2 inches within $\pm$ 1/8" (1-1/8" between back of channel supporting die and the slot in mandrel).

14. Verify that cam bars are rotated to "down" position.

15. Insert ribs into slots in mandrel.

Leading edge of ribs must be rounded both top and bottom so ribs will not hang up on tube or springs. DO NOT BEND RIBS! Preferred method is for one man to grip spring end while the second man pushes ribs about 6 inches at a time using needle nose pliers operating near the entrance to the tube so that the groove restrains sideways movement of the rib and thus prevents bending.

Ribs should extend until they just become visible in the slot in the front end of the tube. If rib is too short to be visible in slot in rear end of tube, add 4-inch-long filler ribs pushed in to butt against the long rib.

Safety: Clean leather gloves should be worn to prevent cutting fingers on possible sharp edges in case hands slip. Do not touch rib with leather glove.

16. Rotate cams to 90° up position to spring load ribs against tube.

17. Observe that ribs (or groove in mandrel) are visible through the slots in the tube.

If not, rotate cam bars "down" and rotate tube on mandrel to proper position.

18. Transfer mandrel to the portable table and set on blocks preparatory to loading into E.B. welder cabinet; Important! Support blocks must be under mandrel not tube.

19. Insert 4 tungsten test blocks into the slots on rib centerline at the front end of mandrel. Push target hold-down tube over mandrel to lock targets in place.

20. Proceed to Section B.

B. <u>Positioning Tube in E.B. Weld Cabinet</u>

1. Attach front truck to mandrel.
   This is the small two-wheel truck. Tighten with wrench.

2. Attach rear truck assembly to mandrel.
   Insert mandrel into chuck so that guide pin is in chuck slot. Insert pip-pin. Rotate mandrel so that groove nearest tube identification number is on top. This is the 0° rib. Tighten the locking screw on the rear truck clamp.

3. Load into E.B. welder right extension tube. VERIFY THAT BRIDGE IS EXTENDED.
   Push assembly in by hand until slot in rear truck is over lead screw follower. Raise follower by hand into the truck slot, grasp roller chain, and turn lead screw by hand until follower moves far enough that it will not fall back into table slot when released.

   Caution: This operation is done by hand, <u>not</u> by motor. Operator must determine that power to the lead screw motor drive control (toggle switch in upper left hand corner) is OFF before performing the above operation.

4. Using the power drive in "Forward" direction (tube moving from right to left) move tube until front truck moves across bridge and onto left table several inches.
   Be sure bridge remains extended.

5. Retract bridge.

6. Raise "black box" and lower lead weights alternately, until bottom guide wheel raises front truck approximately 1/16 inch off extension floor. Leave lead weight rollers suspended approximately 1/2" above tube.

   Caution: This operation must be synchronized to prevent lead weights hitting ceiling of welder cabinet.

7. Bring rear guide roll into contact with tube.
   Continue to crank until spring is loaded approximately 1/4".

8. Move tube in "Forward" direction (right or left) until slot in right hand end of tube is approximately under the E.B. telescope.

9. Unbolt right extension. Separate flanges 4 inches.
   Use length of wrench handle as a gage. This flange opening should be held within ± 1/4".

10. Insert wrench and loosen locking screw on rear truck clamp.

11. Drive rear truck forward until tube slot is under E.B. telescope cross hairs.
    Caution: Drive truck slowly. Do not let wrench handle become jammed between flange faces.

12. Open top port on left extension cabinet.

13. Raise top rollers (if they are down on tube).

14. Retract rear guide roll.

15. Lower black box approximately 1/4".

(USE RUBBER GLOVES)

16. Rotate the tube by hand, through the left extension port, until the rib to be welded is properly positioned. Lock mandrel in place by turning the wrench handle clockwise.

When properly positioned the rib (or mandrel groove) centerline, as viewed through the 1/32" wide transverse slot 1-1/2" from the end of the tube, should be within 40 divisions of the cross hairs of the E.B. telescope after completion of steps 16 through 22 which follow. Since some of these subsequent moves will rotate the tube slightly, experience will show how much to allow for this. Rib centerline is determined by reading the top and bottom edge of the rib (or groove) and calculating the center point of these two extremes.

17. Remove wrench.

18. Move right extension into place and bolt flanges together.

Experience indicates 2 bolts are sufficient to assure initial vacuum.

19. Move tube in "Reverse" direction (left to right) approximately 12 inches.

21. Bring rear guide roll into contact with tube.

Continue to crank until spring is loaded approximately 1/4".

20. Raise "block box" until bottom roll <u>just contacts</u> tube.

Point at which roll just starts to turn as tube moves over it.

22. Move tube in "Forward" direction until slit for viewing rib centerline is again under telescope cross hair.

During this short run, observe that the bottom roll is turning.

23. Lower top roll into place.
    Rolls are in good contact when cable barely goes slack.

24. Observe rib centerline in telescope cross hair.
    If off more than ±40 divisions from center, steps 9-23 must be repeated.

25. Evacuate chamber by the switching sequence stated in the manual, (do not dwell in positions 2-6 for more than 5 minutes).
    Steps 26 through 29 which follow can be executed while waiting for the cabinet to pump down.

26. Move tube in "Reverse" direction until slot in left end of tube becomes visible under telescope.
    Observe, but do not record rib position.

27. Move tube in "Forward" direction until slot in right end of tube becomes visible under telescope.

28. Observe top and bottom edge of rib in telescope. Record.

29. Calculate rib centerline as the center point of these two extremes. Record.

30. Move tube in "Reverse" direction until slot in left end of tube becomes visible under telescope.

31. Observe top and bottom edge of rib in telescope. Record.

32. Calculate rib centerline as the center point of these two extremes. Record.

(AVERAGE OF B-29 & B-32)

33. Calculate the center point of the rib centerlines at each end. Record as the average rib centerline.

34. If location of rib centerline at each end is the same within 10 divisions, prepare for welding. Record actual difference..
    If variation of rib centerline from end to end is greater than 10 divisions, repeat portions of above procedure as necessary until variation is within 10 divisions, if not possible notify supervision.

35. Proceed to Section C.

C. Welding Ribs in Tube

1. Move tube in "Reverse" direction until target block in left end of mandrel is centered under the telescope.

2. Start up filament current, high voltage and beam current using procedure in E.B. welder manual.

3. Adjust voltage and current as follows:

   a. Operating voltage: 148-154 KV range.

   b. Beam current: 0.35 milli-amps (3.5 M.A. with .1 scale button depressed). This may vary. Use value specifically recommended for tube being welded.

   c. Circle generation: adjust beam size to approximately 40 divisions diameter at low beam current (.01 M.A.).

4. Focus beam.

   A sharp ring of light should be visible through the telescope with the polaroid lens closed.

5. Adjust beam size to the specified number of [redacted] divisions and deflect as required to put circle center at location of average rib centerline. Remove foot from foot pedal. Record location of average rib centerline and upper and lower points of beam deflection ~~(rib centerline +19 and -19)~~.

   Average rib centerline was calculated in step B-31.

6. Slowly move tube in "Forward" direction until target and tube end have passed beneath rollers and slot in left hand end of tube is centered beneath telescope. Observe and record rib centerline location.

7. Move tube "Forward" until slot in right hand end of tube is beneath telescope. Observe and record rib centerline location.

   Note: In steps 6 & 7, use same measuring and recording techniques as outlined in step B-31 & 32.

8. a. Compare reading in step B-29 and C-7
   These must be within 3 divisions.

   b. Compare reading in step B-32 and C-6.
   These must be within 3 divisions.

   c. Compare readings in step C-6 and C-7.
   These must be within 10 divisions.

   If all requirements are met in a, b, &c above, proceed to step 9. If not - consult supervisor.

9. Adjust traverse speed - Setting No. 8 (60 inches per minute).

10. Push "Reverse" button on electrical panel.
    Tube will start to move and reach peak speed within 1/4".

11. Depress foot pedal and begin welding.
    It is important to start welding as soon as possible after mandrel is up to speed. Therefore steps 10 followed by 11 should be coordinated carefully.

12. Second operator must adjust voltage so that the beam current produces an optimum weld - light splatter and sparking from the weld area. Maximum allowable variation of the beam current should be $\pm$ 0.01 milliamps. - Record actual value used on log sheet.

13. When weld beam reaches slot in left end of tube, remove foot from foot pedal to stop weld.

14. Push "Stop" button on electrical panel to stop tube movement.

15. Shut down machine in the manner prescribed in the E.B. welder manual.

16. If additional ribs on the same tube are to be welded, proceed to step 8 of Procedure B. If no additional ribs are to be welded, remove tube from cabinet using Procedure D.
    Order of welding ribs to be as follows: 0°, 180°, 90°, 270°.
    0° by definition is the rib nearest tube identification number.

D. Removing Tube from E.B. Weld Cabinet

This procedure is used after last rib is welded or it is otherwise desired to remove the mandrel and tube from the welding cabinet.

1. Move tube in "Forward" direction if necessary until the front truck is over the left extension table.

2. Fully retract the rear guide roll.

3. Raise the top roll and lower the "black box" to its "full down" position. With the "block box" full down, retract the weighted top rolls to their "full up" position.

   Note: The two moves must be made simultaneously and coordinated to keep the lead bricks from jamming against the ceiling of the welder cabinet.

4. Extend bridge to its full "Out" position.

5. Move tube in "Reverse" direction as far as it will go.

   It will stop automatically. While this step is underway, steps 6 and 7 may be executed to save time.

6. Release vacuum in hood according to procedure in manual.

7. Open door in end of right extension.

   When tube reaches stop, lead screw arm should fall down into hole in table.

8. Pull assembly out onto portable table.

9. Block up front end of mandrel and remove front truck.
   Caution: Do not place support blocks under tube.

10. Release clamp, remove pip pin and disconnect mandrel from rear truck, placing block under mandrel to support it.

11. Rotate cam bars to "Down" position. ~~and withdraw each cam bar completely from mandrel.~~

12. Withdraw strip springs from each of the four grooves.

13. Move mandrel to position on unloading table and execute Procedure E.

E. Stripping Tube from Mandrel

1. Place mandrel on table between the 3" channels.

   Safety: Avoid pinching hands or scraping arms against stripper support frame. Mandrel is heavy - lift properly to avoid backstrain. Wear clean rubber gloves when handling to avoid fingerprints on mandrel or tube.

2. Push mandrel through stripper die until tube is in contact with die.

3. Screw 1" x 12" long adapter rod into mandrel.

4. Attach screw eye to adapter.

5. Attach Dillon force gage to screw eye with shackle.

6. Attach hook from winch to other screw eye on force gage and take up slack in cable.

7. Close wood guard covers over cable.

8. Swing 3 channel clamps in place and lock.

9. Rotate winch and withdraw mandrel from tube.

   Note: Observe force gage and record maximum required during withdrawal. If force exceeds 1000 pounds - Stop and consult supervisor. Tube will have to be stripped off on Fab. Lab. drawbench using alternate procedure.

10. Remove tube from table and enclose in plastic bag.

11. Deliver to machine shop for further processing.

664405

DP-996

Metals, Ceramics, and Materials
(TID-4500)

ATTACHING RIBS TO ZIRCALOY FUEL ASSEMBLIES BY ELECTRON BEAM WELDING

by

Anthony S. Ferrara

and

Forrest F. Glasgow

Approved by

P. H. Permar, Research Manager
Nuclear Materials Division

February 1966

E. I. DU PONT DE NEMOURS & COMPANY
SAVANNAH RIVER LABORATORY
AIKEN, SOUTH CAROLINA

CONTRACT AT(07-2)-1 WITH THE
UNITED STATES ATOMIC ENERGY COMMISSION

ABSTRACT

A guidance system, jigs, and fixtures were developed for electron beam welding longitudinal ribs to either the inside or the outside of 10-foot-long, thin-walled Zircaloy-2 tubing, approximately 3 inches in diameter, or for welding ribs to the outer cladding of otherwise finished, rigid fuel elements. A demonstration run of 26 thin-walled Zircaloy-2 housing tubes indicated that the equipment and techniques were fundamentally satisfactory, and that with minor improvements the equipment would probably also be adequate for welding external ribs on fuel elements.

CONTENTS

LIST OF FIGURES

ATTACHING RIBS TO ZIRCALOY FUEL ASSEMBLIES BY ELECTRON BEAM WELDING

INTRODUCTION

Development of low-cost fuel elements was a principal objective in the Du Pont program on heavy-water-moderated power reactors. Emphasis was placed on the development of 10-foot-long fuel tubes of powder-packed uranium oxide or coextruded, Zircaloy-2 clad uranium metal tubes assembled in a simple concentric array. A highly important feature of these assemblies was accurate radial location of the tubes by the use of spacers. Both tubing with extruded ribs and short, separately attached spacers were considered, but continuous longitudinal ribs attached to the Zircaloy-2 tube by electron beam welding were chosen as the most promising for further development work. The welded-rib concept also provided versatility in the manufacture of fuel elements because ribs could be attached either before or after fabrication of the fuel tubes.

An earlier investigation[1] was performed by Dresser Products, Inc., Great Barrington, Mass., under contract to the Du Pont Atomic Energy Division. In this work, longitudinal ribs were electron beam welded to the outer Zircaloy-2 cladding of short, coextruded metal fuel tubes, and to either the outside or the inside of thin-walled Zircaloy-2 housing tubes. Several 10-foot-long ribbed housings welded by Dresser Products performed satisfactorily in the Heavy Water Components Test Reactor.

After the preliminary work at Dresser Products, an electron beam welder was installed at the Savannah River Laboratory. Development work was continued to provide the necessary techniques and fixtures for production-scale electron beam welding ribs to long, Zircaloy-2 housing tubes and to Zircaloy-2-clad fuel tubes.

The first application of the technique was to weld ribs on the inside of a long, thin-walled Zircaloy-2 tube. Such a ribbed tube might serve either as a housing for a fuel element assembly, or as the inner sheath of a powder-packed fuel element, as described in DP-997[2].

This report describes the welding guidance system in detail and outlines the weld parameters and operating experience obtained in a short production run of 26 housing tubes.

SUMMARY

Electron beam welding was indicated to be a suitable method for attachment of Zircaloy-2 ribs to Zircaloy-2 fuel sheaths at reasonable cost. Basic equipment and techniques were developed to position ribs relative to tubes and to move an assembly such that the rib-cladding interface was accurately aligned with a fixed electron beam during the welding operation. Although the equipment was designed for welding ribs either to the outside surface of finished fuel elements or to the inside surface of thin-walled tubing, specific techniques were developed and the equipment was demonstrated only for the latter case. Four longitudinal ribs were satisfactorily welded to each of twenty-six 10-foot-long housing tubes scheduled for use in the Heavy Water Components Test Reactor. On the basis of this work, it is expected that a production cycle time of about 2 hours per tube could be achieved on such tubes.

Additional refinement to the equipment would allow the tube to traverse more accurately under the weld beam, which would be required for the more exacting problem of welding ribs to fuel element sheaths. Because the HWCTR program was terminated, this additional development work was not done and ribs were not welded to the outer surfaces of finished fuel tubes.

This report describes the welding fixtures and summarizes the main problems in welding ribs to housing tubes. The dimensional requirements for the housing tubes are recognized to be much less stringent than those required for fuel tubes.

The rib was held within ±0.006 inch of the desired position in an accurately machined mandrel.

The tube remained within the specified roundness tolerances (±0.015 inch) provided it was properly restrained during welding of the four ribs. (When the first short test sections were welded, the tubes tended to become "square", and were as much as 0.100 inch greater in diameter at the ribs than between the ribs. This imperfection was reduced to approximately the specified tolerance in a majority of the welded tubes by adding a pair of weighted top rolls to force the tube down against the mandrel during welding.)

The rib-circle diameter was held within the specified tolerance of ±0.007 inch when an allowance was made for the 0.003- to 0.007-inch hump that was produced over each rib during the welding.

Corrosion resistance of the finished product was acceptable after an autoclave treatment in 750°F steam for 48 hours; samples of the welds on ribs and end fittings displayed the black and lustrous finish that

is characteristic of Zircaloy having good resistance to corrosion in high-temperature water. None of the 26 finished housings were autoclaved.

DISCUSSION

BACKGROUND

For optimum performance in a nuclear reactor, a fuel element spacer for long, tubular fuel elements should be firmly attached for the full length of the spacer.[a] This was demonstrated in a series of tests in the Heavy Water Components Test Reactor (HWCTR) at Savannah River, when spirally wrapped spacers tack welded only at each end of the tube wore through the cladding due to excessive relative motion between the spacers and the fuel tubes after operating less than 2 months.

An extruded ribbed tube is one possible answer to the vibration problem, and several of these tubes were tested in the HWCTR. However, large-diameter Zircaloy-2 tubing with high, extruded ribs is difficult to fabricate and is therefore expensive.

A rib made from a thin strip of Zircaloy attached to a plain tube by some form of continuous welding appeared to be the most reasonable answer to the spacing problem. The basic requirement for this method of attachment was that it should produce an acceptably small heat-affected region in the cladding. Of all the methods that would meet this requirement, electron beam welding was selected because it promised greater process control and would lend itself readily to programmed operation in an accurate indexing mechanism. The spacer design comprised four longitudinal ribs equally spaced around the tube circumference. The simplicity of this shape promised low fabrication cost and positive spacing.

Welding experiments were performed at Dresser Products, Inc., Great Barrington, Mass., under contract to the Atomic Energy Division to establish the feasibility of welding ribs to fuel tubes with the electron beam welder. This work is reported in detail in DP-889[1].

After the success of these scouting tests, the work was transferred to the Savannah River Laboratory where an electron beam welder had been installed. Two vacuum-tight extension tubes were built, long enough to accommodate the guidance mechanism for traversing the 10-foot-long tube under the electron beam welding head. With this guidance system, shown schematically in Figure 1, internal spacer ribs were electron beam welded to Zircaloy housing tubes for the HWCTR.

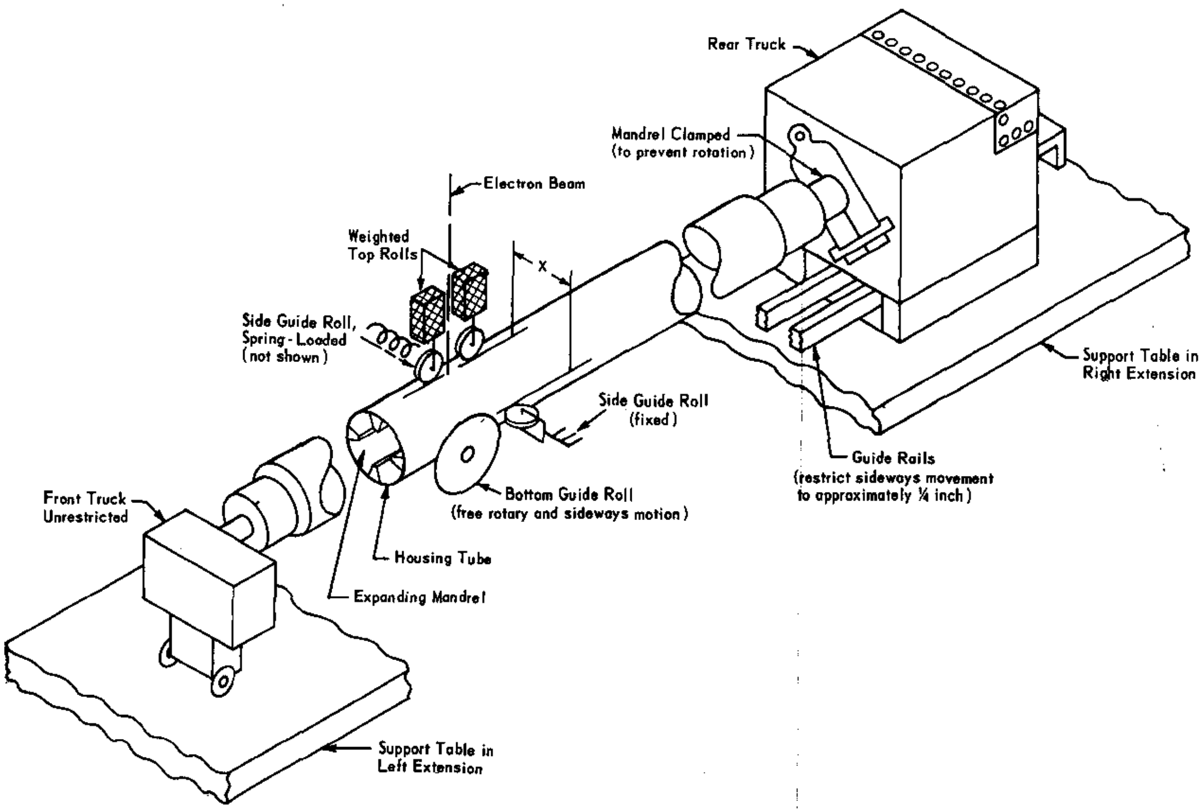


FIG. 1 TUBE GUIDANCE SYSTEM FOR ELECTRON BEAM WELDER
The path of the electron beam is controlled by relation to the fixed guide rolls, not by the position of the front and rear trucks.

ELECTRON BEAM WELDING PROCESS

In the electron beam welding process, fusion is accomplished by the energy of a beam of electrons accelerated in vacuum to the work piece. The electron beam can be focused to circular areas as small as 0.005-inch diameter on the work piece and penetrates the material to form a deep, narrow weld zone. Thus, metallurgical changes in the cladding and distortion due to weld shrinkage stresses are minimized.

EQUIPMENT DESCRIPTION

The electron beam welding facility consisted of a high-voltage electron beam welder manufactured by the Hamilton-Standard Division of the United Aircraft Corporation, to which two cabinet extensions were attached. An over-all view of the assembly is shown in Figure 2. The operator's view of the welder and auxiliary controls is shown in Figure 3. Special items provided by the vendor included fitted flanges

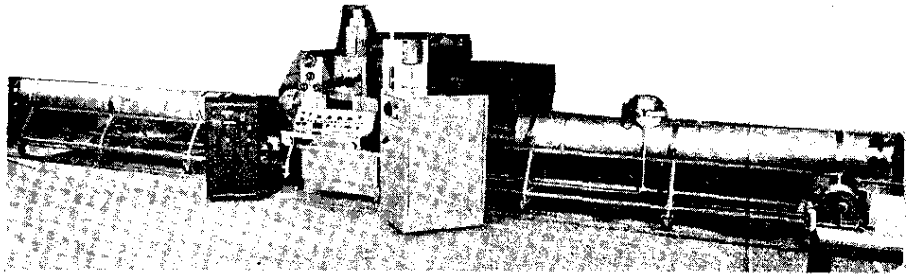


FIG. 2 ELECTRON BEAM WELDER INSTALLATION AT SRL

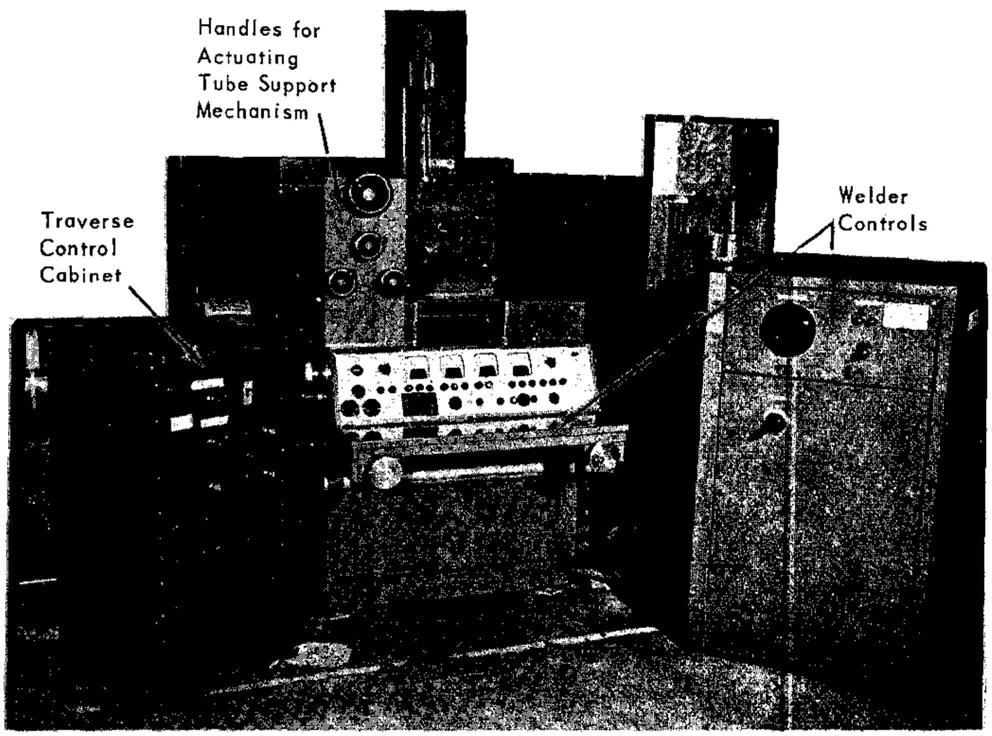


FIG. 3 CONTROL STATION FOR ELECTRON BEAM WELDER

at the cabinet sides for attaching the 16-inch-diameter extensions, and sealed drives in the cabinet top for the control cables which actuated the tube support mechanism. Because a 55-cubic-foot volume was to be evacuated, a 300-cfm roughing pump was provided in the vacuum system. Evacuation of the complete system to a 0.1-micron absolute pressure required only 5 to 6 minutes, if the chamber had been previously evacuated. Up to 10 minutes was required for pumpdown if the system had been exposed to air for an hour or more.

The removable extensions to the welding chamber were fabricated from 16-foot lengths of 16-inch-diameter, schedule 10 pipe, and each was fitted with an O-ring closure. The right extension contained a drive mechanism to move the assembly beneath the electron beam during welding. This drive, shown in Figure 4, consisted of a ball bearing lead screw driven through a vacuum-sealed shaft from outside the cabinet. A motor reducer drove the lead screw through an electromagnetic clutch actuated from the control console.

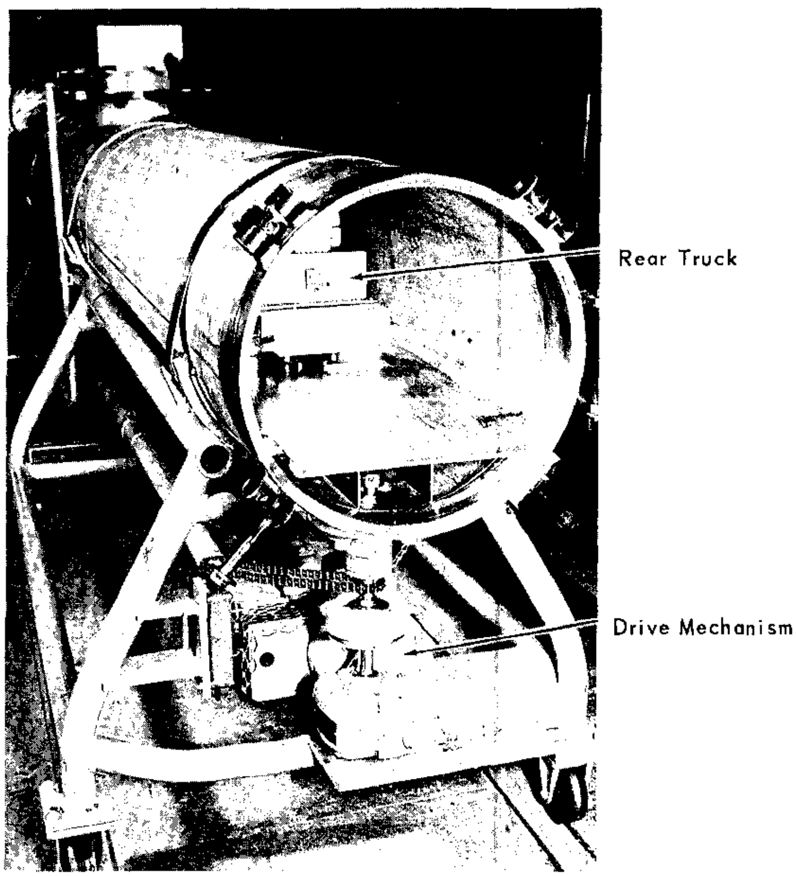
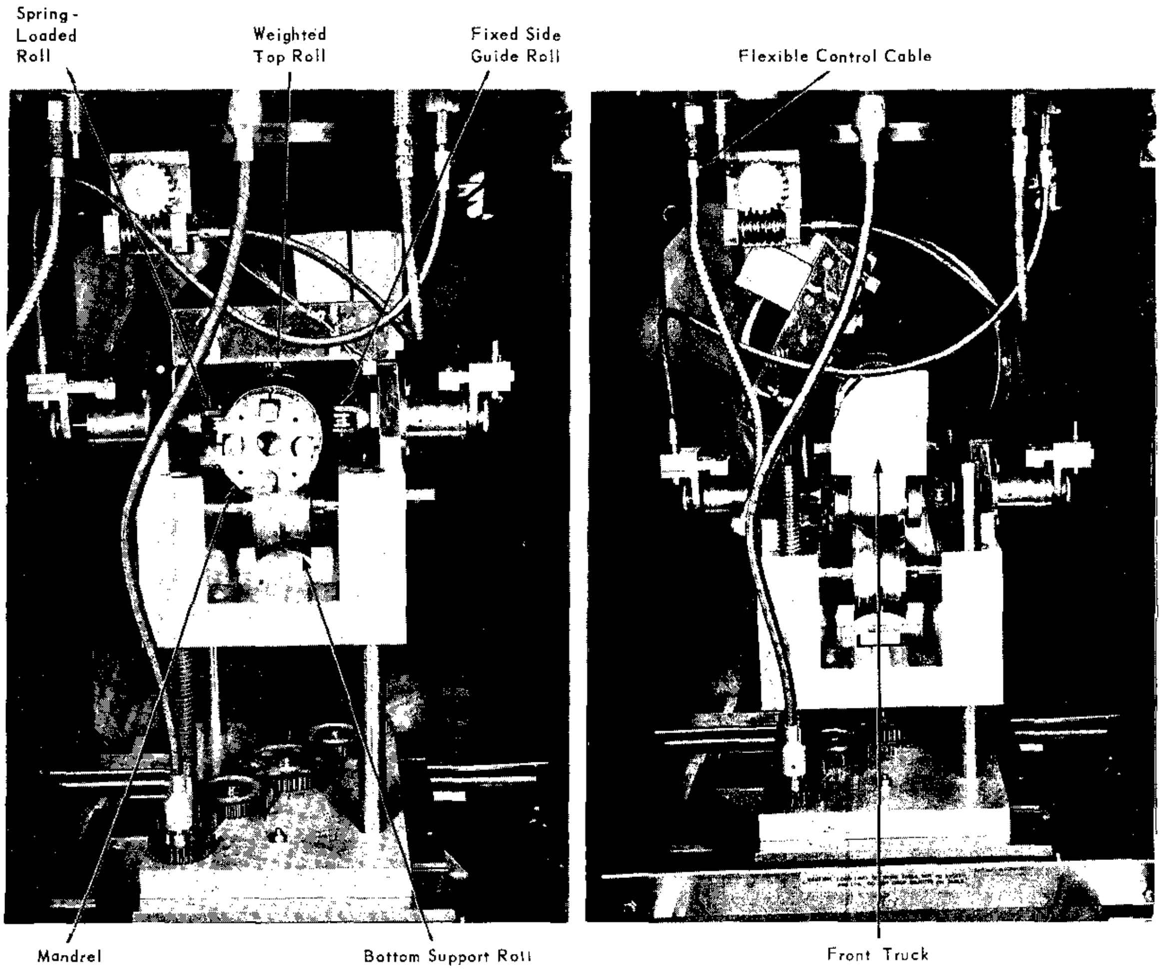


FIG. 4 END VIEW OF RIGHT EXTENSION CABINET

The tube guidance system employed central guide rolls, shown in Figure 1, which accurately positioned the tube beneath the electron beam while each end was allowed to float. This design was necessary because the tubes to be welded were never perfectly straight and therefore would not pass uniformly beneath the electron beam if rigidly guided at each end. As illustrated in Figure 5, the tube was positioned by the fixed side guide roll and the bottom support roll. A spring-loaded side roll and a weighted top roll held the tube in steady contact with the two fixed guide rolls.



a. WELDING POSITION

All Guide Rolls in Place (front truck removed from mandrel, for clarity).

b. RETRACTED POSITION

Spring - Loaded Roll and Weighted Top Roll are Retracted before the Support Mechanism is Lowered, as shown in this Photograph.

Front truck in place (retractable bridge which supports front truck not shown, for clarity).

FIG. 5 TUBE SUPPORT MECHANISM

In addition to positioning the tube in the X,Y direction, it was essential that the tube pass beneath the beam without rotating on its longitudinal axis. This was accomplished by locking the mandrel to the collet on the rear truck.

The mandrel was rotated from one welding position to the next, either manually or remotely. In the original design it was assumed that considerable production time would be lost in repeatedly evacuating the cabinet if it were opened after each rib weld to change the mandrel position. Therefore, an electric motor was installed within the rear truck assembly for this purpose; however, excess play within the gear train and the motor permitted the tube to rotate slightly during welding, and the centerline of the rib deviated from the electron beam. In the demonstration run, the manually operated clamp shown in Figure 6 was adequate, and no production time was lost; the vacuum system could be opened to the air and pumped down to 0.1 micron in 5 minutes. This was less time than was needed for a preweld double traverse of the mandrel to verify its proper alignment.

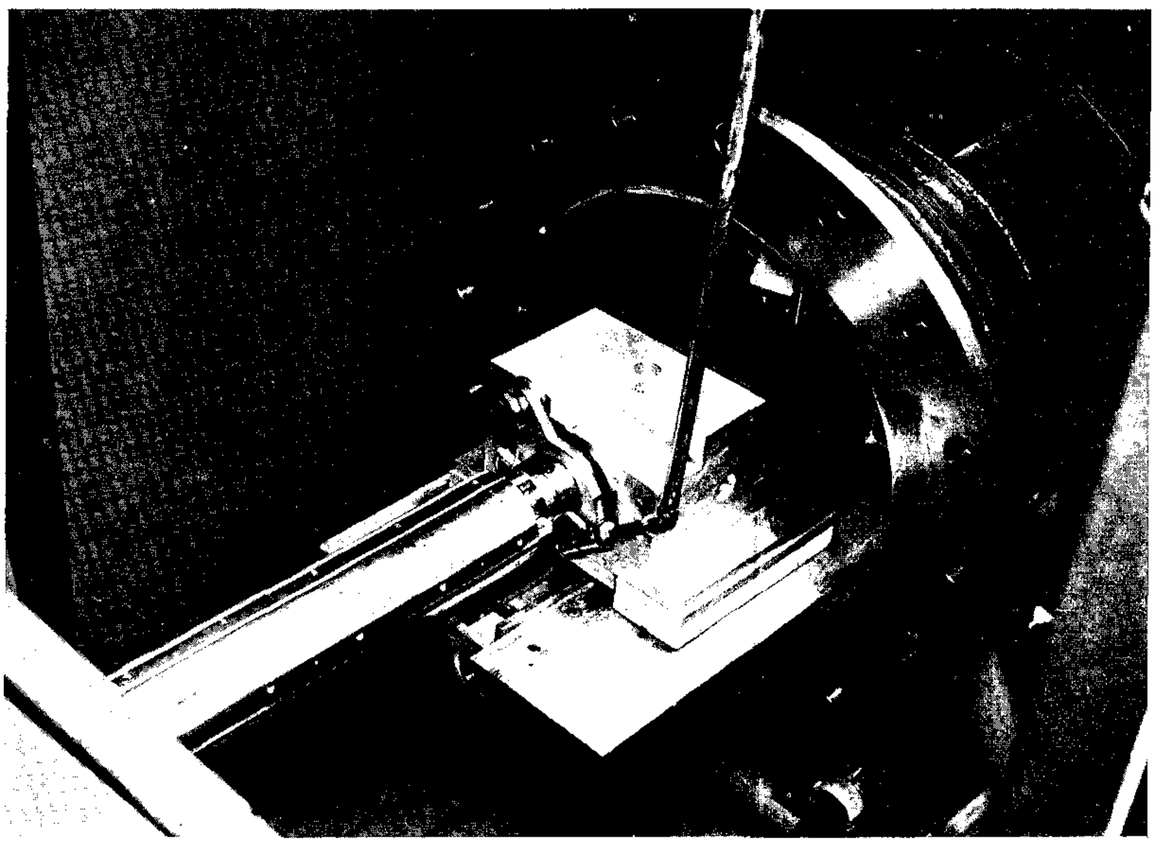


FIG. 6 METHOD FOR ROTATING AND CLAMPING THE MANDREL

The Zircaloy-2 ribs were held in intimate contact with the inner surface of the Zircaloy-2 sheath by an 11.5-foot aluminum mandrel (Figure 7). Slotted, stainless steel inserts 90 degrees apart positioned the ribs. The rib was held in firm contact with the sheath by a cam-actuated, corrugated spring that forced the rib against the inside of the sheath with an average force of 3 pounds per linear inch. A more detailed discussion of the mandrel construction is presented in another report.[4]

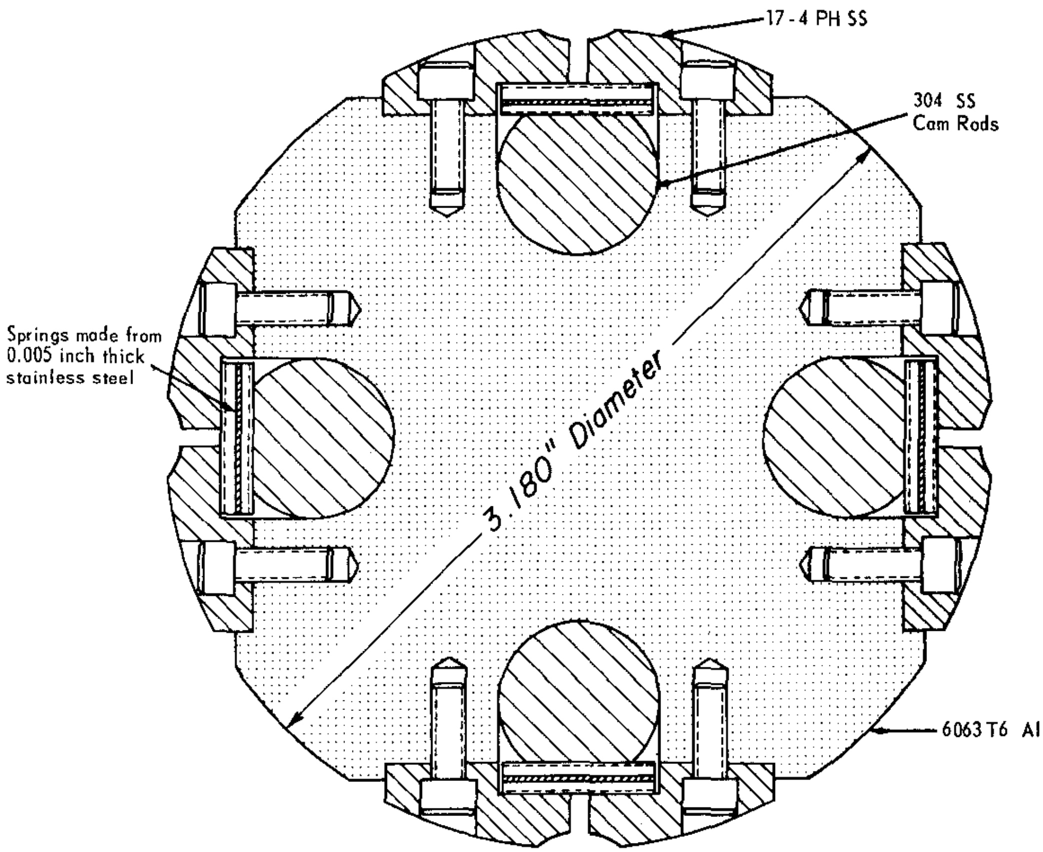
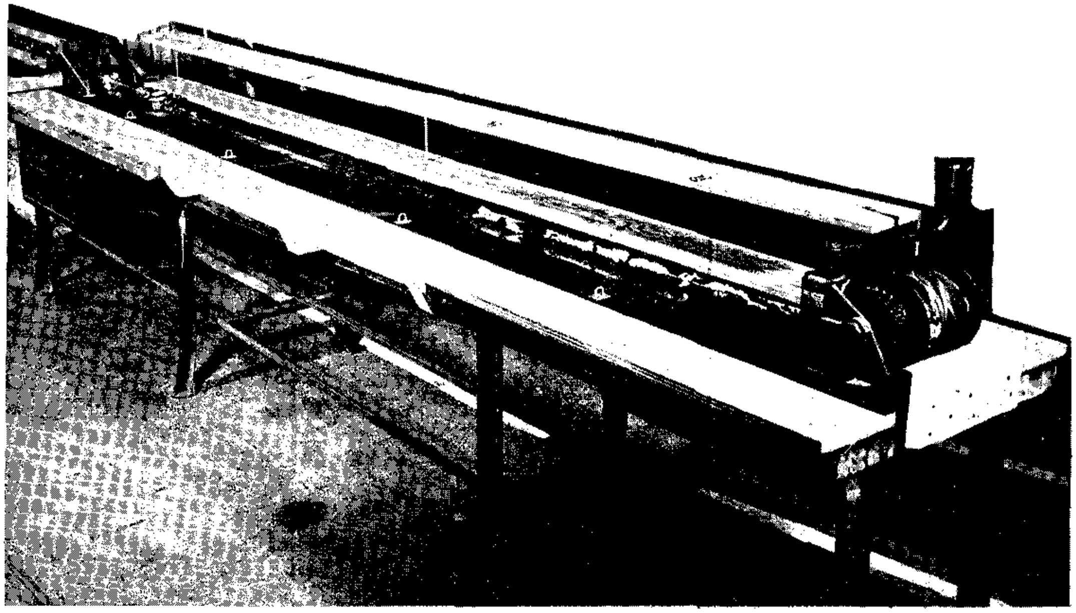


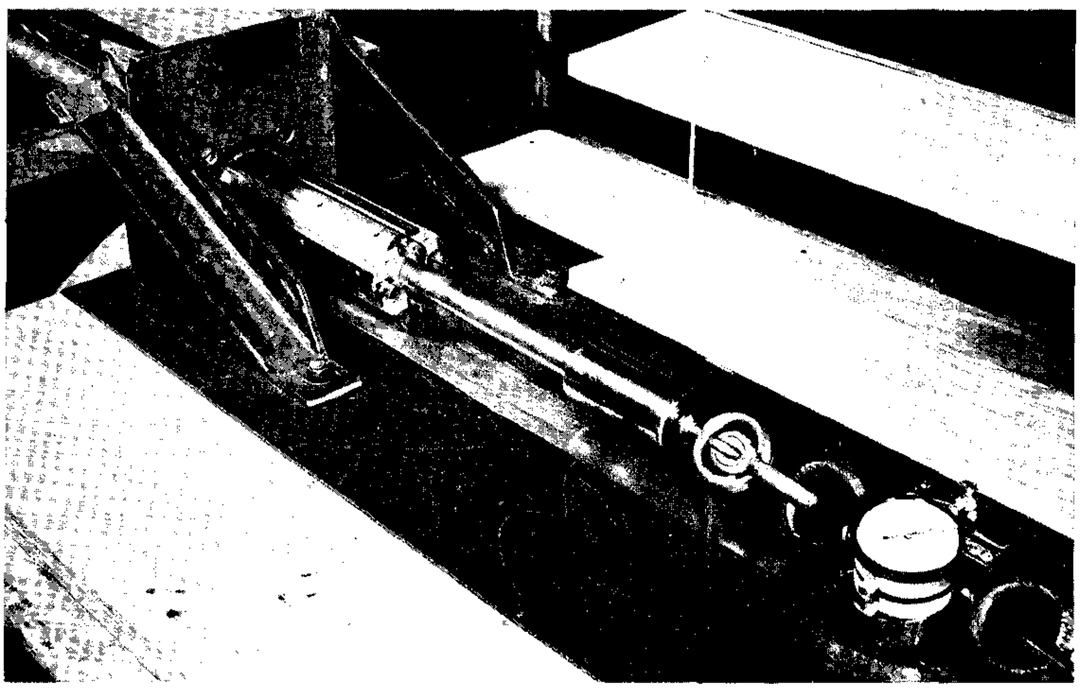
FIG. 7 CROSS SECTION OF MANDREL FOR HWCTR HOUSING TUBE

A simple drawbench shown in Figure 8a was constructed to draw the mandrel into and out of the tube. The cable from a hand-operated winch was attached to the mandrel through a "Dillon"* force gage to prevent overload during the operation. A close-up view of the stripper plate is shown in Figure 8b. The maximum forces encountered during insertion and withdrawal of the mandrel were 600 and 1100 pounds, respectively.

* W. C. Dillon & Co., Van Nuys, Calif.



a. Over-all view, hand-operated winch in foreground



b. Mandrel being withdrawn through stripper plate

FIG. 8 DRAWBENCH FOR INSERTING AND REMOVING MANDREL

EQUIPMENT OPERATION

The essential operations for the electron beam welding facility are summarized below:

General - Cleanliness in the electron beam welding operation was important since the Zircaloy-2 tube could not be cleaned or etched after welding. If cleaning solution became lodged in the cracks between the rib and sheath and were not removed by the wash water, poor corrosion behavior would result when the Zircaloy-2 was exposed to high-temperature water.

Tube loading - Tubes were prepared for loading by cutting four 1/16- x 1-inch radial slots at each end of the tube, one slot aligned with each rib position. The mandrel was drawn into the tube such that the four slots in the tube were perpendicular to the slots in the mandrel. The ribs were then inserted in the mandrel rib slots.

Positioning tube in cabinet - Front and rear trucks were attached to the mandrel; the assembly was pushed through the open hatch in the right extension cabinet (Figure 4) and over a retractable structure which temporarily bridged the gap between the left and right cabinet extensions. The tube support mechanism (Figure 5), which had been lowered, was raised into position, and the spring-loaded side roll and the weighted top rolls were brought into position. The tube was manually rotated and clamped so that the center of the rib, as seen through the radial slot in the tube, was aligned with the crosshair in the welder viewing scope. The cabinet was closed and the vacuum pumps were started. The tube was traversed to the opposite end of the system, and the rib position was observed again.

Welding - Based on the readings of the electron beam position made at each end of the tube, the beam was deflected so that its path bisected the extreme positions of the two end readings. Weld parameters were based on experience gained during test welds and varied slightly from tube to tube. Typical parameters used for the welds were 145 kilovolts, 0.35 milliampere, beam oscillated in a circular path, 0.055 inch in diameter. The tube passed under the weld beam at a speed of 60 inches per minute.

Removing tube from welder - This step was the reverse of the procedure used to insert the tube into the welder.

Mandrel removal - More force was required to remove than to load the mandrel, but the force did not exceed the 1200-pound limit of the winch. The added friction between the welded ribs of cambered tubes and the groove sides increased the force requirements.

Cycle time - With two trained operators, and the equipment at the stage of development described in this report, the highest production rate achieved during the demonstration run was three tubes per 8-hour shift. With moderate improvements in equipment and technique, it should be possible to increase this rate to four or five tubes per 8-hour shift.

PROBLEMS

The problems with startup of the new equipment were solved to the extent necessary for welding ribs to housing tubes. Some of the more pertinent problems are discussed below.

Building vibration - The electron beam welder was installed at ground level because floor vibration in other locations was in excess of the 0.05-mil maximum recommended by the machine vendor. After installation, the maximum detectable amplitude of vibration was only 0.02 mil.

Faulty tracking - Because the interface between the rib and the tube is not visible during welding, accurate tracing of this joint must be maintained by the equipment. Initially the errors in the drive mechanism were sufficient to melt an occasional hole in the tube wall adjoining the rib. The original lead screw, which had become kinked due to lack of support between its two ends, was replaced and several bearing supports were added. Low spots in the right extension table were shimmed to reduce rotational motion of the rear truck and tube to ±0.006 inch from a straight line. The residual deviation was measured with a precision level and is plotted in Figure 9 as a function of position along the tube length.

Tube roundness - Heat generated by the electron beam caused local yielding of the tube wall that was compressed by the side and bottom rolls. The tube became slightly square in shape (Figure 10), and formed a hump approximately 1/4 inch wide by up to 0.007 inch high in the tubing over each rib. Measurements of the first short welded

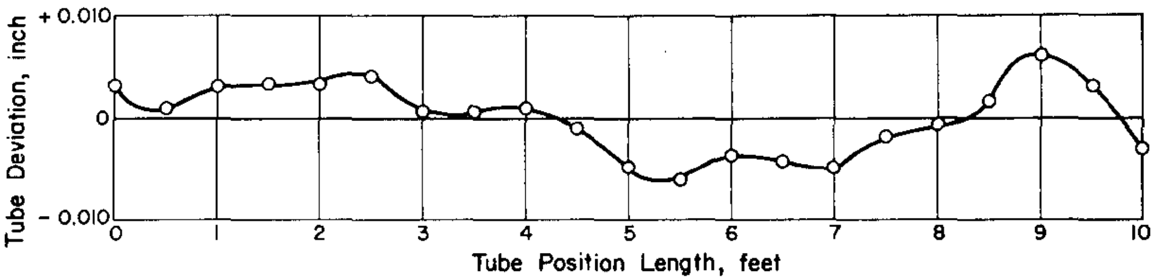


FIG. 9 TRACKING ABILITY OF GUIDANCE SYSTEM

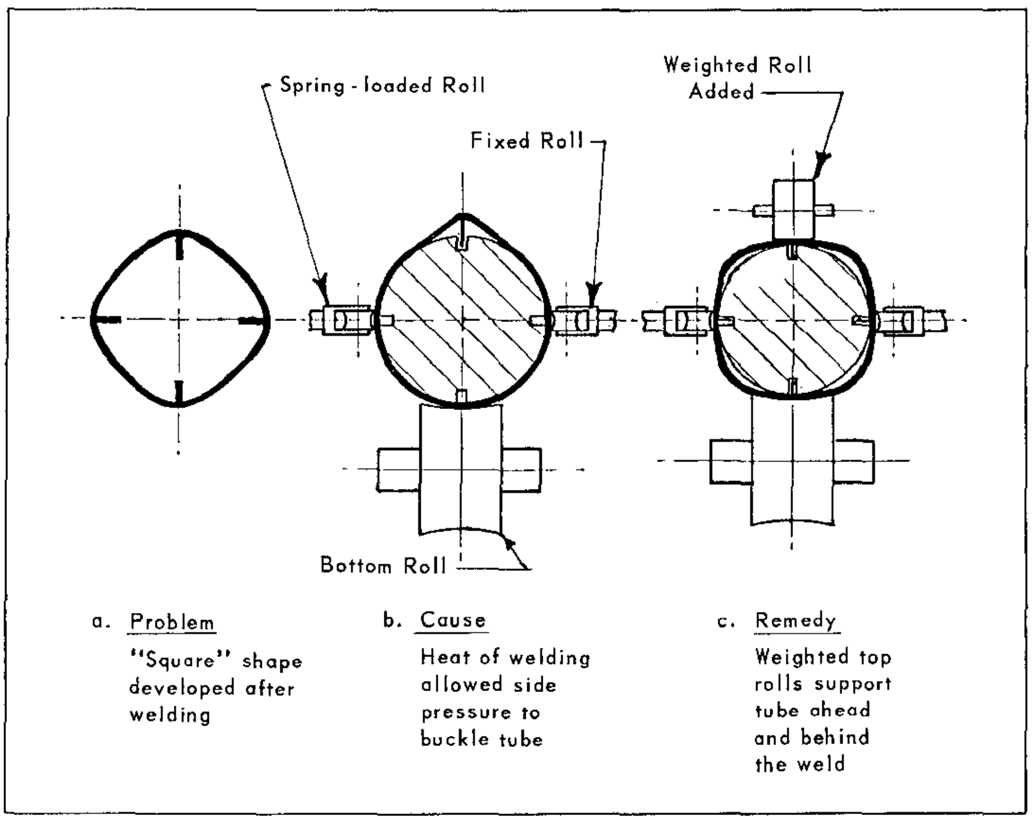
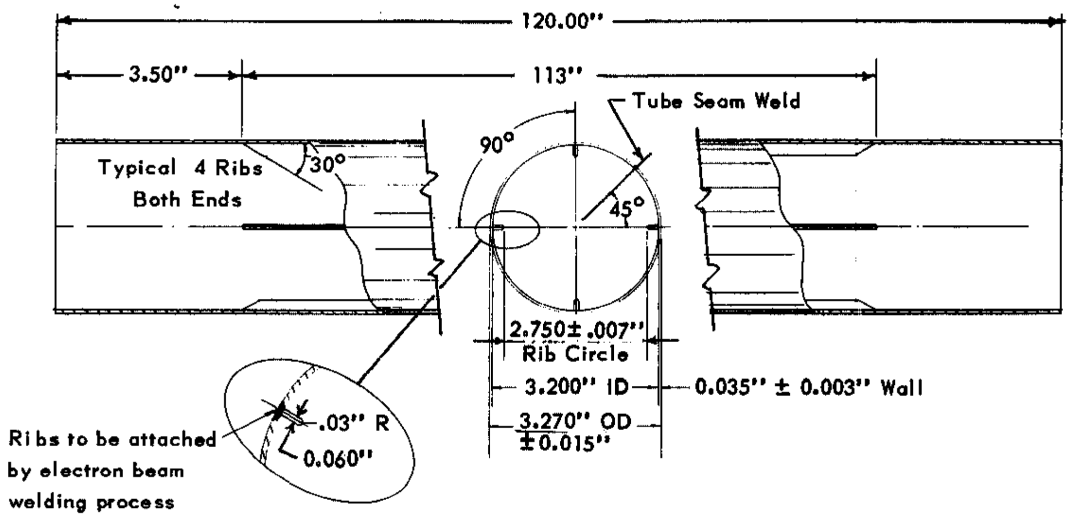
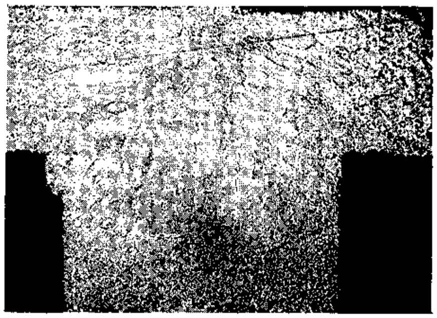


FIG. 10 PREVENTION OF OUT-OF-ROUND TUBES

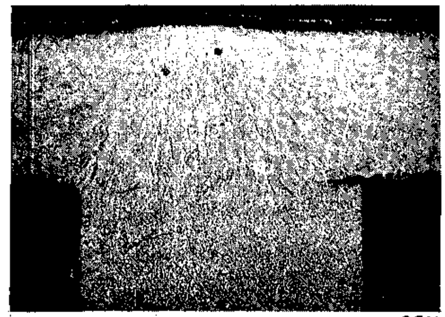


1. Housing tube and ribs: Must be etched approximately 0.00025" per surface and rinsed before attaching ribs.
2. Rib circle and outer diameter to be measured in "Free Condition".
3. Average of 0° and 90° rib-circle measurements must be in tolerance.
4. Individual rib-circle measurements must be 2.750" ± 0.015".
5. Rib must be straight ± 0.125" over entire length.
6. Maximum bow = 0.010" per foot, 0.125" overall.

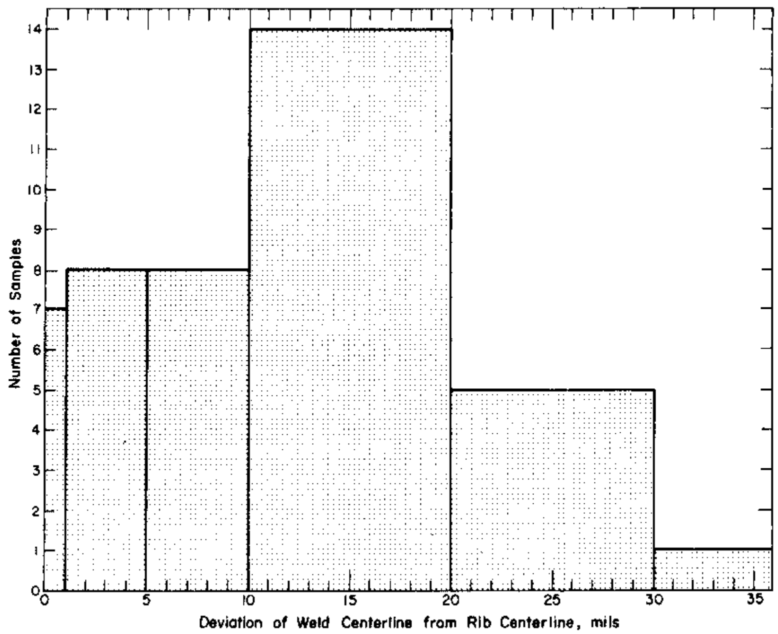
FIG. 11 HOUSING TUBE SPECIFICATIONS

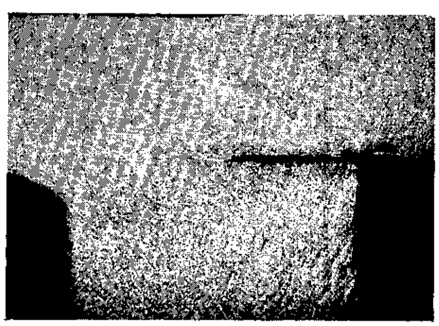


a. No Weld Offset

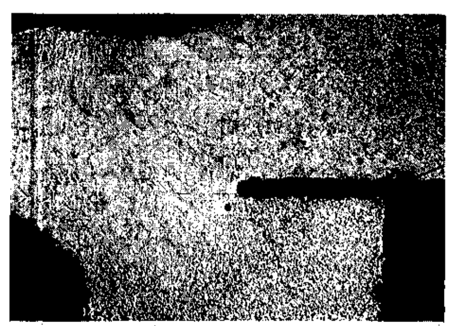


b. 4 Mils Weld Offset





c. 20 Mils Weld Offset



d. 36 Mils Weld Offset

FIG. 12 ALIGNMENT OF WELD WITHIN RIB

Dimensional control - Finished dimensions of the housing tubes could have been held within the required tolerances had the necessary allowances been recognized at the beginning of the run. The outside diameter tolerance of ±0.015 inch was held if the tube did not become partially "square" during rib welding, and provided the tubing was near the nominal dimension when received from the vendor. The rib-circle diameter was held within the ±0.015 inch (individual point) and ±0.007 inch (average of all points); but an allowance had to be made for the small hump, approximately 1/4 inch wide, which formed in the tubing over the rib. This made the rib appear to sink into the inner surface of the tubing by as much as 0.006 inch. A dimensional control chart, shown in Figure 13, lists 27 completed tubes in the order in which they were welded. Tube 1 was used as a test piece and tubes 2 and 7 were rejected before being finished; the rib height was within tolerance after the problem was recognized and corrected.

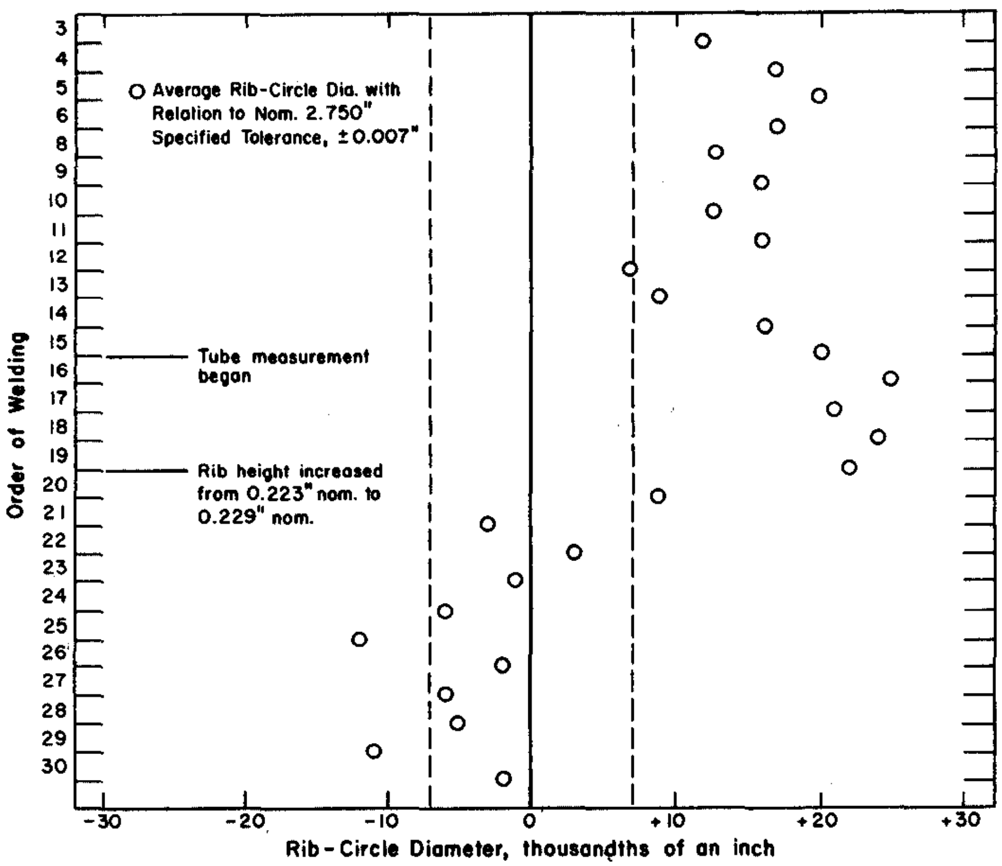


FIG. 13 DIMENSIONAL CONTROL CHART – RIBBED HOUSING TUBES

Corrosion resistance - The corrosion resistance of the rib welds was excellent. Samples of rib welds developed black lustrous films after the standard 14-day, 750°F steam test. Other samples of the rib and end fitting weldments were black and lustrous after autoclaving in 750°F steam for 48 hours; this was true whether or not the welded parts had been etched immediately before autoclaving. Acceptable corrosion resistance for these housing tubes was assured by maintaining the "work input" (expressed as kilowatt-seconds of electron beam energy per cubic centimeter of molten metal) below a range of critical values, as demonstrated in previous work[1]. An average value of 1.0 kw-sec/cc was typical for these housing tubes.

REFERENCES

1. L. J. Scott. Attaching Fuel Assembly Rib Spacers by Electron Beam Welding. USAEC Report DP-889, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. (1964).

2. A. S. Ferrara and W. G. Holmes. The Development of Tubular UO_2 Fuel Elements for Power Reactors. USAEC Report DP-997, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. (to be issued).

3. G. W. Richardson. Fuel Spacer Development. USAEC Report DP-1002, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. (1965).

4. C. R. Pound. Expanding Mandrel for Positioning Ribs Inside Long Tubes. USAEC Report DP-992, E. I. du Pont de Nemours & Co., Savannah River Laboratory, Aiken, S. C. (to be issued).