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FILLER-WIRE FEEDER AND POSITIONER
FOR ELECTRON-BEAM WELDING

J. L. Murphy
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OAK RIDGE Y-12 PLANT
OAK RIDGE, TENNESSEE

prepared for the U.S. ATOMIC ENERGY COMMISSION
under U.S. GOVERNMENT Contract W-7405 eng 26

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FOR ELECTRON-BEAM WELDING**

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ABSTRACT

A filler-wire feeder and positioner device was designed for electron-beam welding to provide automatic features that were necessary for efficient wire feeding in a vacuum chamber. The feeder can accommodate as many as nine individual weld passes and is programmed by the use of dial switches. The positioner has three axes of movement, each of which can be controlled from the exterior of the vacuum chamber of the electron-beam welding machine. These axes of movement are used to locate, precisely, the wire feed nozzle in relation to the weld joint groove and to raise or lower the nozzle between weld passes.

CONTENTS

SUMMARY	4
INTRODUCTION	5
FILLER WIRE FEEDER AND POSITIONER	6
Prior Method	6
Design Criteria	6
Feeder	6
Positioner	7
Feeder and Positioner System	7
Feeder Motor Selection	7
Equipment Description	8
Equipment Operation	8
Evaluation of the Filler-Wire Feeder and Positioner	14
Discussion	17
ACKNOWLEDGEMENTS	18
APPENDIX	19
Electrical and Mechanical Design Drawings	19

SUMMARY

Many welding operations at the Oak Ridge Y-12 Plant^(a) cannot be effectively achieved with conventional electron-beam welding because of resulting weld defects that include "spiking", cold shuts, and lack of penetration control. It is also advantageous for some applications to improve the chemistry of the weld metal by adding filler metal in the form of wire.

Commercially available wire feeders do not meet the requirements that have been set for welding inside the vacuum chamber of an electron-beam machine. A filler wire feeder and positioner device was designed and fabricated in the Y-12 Plant. The system has certain automatic features that make multipass-wire-fed welding with the electron-beam process a useful tool.

(a) Operated by the Union Carbide Corporation's Nuclear Division for the US Atomic Energy Commission.

INTRODUCTION

Problems associated with electron-beam welds in some materials include the presence of weld defects such as cold shuts, porosity, and variations in penetration control. Some metals and alloys cannot be welded with conventional electron-beam-welding techniques without subsequent cracking. Many of the powder metallurgy products cannot be electron-beam welded without excessive loss of material in the melted zone by vaporization.

A solution to the problems that have been mentioned is to prepare the weld joint with a groove, then cold-wire feed the electron-beam weld. Narrower joint grooves are permissible with electron-beam welding, compared to those necessary with conventional arc welding, because of the increased efficiency of the power input with the electron beam.

No commercially built wire feeders meet the design requirements that were established for cold-wire feeding in the vacuum chamber of an electron-beam welding machine. A wire feeder and positioner and associated electrical and mechanical components were designed and purchased or fabricated.

FILLER WIRE FEEDER AND POSITIONER

PRIOR METHOD

Preliminary studies were performed to determine the feasibility of producing welds by wire feeding in the vacuum chamber of an electron-beam welder. This technique consisted of mounting a cold wire feeder, that was used for gas tungsten-arc welding, in the electron-beam welder. The only exterior control for the feeder was to change the feed rate of the wire, but this work established the criteria for the design of the ultimate filler wire feeder and positioner.

DESIGN CRITERIA

Feeder

Performance Requirements - The following performance criteria were established:

Wire Size Range: 15 to 90 mils in diameter

Wire Speed Range: 0 to 300 inches per minute

Wire Speed Accuracy: 0.1 percent of the set speed

Acceleration and Deceleration: Variable from 1 to 99 inches per minute per second

Accessories - The following accessories were listed:

Wire Straightener

Adjustable Wire Spool Brake

Digital Drive Motors: For vacuum use at one micro torr

Positive Wire Speed Sensing Device: Which can sense the speed of the wire independently of the wire driver

Automatic Retractor for the Wire

Operating Conditions - The following operating conditions were proposed for the wire feeder:

1. Feeder will be used in close proximity to the beam of a 150-kv, 6-kw electron-beam welder. Use of magnetic materials in the construction of the wire feeder must be avoided unless absolutely necessary.
2. Feeder will be used in a vacuum chamber at one micro torr pressure and at a 100° C maximum ambient temperature.

3. Feeder shall have the capability for preselecting three speed zones with acceleration or deceleration of speed between zones.

Positioner

The following criteria were established for the wire feeder positioner:

1. Three axes of movement shall be remotely controlled exterior to the electron-beam vacuum chamber.
2. Vertical movement of the wire feeder shall be adjustable from 0 to 100 mils in increments of five mils for nine separate stages. Each stage will represent one complete revolution of the rotary headstock in the electron-beam welder.

Feeder and Positioner System

The following criteria were established for the wire feeder and positioner system:

1. Initiation of wire feed shall be automatically performed and coordinated to the initiation of the electron beam.
2. The wire feeder shall automatically advance vertically a preset value each time the rotary headstock makes a complete revolution.
3. Up to nine total revolutions of the rotary headstock shall be available.
4. The wire feeder shall be deactivated automatically at the end of a preset number of rotary headstock revolutions.

FEEDER MOTOR SELECTION

It was questionable whether the magnetic flux fields that exist around electric motors would have any influence on an electron beam. Measurements were made on three available wire feeders: Ryteck, Inc^(b) (equipped with a Slo-Syn SS-50) and two feeders identified in this report as Feeders A and B. Each feeder was evaluated by operating it in close proximity to an electron beam and by bench testing. Feeder A caused movement of the electron beam when the wire feed was started; the other two wire feeders did not.

Table 1 reports the results of bench tests that were made to determine the magnetic flux fields around the feeder motors. It was determined that the magnetic flux field varied around Feeder A when the wire feed was initiated; the other two feeders showed a stable

(b) Product of Rytek, Incorporated, Santa Fe Springs, California. Rytex, Incorporated is now owned by Data Science Corporation, 3740 Houston St., San Diego, California.

flux field when the wire feed was started. These tests showed that a wire-feed motor would be acceptable to use in close proximity to an electron beam if the flux field was stable when the wire feed was initiated, changed, or terminated.

EQUIPMENT DESCRIPTION

A view of the wire feeder, wire feeder positioner, and control cabinet is provided in Figure 1. The wire feeder positioner and the headstock and tailstock of the welding machine were mounted on a base plate, which, in turn, was mounted on the carriage table that was supplied with the welding machine. Mounted in the control cabinet is an optical tachometer, the transport control, the wire-feed controller, and motor controls for the three-axis wire feeder positioner. The optical tachometer shows, in degrees, the position of the part that is being welded. Thumbwheel switch selections on the transport control, determine the automatic features of the system. These features include initiation of the electron beam, initiation of the wire feed, wire-feed-rate selection, and selection of the number of weld passes combined with an automatic cutoff of the wire feed and electron beam. The wire-feed controller determines the wire-feed upslope, rate, and downslope. The positioner motor controllers are used to position the wire-feed nozzle and to raise or lower the nozzle between weld passes. Figure 1 also shows that ball screws and alignment shafts were used to provide precise three-axis movement of the wire feeder. Details of the mechanical design layout of the mechanism are given in the Appendix. Figure 2 is a view of the remote-control pendant that is situated at the welding machine, and it is used to: (1) select manual or automatic operation of the system, (2) start the automatic operation of the system, and (3) position the wire feeder and associated wire guide nozzle in relation to the part being welded.

EQUIPMENT OPERATION

Coordination of the wire feeding system to the part that is being welded was done by installing a position readout to the rotary headstock. The position readout (synchronizer) can be seen in Figure 3. The synchronizer is geared (1:1) to the rotary headstock drive gear. The synchronizer is electrically coupled to an optical pulse tachometer (encoder) shown installed in the control cabinet in Figure 1. Therefore, the encoder will read out the exact position of the rotary headstock and concurrently the position of a part or weldment that is installed in the headstock. The electrical schematics are given in the Appendix.

Figure 4 shows the switches on the transport control that select the sequence of the electron-beam and wire-feeding parameters. The transport control becomes active when the operator sets the selector switch, shown in Figure 2, at the "automatic" position and presses the "start" button. All action of the system is referenced from zero degree. If a part is installed in the rotary headstock and the encoder is showing, for example, 195 degrees, the part must be rotated to zero before action will begin.

Table 1
MAGNETIC FLUX FIELD COMPARISON OF
ELECTRIC MOTORS USED IN WIRE FEEDERS
(Measurements Taken Six Inches from the Motor)

Description of Motor	Motor not Running - Switch Off (gauss)	Motor Running and Feeding Wire (gauss)	Field Current Transient (gauss)
Feeder A	0.15	0.10	0.25
Feeder B	0.26	0.26	NI(1)
Slo-Syn (SS250)	NI	NI	NI

(1) None indicated.

Figure 1. FILLER WIRE FEEDER AND POSITIONER.

151106A

Figure 2. REMOTE CONTROL PENDANT.

141082

141079

Figure 3. WIRE FEEDER SETUP, SHOWING INSTALLATION OF THE POSITION READOUT. (The Three-Axis Positioner is not Shown)

Figure 4. CONTROL PANELS FOR THE WIRE FEEDER AND ELECTRON-BEAM WELDING SEQUENCE.

141080

The following sequence of events will occur after the operator has pressed the "start" button: The settings that are shown on the switches in Figure 4 will be used to demonstrate a typical weld schedule. Figure 5 illustrates the sequence of events. At zero degree, the transport control, seen in Figure 4, will be active. The electron beam will automatically initiate when the part rotates from the zero reference to the setting shown at "start beam" (10 degrees). Wire feeding will automatically begin when the setting shown at "start wire feed" (30 degrees) is reached. Also, at this time, the wire feed controller (seen in Figure 4) is activated. Wire feed will be upsloped according to the rate that is set on the switch 20"/min-sec) and then fed at the preselected value of 30 inches per minute for the first pair indicated as "Zone 1". The upslope change of rate of speed can be selected from 1 to 99 inches per minute per second. Therefore, since acceleration is change of velocity with respect to time, it would take 1.5 seconds for the wire to accelerate to a speed of 30 inches per minute, or an upslope rate of 20 inches per minute per second. Three channels of wire feed are available, and up to nine revolutions (or weld passes) can be programmed. Any channel of wire feed rate can be used during the weld passes. For example, Channel 1 can be used from one to nine weld passes; Channel 2 or 3 can be automatically selected on any of the nine weld passes. Selection of the wire feed rate is made by dialing the desired selection on the zone feed selector. Figure 4 indicates that a feed rate of 30 inches per minute (Zone 1) is selected for two revolutions of the part. At the 30-degree point in the third revolution, Zone 2 is activated and the feed rate is 50 inches per minute. On the fourth revolution, Zone 3 is activated and would remain so until the fifth revolution (or weld pass), at which time the system is deactivated.

Revolutions of the part being welded are counted and shown on the transport control. When the number of passes (5) that are set on the switch, marked "passes", have been reached and the 30-degree location at which the wire feed was started is reached, the wire feed will downslope according to the rate that is set at the final zone ("fin zone") (20).

When the wire has downsloped to a feed speed of 0 inch per minute, it will be automatically retracted away from the area of the molten pool. The beam will then deactivate according to the number of seconds (3) that are set on the beam cutoff switch.

Another feature of interest on the remote control pendant, shown in Figure 2, is the toggle switches that are used to engage the motors for the three axes of wire feed location.

A manual setting of the selector switch makes the wire feeding system independent of the electron-beam welder. None of the automatic features of the system are then operational. Zones for the wire feed rate are then selected by push switches on the controller.

It was desirable that the wire feeder be advanced vertically between successive weld passes to provide improved relationship of the wire being fed to each reinforced weld pass. A view of the control panel for vertical movement and also longitudinal and transverse movement is provided in Figure 6. The Slo-Syn indexer will index according to the desired settings; the Slo-Syn motor will move the shaft supporting the wire feeder in increments up to a total of 0.117 inch for any weld pass.

The wire feeder will be advanced vertically when the weld pass counter, shown in Figure 4, counts a complete revolution of wire feed and each time another revolution is made.

EVALUATION OF THE FILLER-WIRE FEEDER AND POSITIONER

Views of a typical weld that was made on 0.213-inch-wall-thickness, Type 6061-T6 aluminum alloy using Type 4043 filler are given in Figure 7. Depth-to-width ratio of the weld is 1.5 to 1. This weld does not illustrate the optimum cold-wire-feed welds that can be made. The depth-to-width ratio can be improved and the number of weld passes to complete the weld could be reduced. The weld in Figure 7 was performed in a fully automatic mode of operation. Table 2 lists the welding parameters that were used. These parameters were selected for an optimum root pass as far as appearance and radiographic acceptance is concerned. The remaining passes were to fill the joint and not burn through the root pass. Average tensile strength of the weld was 30,000 psi; average yield strength, at 0.2% offset, was 21,000 psi; and average elongation, in one inch, was 7.5%. Figure 8 reports the average hardness measurements for each weld pass. Hardness readings in various locations on any single weld pass did not vary more than 5%.

Figure 5. TYPICAL MODEL OF THE PROGRAMMING OF A FIVE-PASS WIRE FEED WELD.

Figure 6. CONTROL PANELS FOR THE THREE AXES OF THE WIRE FEEDER MOVEMENT.

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(a) Cross Section of a Four-Pass Wire-Fed Weld. (10X)

MS-72-1357-1

(b) Typical Backside of the Root Pass of a Multipass Weld. (10X)

MS-72-1357-4

Figure 7. MULTIPASS WIRE-FED ELECTRON-BEAM WELD ON TYPE 6061-T6 ALUMINUM WITH A WALL THICKNESS OF 0.213 INCH AND WITH TYPE 4043 FILLER.

Table 2
WELDING PARAMETERS FOR MULTIPASS WELDING OF THE
TYPE 6061-T6 ALUMINUM ALLOY

Weld Pass Number	Parameter				Wire Feed Rate (ipm)
	Kilovolts	Milliamperes	Focus ⁽¹⁾	Part Travel Speed (ipm)	
1	75	9	410	18	18
2	75	9	420	18	30
3	75	9	430	12	30
4	75	9	430	12	30

(1) Represents a defocus of the electron beam. A setting of 385 milliamperes was established for a sharp focus at the surface of the part.

DISCUSSION

The automatic features that are designed into the filler-wire feeder and positioner will make it more amenable than available commercial wire feeders for usage in a vacuum chamber. It would be extremely difficult to manually manipulate the wire being fed into the weld. The automatic vertical lifting mechanism will keep the wire at a proper relationship to the weld. Mechanical gages could be fabricated that would assure that the initial setup of the wire being fed was correct.

All sequences of the system are referenced from the rotary motion of the part being welded. Therefore, the automatic sequences of the system are directly related to the part that is being welded.

Many of the metals and alloys that were difficult, if not impossible, to weld with conventional electron-beam welding can be welded with the cold-wire method.

Figure 8. TYPE 6061 ALUMINUM MICROHARDNESS (DHP) FOR A MULTIPASS ELECTRON-BEAM WELD. (ER 4043 Filler)

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APPENDIX

ELECTRICAL AND MECHANICAL DESIGN DRAWINGS

Electrical design drawings are provided that show the wiring and components of the wire feeder and positioner. These schematic drawings also show the electrical connections to the electron-beam machine to make the system function in an automatic welding mode. Also included is a layout of the mechanical design of the three-axis wire-feed mechanism.

RELAY PCB MAP 14 DG 24 VOLTS		
11 PIN TUBE SOCKET		
45	1-3-57	1 GRIPPER, 3/16" x 1/2" x 1/2" U.C.
46	1-3-56	1 SURKIT, FOR ALLO READING
47	1-3-55	1 READOUT, ALCO MS-6A READING
48	1	SHIELD, PER DET H, E-1-78393
49	1	BRACKET, PER DET C, E-1-78393
50	1	PANEL, PER DET G, E-1-78393
51	1	PANEL, PER DET F, E-1-78393
52	1	BRACKET, PER DET A, E-1-78392
53	1	BRACKET, PER DET S, E-1-78393
54	1-3-35	1 WHEEL, PER DET D, E-1-78392
55	1-3-35	1 SHELL, AMP. 2102A-22
56	1-3-34	1 INSERT, AMP. 22-1AP
57	1-3-33	2 SHELL, AMP. 3102A-20
58	1-3-32	1 INSERT, AMP. 20-215
59	1-3-31	1 INSERT, AMP. 20-21P
60	1-3-30	1 RELAY SOCKET
61	1-3-29	1 RELAY, RHP 17C11
62	1-3-28	1 FILTER, ALT. POWM17
63	1-3-27	1 LOGIC CABLES, PER R/M 1-2
64	1-3-26	1 TRANSFORMER, CEC 4K-7A1
65	1-3-25	1 FUSEHOLDER
66	1-3-24	1 TRANSFORMER, 115/6.3, THORO. 21F08
67	1-3-23	1 STRIP, TERMINAL CABLE, X17050
68	1-3-22	1 POWER SUPPLY, ACOPHAN 2N406
69	1-3-21	1 SHEET STEEL, PERFORATED
70	1-3-20	1 BASE, MUEBELL #7N05
71	1-3-19	1 BOX, MINI, BUC #20300, CEC. P. E-1-78393
72	1-3-18	1 CHASSIS, PER E-1-78388
73	1-3-17	1 BAR, PER DET H, E-1-78392
74	1-3-16	1 BAR, PER DET M, E-1-78392
75	1-3-15	1 PANEL, PER C-1-78392
76	1-3-14	1 CATCH, MAGNETIC
77	1-3-13	1 HANDLE, CAMBRIDGE #415-125G-02-02
78	1-3-12	1 MOUNTING HARBOR, FOR THUMBWHEEL SWITCHES
79	1-3-11	1 SWITCH, THUMBWHEEL, 10 POSITION, CECALIGHT OUTPUT, WITH POSITION 6 THROUGH 9 LOCKED OUT, CIGITRAN NO. 6024
80	1-3-10	2 SWITCH, THUMBWHEEL, 10 POSITION, CECALIGHT OUTPUT, CIGITRAN NO. 8025
81	1-3-9	2 SWITCH, THUMBWHEEL, BCC WITH A THROUGH 9 LOCKED OUT, CIGITRAN NO. 8015
82	1-3-8	1 SWITCH, THUMBWHEEL, BCC, CIGITRAN NO. 8015
83	1-3-7	1 LENS CAP, REC. SQUARE
84	1-3-6	1 SWITCH BASE, WITH PILOT LIGHT
85	1-3-5	1 CAP, LENS HOLDER, WHILE, CIALIGHT 101-0975
86	1-3-4	1 LIGHT, PILOT, CEC. 1/2" DIA., CIALIGHT 101-0975
87	1-3-3	1 LAMP, 110 VAC, T 3-1/2" NEON
88	1-3-2	1 LIGHT, PILOT, CIALCO 55-0408-0935-3A2
89	1-3-1	1 SWITCH, TOGGLE, CPST

ITEM	R/M	QTY	DESCRIPTION
MATERIALS LIST			

Figure A-3. ELECTRON-BEAM WELDER. (Chassis Assembly)

Figure A-4. ELECTRON-BEAM WELDER. (Readout Driver)

Figure A-5. WIRE FEED MECHANISM.

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