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**RESULTS OF THE AUTOMATIC
ORBITAL WELDING EQUIPMENT DEMONSTRATION**

RN-DR-0197

April 1970

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AEROJET NUCLEAR SYSTEMS COMPANY

A DIVISION OF AEROJET-GENERAL CORPORATION

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RESULTS OF THE AUTOMATIC
ORBITAL WELDING EQUIPMENT DEMONSTRATION

NERVA Program

Contract SNP-1

April 1970

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RESULTS OF THE AUTOMATIC
ORBITAL WELDING EQUIPMENT DEMONSTRATION

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I. INTRODUCTION AND SUMMARY

Relatively recent advances in state-of-the-art "in place" automatic tube and pipe welding equipment and power supplies make automatic welding of NERVA lines not only feasible but highly desirable. An investigation of available automatic equipment had been conducted, and two orbital D.C. TIG Welding System manufacturers emerged as candidates for more detailed investigation. The Dyna Surge manufactured by Liquid Carbonic Corporation, and the Astro-Arc manufactured by Astro-Arc Company were selected as the most applicable systems for NERVA line welding.

Both manufacturers were given a program plan for a minimal demonstration of their equipment and asked to submit bids. Both manufacturers were to weld 5086 aluminum and Inconel 718. Liquid Carbonic was asked to further submit sample welds on AISI 347 and 6061T6 aluminum.

The Liquid Carbonic system has the capability of feeding filler wire; the Astro-Arc unit fuses the parent material or a consumable insert to weld the joint, it does not feed wire.

The demonstration welding was accomplished at the Liquid Carbonic Corporation facility in Los Angeles, and at the Astro-Arc Company in Sun Valley, California.

Aluminum and stainless steel tubing in the sizes and quantities as noted in Tables 1 and 2 were supplied by Aerojet for the demonstration. 6061-T6 aluminum tubing was not supplied to Astro-Arc because it would have involved the development of consumable inserts to accomplish the welding. The AISI 347 tubing which was supplied to Liquid Carbonics was left over from a previous weld program. Since these pieces had previously been machined with a V groove weld preparation, which requires filler wire to weld, they were sent to Liquid Carbonic.

An Aerojet Materials Engineer was on hand during most of the welding in order that system operational deficiencies and virtues could be observed. Both systems performed well and demonstrated that they could join tubing satisfactorily.

The appearance of the welds as received from Liquid Carbonic were definitely inferior to those received from Astro-Arc; however, this was primarily due to Liquid Carbonic's lack of knowledge for basic welding techniques and not to be considered as an equipment deficiency. The Astro-Arc unit welded 0.260 inch thick aluminum and 0.050 inch thick Inconel 718 without filler wire. The 718 tubing was poorly matched and yet the appearance of the welds was excellent around the entire circumference of the tubes supplied. Liquid Carbonics samples showed short sections of fairly good welds indicating that when correct settings and weld techniques are employed, quality joints can be obtained. The Astro-Arc System is more compact, more easily set up, requires less joint preparation, and has better atmosphere control than the Dyna-Surge head. The Liquid Carbonic Dyna Surge is better suited for thick wall large commercial pipe where filler metal is required.

After careful consideration of the advantages and limitations of both systems coupled with the results of the demonstration, the Astro-Arc automatic orbital welding system was selected as the better candidate for NERVA feed system construction.

Radiography of preliminary samples indicates potential for producing high quality welds equivalent to nonorbiting TIG welding methods. Moreover the high-frequency current pulsation of the Astro-Arc CA-150-P system showed potential for producing better joints in aluminum alloys than those produced by conventional constant current TIG welding.

II. OBJECTIVES

The objective of this program was to evaluate two automatic orbital welding systems using representative materials and sizes of NERVA Feed System components, and select one for further study and development. Welding techniques, potential problem areas, system limitations, and system potential were further objectives to be realized from this demonstration.

It should be emphasized that weld quality, and weld joint integrity were not objectives of this program. This is not to say that efforts were not made to obtain high quality joints; however, time and numbers of joints attempted precluded any hope of conducting a successful joint development program.

III. CONCLUSIONS

Astro-Arc is functionally the better welding system for in-place welding of NERVA lines, although at this time further testing is required to develop optimum weld quality. This judgment is based on the following observations:

1. The compactness of the Astro-Arc clamp-on weld head assembly will permit its extensive use on the intricate, curved NERVA line configurations.
2. The system performs one basic mechanical function, rotation of a tungsten electrode around a tube joint, thereby greatly reducing the possibility of mechanical malfunction.
3. The solid-state, full wave, silicon transistor current source, the accurate electronic weld sequence control, and the punch card reader, provide assurance of high quality welded joint repeatability.
4. It provides the capability for experimentation with automatic welding techniques by providing a choice of five fully adjustable, current wave forms.

5. The weld head can be operated remotely up to 100 feet from the control console.

6. The compact package of the orbital welding head provides a potential for fabrication of semi-permanent joints for "in-place" field repair or replacement of engine modules.

IV. RECOMMENDATIONS

1. Table 3 represents the qualifications of each system. After comparison of each feature it was concluded that the Astro-Arc head should be selected as the prime orbital welding head for NERVA Feed System Lines and that the Astro Arc CA-150-P power supply, including the punch card reader option, be the prime selection.

2. Further investigation should continue in order to evaluate the relative advantages of methods by which the equipment could be obtained for development of NERVA feed system joints as follows:

a. Procurement of the equipment, or lease with an option to buy, with capital funds for use in the AGC, Sacramento Shop.

b. Procurement of the equipment as tooling in consideration of its unique application to NERVA Feed System Fabrication.

c. Procurement of the equipment as AGE in consideration of its unique application to NERVA Engine assembly at NRDS.

d. Usage of subcontractor equipment; prepare a listing of equipment owners who are qualified to develop an optimum weld process and fabricate NERVA Feed System components.

3. A formal joint development program should be formulated in order to isolate the NERVA Feed System fabrication requirements.

V. TECHNICAL DISCUSSION

A. DESCRIPTION OF EQUIPMENT

1. Liquid Carbonic Corporation

a. Dyna Surge Head

The original concept of this system was developed by the Electric Boat Division of the General Dynamics Corporation to accomplish "in place" welds in Nuclear Submarine piping systems. Many systems are in use today, including units in North American Aviation, Lockheed, Mare Island Navy yard, Electric Boat Co., and in Canada and USA Nuclear Power Plant installations.

The Dyna Surge System as shown in Figures 4 and 5, features a clamp-on-pipe weld-head carriage assembly with a motor driven, split-ring gear drive which propels the tungsten inert gas (TIG) weld head around the tube joint. A small motor driven wire feeder, torch head oscillator, and arc voltage control (AVC) mechanism are an integral part of the weld head carriage assembly. The electrode assembly is a standard Linde hand TIG torch and coaxial gas lense unit attached to the AVC mechanism.

Carriage assemblies are available for pipe or tube sizes from 1/2-inch diameter to 36-inch diameter.

b. Model APW-4 Power Supply

The APW-4 Power Supply used for this demonstration, is a prototype unit for the APW-3D unit and similar to the unit shown in Figure 5. D.C. current is supplied by a specially modified, 300 amp rectifier, controlled by a magnetic amplifier. Control of weld parameters, including current pulsation is accomplished through a solid-state console.

Pulsing, as used in the Liquid Carbonic System, consists of a periodic variation of the arc current amplitude at a predetermined rate which generates a definite unidirectional wave shape as shown in Figure 1. With the APW-4 model, only the pulse amplitude may be varied, the pulse frequency rate is fixed at 10 Hz (Hertz). A new model, APW-3D, will provide controls to vary the pulse frequency in a range of 1 to 15 Hz. This unit will soon be available as a production unit.

Weld current and travel speed are preset for constant output prior to initiation of the weld sequence. Weld current can be pre-programmed only for slope-down to the low amplitude pulse setting at weld termination, and weld travel speed can be adjusted during the weld sequence only by manual dial adjustment at the control console. The new APW-3D will incorporate controls to pre-program up or down-slopes in both current and travel.

2. Astro-Arc Company

a. Astro Arc Head

The orbit-arc concept employed by the Astro-Arc welder was originally developed by North American Aviation to weld small diameter steel feed lines for aircraft and space vehicles. Many Astro-Arc weld systems are in use in the aerospace industry, (Bell Aerosystems, North American Aviation, Douglas, Convair, Lockheed, Pratt-Whitney, etc.) mainly in weld head sizes of 1/16 inch to 2 inch diameters. Weld heads up to 4 inches diameter are standard equipment, with larger diameters available upon special order. Special heads to fit tubing as large as 7.00 OD have been developed and are operational.

The Astro-Arc welding system shown in Figure 6, features a unique, compact, clamp-on, tube welding device which automatically rotates a tungsten electrode around the tube joint and fuses the parent material, or a consumable insert, to produce a joint. The weld head is completely enclosed in a split type precision machined housing which retains the inert-gas and affords optimum atmospheric shielding during welding. The housing is made of a boron-nitride material to withstand the high temperatures generated by the welding arc. The weld head is moved around the joint by means of a split ring gear inside a stationary housing which is driven by a small, high torque permanent magnet DC motor. The weld heads are obtainable with single or double tube clamps. The double clamp arrangement, with a clamp on both sides of the joint, provides for accurate tube and joint alignment. The weld head used for the NERVA welding had a single clamp. The clamps are made of "Vasco-Jet 1000" steel which has high strength at elevated temperatures. The weld head clamp has a removable insert that must be changed when going to a different tube diameter.

b. Model V-300 Power Supply

The V-300 is a full wave, 3-phase D.C. rectifier, magnetic amplifier controlled, 300 amp power supply, modulated by a transistorized welding current programmer. This unit was used to weld the Inconel 718 tube joints and part of the 5086 aluminum tubing. This model has the capability of producing two welding current wave shapes as illustrated in Figure 3 wave forms 1 and 2. Wave 1, producing linear current slopes and zero ripple constant current, and wave 2, designated as square wave pulsation, is produced by controls which alternately raise and lower the current magnitude throughout the welding cycle. Duration and amplitude of both high and low current pulses are separately adjustable, with the pulsation rate being adjustable between one and 100 Hz.

All weld variables are preset and controlled through a transistorized programmer which is an integral part of the power supply package. Electrode travel speed can also be programmed. A typical weld sequence, as shown in Figure 2 would be programmed as follows: Arc ignition followed by a travel delay to buildup initial heat, then constant speed to a point 180° from the start, followed by an increase in travel speed which continues at a predetermined rate to completion of the weld, at which time a slope down in current is initiated, and the weld is tapered off and eventually terminated past the point of tie-in. Plug-in jacks are provided for an oscillograph recorder to record the motor speed, arc voltage, and current. Panel meters are provided for weld current, arc voltage and weld head speed (RPM); and indicator lights show progress through the timing functions of the pre-programmed weld sequence. Further options include remote control up to 100 ft.

c. Model CA-150 Power Supply

The CA-150 is a full wave, 3-phase DC rectifier, magnetic amplifier controlled, 150 amp power supply, modulated by a transistorized welding current programmer. This unit is capable of producing five current modes as illustrated in Figure 3. Mode 1 is a standard DC constant current with fully adjustable, up and down slopes. Mode 2 is a square wave, with a slow rate pulsation adjustable from 1 to 100 Hz of either high or low current settings. Mode 3 is a fast current pulsation, adjustable through a frequency range from 1,000 to 25,000 Hz, with a full range of current settings. Mode 4 is a dual wave form, one superimposed over the other. Mode 4 is composed of Mode 3, superimposed over Mode 2, featuring simultaneous slow square wave and fast pulsation modes. Mode 5 is similar to Mode 4 with the exception that the high frequency modulation is superimposed on the high amplitude portion of the square wave only. Current modulation amplitude adjustment is accomplished by means of digital readout dials.

The CA-150 model incorporates a 3-channel servo recorder which records arc voltage, weld head speed, and arc current, with a punch card reader for programming the weld sequence. The punch card reader, when used, disables all manual front panel program controls.

B. EQUIPMENT DEMONSTRATION

1. Liquid Carbonics Corporation

All welds by the Liquid Carbonic welder utilized filler wire during welding. It should be noted also that all the welding at Liquid Carbonic was performed by an electronic technician who was highly skilled and knowledgeable in the equipment circuitry and operation but had practically no knowledge of good welding procedure.

a. AISI 347 Tube Welding

The first welds with the Liquid Carbonic System were made on the AISI 347 tubing. Electrical circuit malfunctions which occurred during this welding made the establishment of acceptable weld parameters difficult to achieve. However, observation of the function of the equipment and the welds that were made indicated that the system could produce satisfactory welds on in-place 347 tubing.

b. 5086 and 6061-T6 Aluminum Tube Welding

The aluminum welding appearance was poor. This was due in part to the joint configuration, which was not suited for this type of welding, and to the inexperience of the Liquid Carbonic operator.

The standard "V" joint tended to promote uneven melting of the side walls, resulting in nonuniform penetration. The close proximity of the electrode to the edge of the "V" caused the arc to move to the side of the groove which gave a signal to the (AVC) unit to back out the head from the work piece, thereby promoting uneven heat distribution.

The modified "V" joint as defined in Table I with a 0.070 inch thick rootland was not satisfactory because the land, when machined, was indexed to the OD of the tube causing variations in tube wall thickness to be reflected in land thickness. In some areas the land thickness was reduced to 0.050 inches which resulted in a burn-through during welding.

While the Dyna Surge head has been used extensively to weld thick wall pipe, little or no experience exists with small or large diameter, thick or thin wall aluminum tubing.

Despite the difficulty encountered in welding the aluminum the APW system did demonstrate the capability to produce satisfactory welds in aluminum tubing, given the right joint design, power supply settings, and operated by experienced personnel.

c. Inconel 718 Tube Welding

No completely welded joints were achieved on the 718 tubing. This was due in part to the grossly out-of-round condition of the tubing as received, which resulted in burn through blow holes, lack of fusion, and mismatch. Here again, inexperience of the Liquid Carbonic operation in conducting the demonstration was noted as the major cause for failure to achieve good welds. The tubing could have been reshaped by hand in order to minimize concentric mismatch and the ends should have been fitted by hand grinding. If these precautions had been taken, adequate joint fusion could have been achieved.

2. Astro-Arc Company

All welds by the Astro-Arc weld system were produced by fusion of the base material of the tube utilizing a square-butt joint. No additional material was fused to the joint.

a. 5086 Aluminum Tube Welding

While Astro-Arc systems have been used extensively to weld thin-walled steel and stainless tubing, only limited experience exists with small diameter thin wall aluminum tubing, and none at all with heavier wall, large diameter aluminum tube such as supplied by Aerojet for this demonstration.

The aluminum welding should rightly be classified as experimental in nature. Because of the limited scope of the demonstration welding it was not possible to develop optimum weld parameters.

The first aluminum weld joints were made with the Model V-300 using Mode 2 current output shown in Figure 3, and a pulsation rate of approximately 2 cycles per second. The tube was positioned vertically with the Astro-Arc head circling the joint in a horizontal plane.

These welds exhibited nonuniform penetration, the OD bead tended to be concave with a coarse, wide ripple, similar to overlapping spot welds, with a roll-over of the ID penetration bead at the lower edge. This condition was attributed to gravity on the molten weld bead during the weld sequence induced by the vertical position of the tube.

Some weld joints were made with the Mode 1 current, (no pulsation) shown in Figure 3. These welds exhibited a smoother surface appearance, without the ripple of the low pulse bead, and a narrower width. However, the penetration bead size tended to vary extensively.

The best appearing welds in the 5086 aluminum tubing were made with the Model CA-150-P using Mode 3 current output shown in Figure 3, and a current pulsation frequency of 14000 Hz. The DC current was modulated between 190 amps peak to a minimum of 90 amps with equal amplitude duration distribution between two extremes. These welds had a narrower bead and heat affected zone and more uniform penetration than any of the aluminum welds made with the other current modes.

The results of the welds made with the fast rate current pulsation indicate that with further development of welding parameters, acceptable welds in thin wall aluminum tubes could be made without joint edge machining.

b. Inconel 718 Aluminum Tube Welding

Astro-Arc had little difficulty in setting-up and establishing parameters to weld the 718 tubing. The welding was accomplished with the Model V-300 machine, using Mode 2 current output shown in Figure 3. The high pulse was set at 56 amps, low pulse at 25 amps, and the pulse frequency was set at 3 Hz. Initial current was 15 amps with a 1 second travel delay. The constant speed was set at approximately 5.7 IPM with a slope up initiated at 180° of rotation to a maximum of 8.5 IPM at weld termination followed by a gradual tail-off.

The 718 tube was difficult to fit up accurately because of the gross out-of-round, condition. Considering that the mismatch in some areas of the joint exceeded half the thickness of the 0.050 inch tube wall, the performance of the Astro-Arc welder in successfully fusing the joint without filler wire was impressive.

VI. RESULTS

A. GENERAL DISCUSSION

The Liquid Carbonic and Astro-Arc in-place tube and pipe welding systems present two different approaches to accomplish the welding of tubing and pipe in fixed positions. In their separate engineering concepts they represent probably the best systems in industry today.

B. RESULTS

1. Liquid Carbonic

Liquid Carbonic has taken the basic TIG (tungsten inert gas) process intact with cold filler wire feed, automatic voltage control, and oscillator; and mounted it all on a precision made carriage assembly which clamps over the tube or pipe to perform the welding. They have modified a standard 300 amp power supply, added a control system to control the weld sequence, feed wire, maintain arc length, and deliver current pulsation in a frequency range (1-15 Hz) adequate to maintain control of the molten weld metal for 360° around the joint. The demonstration welding showed that it performs these functions, for which it was designed, efficiently.

a. Advantages

The APW system provides the user with the ability to feed filler wire. This becomes a special advantage when welding Aluminum 6061 alloy because 6061 is crack-sensitive and generally cannot be welded successfully without the addition of filler wire containing crack resistant constituents such as silicon.

The automatic-arc-voltage control (AVC) which maintains the desired arc to work distance is advantageous because it automatically adjusts the torch head for uneven surface conditions, thus maintaining a constant current output regardless of surface irregularities.

The ability to horizontally oscillate the torch head is a desirable feature, especially when welding thick sections, to deposit heavier fill passes in the joint.

The weld head itself is in the open which enables the operator to more closely monitor the weld as it is being made. This is a desirable feature for development purposes; occasionally a potential problem can be rectified if caught in time.

b. Disadvantages

The weld carriage assembly, because it does incorporate functions such as wire feed, AVC, and oscillator, is cumbersome and takes up considerable axial space when mounted on the tube; 7-1/4 inch width for a 3 to 6 inch diameter carriage assembly. This is a serious disadvantage for NERVA line welding. Furthermore, the bulky AVC unit appeared to be ineffectual when called upon to weld poorly matched tubes as in the Inconel 718 demonstration. While the ability to feed wire is desirable, and in some instances on heavy wall pipe, a necessity, it is a mechanical function that can introduce problems during welding and have an adverse effect on repeatability of approved procedures. The wire feed angle into the arc is a manual adjustment therefore subject to operator error, the feed rate can vary, or the mechanism can jam stopping the wire feed during the weld sequence.

2. Astro-Arc Company

a. Advantages

The Astro-Arc weld head clamp on assembly was designed to accomplish three things: (1) clamp and align the tube joints, (2) rotate a tungsten electrode precisely around the joint, and (3) provide for a housing to dispense inert-gas coverage completely around the joint while welding. It accomplishes these functions in a compact (axial width for 7-inch diameter weld head assembly is 2-1/2 inches) device that is easily and quickly installed on the joint.

The rather recent advent of current pulsation is a feature, which more than any other technical advance, has improved automatic orbital welding of tube and pipe. The primary benefit derived from pulsing the current is in controlling the weld puddle size, and fluidity in any position 360° around the pipe or tube.

Astro-Arc has concentrated on developing several additional current pulsation modes as shown in Figure 3, and as a result, has expanded on the basic benefit derived from pulsation to include several additional benefits. In conjunction with the Astro-Arc total weld programming, the various current pulsation modes have greatly expanded the use of the system. The square wave, slow rate pulsation as shown in Figure 3, wave 2, increases arc stability, especially at low current settings, and this becomes useful on light gauge tubing, especially where mismatch exists. The fast rate pulsation as shown in Figure 3, wave form 3, introduces puddle vibration to improve weld appearance, joint strength, and consistency of penetration. The simultaneous action of slow and fast pulsation as shown in Figure 3, wave forms 4 and 5, expands the process limits to include thick walled aluminum as well as other alloyed tubing.

b. Disadvantages

The obvious disadvantages of the system, i.e., no wire feed capability and no arc voltage control, are largely overcome by the versatility which the variety of pulsed current modes bring to the system.

In cases where filler material becomes a necessity, special joints, such as the flange joint, or consumable inserts may be used.

Inability to see the weld while it is being made poses a minor problem for joint development. It was felt that the improved cover gas control and fixturing capability created by the unique Astro-Arc head and clamp design outweighed this undesirable feature.

VII. REFERENCES

1. Memorandum 7750:M:0694, dated 23 October 1969, G. D. Livers to K. E. Unmack; "Trip Report to Astro-Arc Company on 16 October 1969"
2. Memorandum 7732:MM:69-209, dated 3 December 1969, C. W. Fletcher to K. E. Unmack; "NERVA Lines Automatic Weld Development Program"
3. Memorandum 7750:M:0738, dated 11 December 1969, G. D. Livers to K. E. Unmack, "NERVA Lines, Automatic Weld Development Program"
4. Memorandum 7300:0708, dated 9 February 1970, S. A. Komjathy to G. D. Livers; "NERVA Lines Automatic Weld Development Program Q.E. Review"
5. Memorandum 7300:0715, dated 16 February 1970, S. A. Komjathy to G. D. Livers; "Quality Assurance Provisions for NERVA Lines Automatic Weld Development Program"
6. Memorandum 7750:M:0801, dated 26 February 1970, G. D. Livers to K. E. Unmack; "Tour of Mare Island Welding Facilities"
7. Memorandum 7732:MM:70-085, dated 26 February 1970, C. W. Fletcher to K. E. Unmack; "Preliminary Evaluation of the Dyna Surge Orbiting Pipe and Tube Welder - Trip Report - 2 and 11 February 1970"
8. Memorandum 7732:MM:70-106, dated 12 March 1970, C. W. Fletcher to K. E. Unmack; "Preliminary Evaluation of the Astro-Arc Orbiting Tube Welder - Trip Report, 24-28 February 1970"
9. Memorandum 7300:0741, dated 16 March 1970, C. R. Orr to G. D. Livers; "Automatic Orbital Weld Nondestructive Test Plan"
10. Memorandum 7732:MM:70-112, dated 20 March 1970, C. W. Fletcher to K. E. Unmack; "Evaluation of the Astro-Arc and Liquid Carbonic In-Place Pipe and Tube Welding Systems for NERVA Line Welding"
11. Memorandum 7300:0750, dated 23 March 1970, C. R. Orr to G. D. Livers; "X-Ray Results of Orbital Weld Samples Selected for NDT"

TABLE 1

MATERIAL FOR DYNASURGE WELDING DEMONSTRATION				
TUBE ALLOY	TUBE DIA	TUBE WALL THICKNESS	WELD JOINT CONFIGURATION	NUMBER OF WELDMENTS
ALUM 6061-T6	5-1/2"	0.258	STD "V" GROOVE MOD "V" GROOVE	4 5
ALUM 5086-H32	5-9/16"	0.250	STD "V" GROOVE MOD "V" GROOVE	2 3
INCO 718	6"	0.050	SQUARE BUTT	3
CRES 347	4-1/2"	0.125	STD "V" GROOVE	3

TYPICAL
TUBE
WELDMENT

SQUARE BUTT

STANDARD
"V" GROOVE

MODIFIED
"V" GROOVE

TABLE 2

MATERIAL FOR ASTRO-ARC WELDING DEMONSTRATION				
TUBE ALLOY	TUBE DIA	TUBE WALL THICKNESS	WELD JOINT CONFIGURATION	NUMBER OF WELDMENTS
ALUM 5086-H32	5-9/16"	0.250	SQUARE BUTT	6
INCO 718	6"	0.050	SQUARE BUTT	3

TYPICAL
WELDMENT

SQUARE BUTT

TABLE 3
EQUIPMENT FEATURES

FEATURES		WELD HEAD	
MANUFACTURER		ASTRO ARC	LIQUID CARBONICS
EQUIPMENT DESIGNATION		ASTRO ARC WELDING HEAD	DYNASURGE WELDING HEAD
DISPLACEMENT	RADIAL	1.75 + TUBE RADIUS	5.00 + TUBE RADIUS
	AXIAL	2.50	7.25
TACK WELD CAPABILITY		YES	YES
TUBE ASSEMBLY FIXTURING		YES	NO
AUTOMATIC ARC GAP CONTROL		NO	YES
FILLER WIRE FEEDER		NO	YES
PORTABLE		YES	YES
WATER COOLED CLAMPS		YES	NO
POWER SUPPLY			
MANUFACTURER		ASTRO ARC	LIQUID CARBONICS
EQUIPMENT DESIGNATION		MODEL V-300	MODEL CA-150-P
TYPE		SOLID STATE - 3 PHASE RECTIFIED D.C.	SOLID STATE - 3 PHASE RECTIFIED D.C.
VOLTAGE RANGE		240/480 VOLTS	240/480 VOLTS
CURRENT RANGE		0-300 AMPS	0-150 AMPS
AVAILABLE CURRENT FORMS		2	5
ADJUSTABLE FUNCTIONS			
1. PULSE CONTROL			
AMPLITUDE		5-300 AMPS	1-150 + 50 AMPS
FREQUENCY		1-100 Hz	1-25000 Hz
DURATION OF HIGH/LOW		0.1-1.1 SEC	0.00004-0.99 SEC
SLOPE		YES	YES
2. FILLER WIRE FEED RATE		N/A	N/A
3. TRAVEL DELAY		YES	YES
4. BACK-UP GAS		YES	YES
REMOTE CONTROL		YES (OPT)	YES (OPT)
PUNCH CARD READER		YES (OPT)	YES (OPT)
RECORDERS			
1. VOLTAGE		YES (OPT)	YES (STD)
2. CURRENT		YES (OPT)	YES (STD)
3. TRAVEL		YES (OPT)	YES (STD)
PANEL METERS			
1. VOLTAGE		YES	YES
2. CURRENT		YES	YES
3. TRAVEL		YES	YES

LIQUID CARBONIC DYNASURGE
WELD SEQUENCE DIAGRAM

CURRENT PULSATION WAVE SHAPE

FIGURE 1

WELD SEQUENCE DIAGRAM ASTRO-ARC WELD SYSTEM

FIGURE 2

D C CURRENT OUTPUT MODES FOR MODEL CA-150-P POWER SUPPLY

FIGURE 3

DYNA SURGE ORBITAL WELDING HEAD

FIGURE 4

FIGURE 5

ASTRO-ARC ORBITAL WELDING HEAD

FIGURE 6

ASTRO-ARC POWER SUPPLY MODEL CA-150-P

FIGURE 7

ASTRO-ARC POWER SUPPLY MODEL V-300-P

FIGURE 8

5086 ALUMINUM JOINT
WELDED AT 2 HZ PULSE -
SQUARE WAVE AS SHOWN
IN FIGURE 3, WAVE FORM 2

FIGURE 9

5086 ALUMINUM JOINT
WELDED AT 14 KHZ WAVE
FORM AS SHOWN IN FIGURE
3, FORM 3

FIGURE 10