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Technical Memorandum 33-544

Development of Automatic Through-Insulation Welding for Microelectronic Interconnections

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PREFACE

The work described in this report was performed by the Engineering Mechanics Division of the Jet Propulsion Laboratory.

ACKNOWLEDGEMENT

The author would like to thank Mr. Frank Lane for his valuable assistance and technical consultation during these developments, Mr. Leonard Katzin for helpful discussions relating to prior developments in through insulation welding, Mrs. Gloria Thompson for preparation of many of the test specimens, and Mr. James Lonborg for his review and suggestions for the preparation of this report.

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ABSTRACT

The capability to automatically route, remove insulation from, and weld small-diameter solid conductor (magnet) wire would facilitate the economical small-quantity production of complex miniature electronic assemblies. The Jet Propulsion Laboratory has developed and evaluated an engineering model of equipment having this capability. Whereas early work in the use of welded magnet wire interconnections was concentrated on opposed electrode systems and generally used heat to melt the wire insulation, the present method is based on a concentric electrode system (patented as "Through Insulation Welding System")[1] and a wire feed system (patent on "Wire Feed System" pending)[1] which splits the insulation by application of pressure prior to welding. The work described deals with the design, fabrication, and evaluation testing of an improved version of this concentric electrode system. Two different approaches to feeding the wire to the concentric electrodes were investigated. It was concluded that the process described is feasible for the interconnection of complex miniature electronic assemblies. Recommendations for further work are presented.

[1] The "Through Insulation Welding System" is the subject of U.S. Patent 3,596,044, and the "Wire Feed System" is the subject of a pending U.S. patent application. Both are licensed exclusively under terms which require that sublicenses be granted. Information regarding these inventions may be obtained from: Patent Officer, 1201 East California Blvd., Pasadena, Calif., 91109.

I. INTRODUCTION

The ability to automatically route and join discrete wire interconnections, with a minimum of operator intervention, has potential for reducing the costs of small-quantity production of electronic assemblies. This is evidenced by the increasing use of wire-wrapping and similar assembly techniques.

The Jet Propulsion Laboratory (JPL) and others have investigated the use of small-diameter, insulated, solid conductor (magnet) wires for interconnecting complex miniature assemblies, such as are employed on spacecraft. Designs envisioned by JPL employ edge-supported terminal boards having wiring and parts on opposite surfaces. To effectively automate the wiring of these designs, two things are necessary: (1) that joints between the wires and the terminals be such that they will not degrade during subsequent part attachment and (2) that the removal of wire insulation, in the area to be joined, be automated. The ability to weld through wire insulation would permit both of these requirements to be satisfied.

Early through-insulation welding development work involved the use of opposed electrodes and generally used heat to melt through the insulation prior to welding. Subsequent work at JPL resulted in the development of a concentric cold-electrode through-insulation welding system, which overcomes many of the disadvantages of the opposed heated-electrode systems. This has been patented (see Ref. 1 and disclosure in Appendix A) and is described in some detail in Ref. 2. The basic features of the concentric electrode concept are illustrated in Figs. 1 and 2, the key one being the splitting of the wire insulation by electrode pressure, prior to the actual welding operation.

The work described herein deals principally with the design, fabrication, and evaluation testing of an improved version of the concentric electrode welder (CEW), as shown in Fig. 3. Tests were conducted to establish range of force required for insulation break-through, suitable weld cycle parameters, and positioning requirements for electrodes with respect to terminals. Ultimately, the CEW was combined with a numerically controlled X-Y table, and the fully automatic routing and welding of insulated magnet wire interconnections was demonstrated on an integrated circuit module.

Operation of the system indicated that an alternative process for feeding the wire to the electrodes was needed. An approach using a simple, but unique, side-wire feed was conceived, which resulted in design, fabrication, and demonstration of an improved concentric electrode with a solid inner electrode. This configuration was also run in the fully automatic mode using other terminals on the same module. A patent application has been filed covering implementation of this side-wire feed. Finally, with the successful demonstrations complete, preliminary design was begun on an electrode system which could be applied to an interconnection with terminals located on 1.27-mm (50-mil) centers.

In this work, English Tehnical System units were used for primary measurements and calculations. Conversion to International System (SI) units was done for reporting purposes only.

II. OBJECTIVES

The objective of the work described herein was to design, fabricate, and demonstrate the feasibility of a new wiring machine capable of effecting cost and time savings in the fabrication of small numbers of complex, miniature spacecraft electronic assemblies. More specifically, it was desired to build up a system using the magnet wire welding techniques to which JPL had contributed significantly, but circumventing the problems associated with opposed electrode systems. Ultimately, the automatic wiring of a typical composite integrated circuit module was to be demonstrated, using the concentric electrode through-insulation welding system.

III. ACCOMPLISHMENTS

The following were accomplished:

(1) Design, fabrication, and assembly of a new through-insulation welding machine using a unique concentric electrode assembly.

(2) Development of required insulation breakthrough and welding process parameters.

(3) Combining of the welding machine with a numerically controlled X-Y table.

(4) Design and fabrication of a timing sequence and control unit for the insulation breakthrough and weld cycles, and the incorporation of this unit into the system.

(5) Generation of numerical control tape program software for a variety of module and terminal layouts.

(6) Automatic routing, insulation breakthrough, and welding of insulated nickel wire to specially designed terminals installed in a typical composite integrated circuit module.

(7) Design and development of an improved wire feed device.

(8) Study of the results of these tests in connection with the possible application of the technique to outer planet missions.

IV. EQUIPMENT AND PROCESS DEVELOPMENT

A. General

This development was accomplished in five phases, as described in the following paragraphs:

First, the design of the concentric electrode welder was carried to completion, using the ultimate goal of automatic wire routing and welding as the criterion for establishing geometrical and configuration constraints for mating the weld head to the X-Y table. Design requirements included: (1) independently adjustable breakthrough and welding forces, (2) X-Y table clearances, (3) electrical interfaces with the weld power supply, electrical control equipment, and numerical tape controller, and (4) configuration and alignment of the electrode system.

Second, the assembly was fabricated according to the drawings and assembled, prior to mating with the X-Y table. A number of dimensional tolerance and functional problems had to be solved before the weld head performed its mechanical operations properly.

Difficulty was experienced in obtaining satisfactory inner electrodes. A large number were fabricated and rejected before a redesign resulted in a configuration which could be produced and could withstand handling and operating forces during weld cycles.

A weld cycle and timing/sequence controller was designed and fabricated, to provide a capability for both manual checkout and automatic operation with the numerical control system.

The third step was the procurement of wire and determination of required breakthrough and weld pressures. This entailed extensive contact with manufacturers of magnet wire, in order to obtain a suitable insulation. While many vendors had Teflon[2]-insulated copper wire, no source for a nickel (weldable alloy) wire with soft insulation was available during the early development. The best wires that were ultimately procured were 32 and 34 AWG nickel with up to 0.08 mm (3 mil) of FEP Teflon. Several constructions combining FEP with a polyimide dispersion were also investigated, in spite of higher costs, in an attempt to improve abrasion and cold-flow resistance while still permitting intentional breakthrough. Unfortunately, these offered no improvement over straight FEP.

The breakthrough and weld parameters were studied in parallel with the fabrication of the CEW by using a modified Micropoint MP-1201 opposed cold-electrode through-insulation welder. Thus the required operating pressure range was established. An additional result of this part of the development was the establishment of visual inspection guidelines for adequate splitting of the insulation and set-down deformation area of the conductor to assure a proper joint resistance for welding.

[2]"Teflon" is the trademark of E.I. duPont de Nemours & Co., Inc., for tetrafluoroethylene.

The fourth step was to install the CEW on the X-Y table and verify the capability for accurately positioning the electrode assembly over successive terminals. The principal problem encountered here was that the terminal and insulator tolerances combine to yield position errors as great as 0.1 mm (0.03 in.). Thus, even though the X-Y controller can position the weld head accurately within ±0.01 mm (±3 mils), precise measured (rather than nominal) terminal location coordinates had to be put in the numerical control program for each development module.

A preliminary design was made for a work-piece holder (see Fig. 4) which would allow up to ±0.25 mm of compliance in each axis. This would allow the outer electrode to exert a centering action as it enveloped the terminal. With such an arrangement, the tape program could be prepared directly from the module interconnection design drawing. Ultimately, it should be possible to prepare the numerical control tapes directly from computerized wiring lists, thus providing a significant decrease in turn-around time from design to hardware.

The fifth step was to demonstrate the operation of the total system in a fully automatic mode. For this demonstration, a module configuration was chosen which was under development as part of the Thermoelectric Outer Planet Spacecraft (TOPS) project. The module circuit board was redrilled to accept the spherically shaped U-terminals designed for the CEW system (Ref. 2) and installed on the X-Y table. The wire feed system and the inner electrode were modified to assure alignment. The initial demonstration was then accomplished by making a series of welds automatically. A close-up view of the welds on two adjacent terminals of the demonstration module appears in Fig. 5.

An improvement in the operation of the system was obtained from the development of a side wire feed, which also resulted in redesign of the electrode. This was successfully demonstrated in a similar mode.

B. Design and Fabrication of Weld Head Assembly

Experience with the first model of the CEW (Ref. 2) showed that the assembly would have to be fairly rugged in order to assure positioning accuracy and that the design would have to be modified to meet the mounting and clearance requirements of the X-Y table. This dictated the overall height of the weld head and created some problems that were discovered after the assembly was complete.

It was found that the spring force adjustment thread was too coarse. A full turn of the nut changed the breakthrough force[3] approximately 8.8 N (2.0 lbf). To alleviate this, the nuts were indexed at 15 deg intervals, but the adjustment was still coarse in comparison with the ±0.14 N (±0.03 lbf) capability of a Unitek weld head.

The other problem was that accessibility for working on the springs, or for replacing or adjusting the electrode system, was very poor. This condition will require correction before any future production application. A list of the JPL drawings comprising the as-fabricated CEW is included with this report as Appendix B.

C. Weld Cycle Controller

The control of the CEW is based on sequencing a pair of solenoid-valve-operated air cylinders to first apply insulation breakthrough force, then apply weld force and trigger the weld pulse, and finally retract the weld head before allowing the X-Y control system to move the electrode to the next terminal. Motor-driven cams operate a set of switches to sequence and time the various functions. The motor initially selected provided one complete cycle per second. With an average routing travel of 5 cm and a table speed of 250 cm/min, as many as 1600 welds per hour could be made. However, it was found that 1 weld cycle per second was too fast to allow adequate set-down and insulation deformation. Timing was changed to 7 s/cycle and the equipment operated properly. The routing speeds were unchanged, thus producing about 450 welds per hour.

The electrical control equipment, which included the interface connectors to the tape controller, weld head, and power supply, was packaged in the chassis seen at the right in Fig. 3. A schematic of the control assembly appears as Appendix C.

[3] The term "breakthrough force" is preferable to the commonly used term "breakthrough pressure," since the event causing the breakthrough is expressed in units of force (pounds force or newtons) rather than units of pressure.

D. Insulation Breakthrough and Weld Forces

During the design and fabrication of the CEW, an investigation was performed to determine suitable process parameters for through-insulation welding. (Considerable through-insulation development work was done prior to the disclosure of the system by the inventor, but at that time the effort was limited by wire availability.) During the subsequent development and application of the cold electrode through-insulation technique to opposed electrode systems, by several companies, weldable nickel wire with suitable insulations became available.

In general, the opposed electrode machines are set up to provide a fixed relationship between breakthrough and weld forces for a given wire construction. Thus, variations in conductor hardness and in the thickness, concentricity, density, and material of the insulation can affect the parameters. In order to establish the best force settings for the CEW, a Micropoint MP-1201 welder was modified to permit independent adjustment of the breakthrough and weld forces.

The wire ultimately chosen for use in the development was 32 AWG nickel A with 0.02 mm (1 mil) of FEP Teflon insulation. On the basis of results of a number of tests with this wire on the modified MP-1201 welder, and using the same electrode diameters as in the CEW, it was determined that the weld force should be between 11 N (2.5 lbf) and 19.8 N (4.5 lbf) and that breakthrough force should be between 26.4 N (6 lbf) and 30.8 N (7 lbf). These forces, which produced a uniform configuration in the breakthrough and in the weld joint, were used in setting up the CEW when its assembly was complete. Photographs of the nominal breakthrough and welded interconnections, along with tables of the data obtained from the test samples, appear in Appendix D.

E. CEW Installation on X-Y Table

Installation of the weld head on the X-Y table was quite straightforward, although the automatic stops had to be relocated to limit the X-axis table travel to 33 cm to preclude hitting the CEW supports. However, since a typical module length is only 15 cm, this caused no problem.

A 1.3-cm-thick work-piece holder was installed on the table. The holder is provided with a universal array of 6-32 NC threaded holes for attachment of L-shaped clamps which fasten the module. The module is aligned by alternately moving the table, in the manual operation mode, from the first to the last terminals and applying small incremental corrections to the module position until the X-Y coordinates of the terminals agree with inspection measurements.

A test board having a small number of the special U-terminals located on a simple grid pattern was used for the initial experiments in programmed machine operation. A tape program, designed to interconnect these terminals in sequence, was written on the basis of nominal terminal locations (see Table 1). The first time the program was used with the test board, the electrode assembly jammed on top of the second terminal, because the terminal was too far from its nominal location. At this time, the programming approach was changed to incorporate measured, rather than nominal, terminal locations. This experience also prompted the design of the compliant work piece holder previously mentioned.

Several more programs were written simply to gain experience. Input data for these were measured terminal locations and the wiring list for a Mariner 1969 "green stick" integrated circuit module. The program tapes were prepared and run on the assembled CEW/X-Y table, with the weld cycle bypassed, to check sequencing operation and positioning accuracy.

The fabrication of the composite integrated circuit module with the special gold-plated 302 stainless steel U-terminals was completed, terminal locations were measured, and the program to be used in the feasibility demonstration was prepared. This program is given in Table 2. Running this program, after accurately installing the module on the holder, demonstrated the capability for accurate weld head positioning by the X-Y table. The principal problems encountered were that the initial module positioning was time-consuming (which could be solved in several ways) and that access to the weld head (for adjustment of pressure, spacing, and electrode height and for connection of power supply leads) was poor.

F. Demonstration of Automatic Wiring

With the assembled CEW mated to the X-Y table, the sample module positioned, and the tape program positioning accuracy verified, the final step was to proceed to the feasibility demonstration. This was done in an exploratory manner, beginning with moving to each terminal on the first row, in sequence, and then manually actuating (1) breakthrough, (2) force release, (3) weld force, (4) weld power pulse, and (5) force release and then proceeding to the next instruction. Prior to beginning the demonstration, the force levels and weld energies had been selected on the basis of preliminary work done with the MP-1201 welder. The additional lead length and slightly higher resistance of the longer tungsten electrode used with the CEW required an increase in energy from 3.0 to 4.0 W-s.

The force adjustment was found to be very critical with respect to the height of the terminal above the board. After several poor welding experiences, including one instance in which the terminal was too low even to obtain complete insulation breakthrough, the module was removed and the terminals inserted to a uniform depth, by means of a gage block, and adhesively bonded in place. Minor adjustments were then made to the tape program to compensate for terminal re-alignment during the height adjustment and bonding.

With the terminals fixed at a uniform height, the first row was successfully rerun in the manual mode. On the second row, the program was initiated with an M-function interrupt to permit verification that the electrode system would seat properly on the terminal, by gently lowering the weld head by hand until the outer electrode just started to slide over the terminal. Then an automatic cycle of forces and weld current was initiated, but the signal to route to the next terminal was inhibited, thus giving an opportunity to verify weld formation before proceeding.

At this point, the sensitivity of the breakthrough process to the duration of applied force became evident. On the first three tries in this mode, neither breakthrough nor welding was accomplished. Investigation indicated that when the breakthrough force application was followed too quickly by release and weld pressure application, there was not enough time for the FEP insulation to flow aside, exposing the conductor. The operating cycle was lengthened from 1 to 7 s, thus increasing each portion accordingly and, incidentally, assuring that the weld force would be maintained throughout the weld energy pulse. After this modification, weld head positioning and proper welding were verified on three terminals in the semiautomatic mode. The remaining terminals in this row were then welded in the fully automatic mode to demonstrate feasibility.

During the welding of the second row, it was also noted that the wire insulation was occasionally being scraped by the inner electrode. To correct this, the electrode system was redesigned. A new side feed was developed to feed the wire through the opposite sides of the outer electrode and across the face of the inner electrode, rather than through a hole in the center. The combination of an entrance feed hole and an exit slot controls the location of the wire during routing and welding. A patent application dealing with this side feed has been filed and is described in Appendix F. This redesign also permitted needed strengthening of the brittle, 1.3-cm-long inner electrode, several of which had broken during preliminary tests. With the modified electrode and wire feed installed, several checks were made to be sure that the weld cycle parameters had not been altered.

The remaining two terminal rows were then interconnected in the fully automatic routing and through-insulation welding mode, as a further demonstration of the system feasibility. Two terminals did not weld properly and were found to be displaced or bent from their programmed locations. The weld head was manually relocated over these terminals and the cycle restarted, resulting in weld formation. Representative samples of the welds made for the demonstration were subsequently tensile-tested in a 90-deg peel test, and all values were greater than 65% of the strength of the wire.

V. CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations are as follows:

(1) It is feasible to apply the automatically controlled, concentric electrode, through-insulation welding concept to the interconnection of complex miniature electronic assemblies. Development of this technique for future electronic packaging design should be pursued.

(2) Further refinement of electrode and terminal geometry is needed in order to optimize this technique, particularly if it is desired to use 1.27-mm (50-mil) spaced interconnection nodes to increase packaging density.

(3) Adjustment of insulation breakthrough and weld force variables should be finer than on the development model.

(4) A provision for automatic wire cut-off at the end of a run is needed in order to permit rapid change-over to the next sequence of interconnected terminals. An automatic wire cutoff device, compatible with the electrode and terminal configuration, should be designed and tested.

(5) The present tape control programs have only point-to-point routing capability. A subprogram should be developed to provide routing around buttons or guide posts, thus reducing the probability of a wire passing directly over a terminal yet to be welded.

(6) An evaluation of the cost effectiveness and reliability of this system, in comparison with "wire-wrap," "green stick," and similar magnet wire techniques should be made.

(7) Additional future applications that may be envisioned are discussed below in Section VI. It would appear advantageous to pursue these applications, which could lead to new capability in interconnecting miniaturized electronic assemblies.

VI. FUTURE APPLICATIONS

The basic terminal location grid used in this development, 1.27 × 3.8 mm, was dictated by the 0.95-mm-diameter cross section and the U shape of the terminals. The terminal design, in turn, was based on the availability at that time of 0.95-mm-diameter 302 stainless steel wire and by the desire to duplicate certain dimensions of the "green stick" integrated circuit module. This terminal and associated weld electrode design are not compatible with the 1.27 × 1.27-mm high-density interconnection grid proposed for advanced projects such as an outer planet mission.

Preliminary sketches of a new terminal and a scaled-down electrode system designed to be compatible with 1.27 × 1.27-mm spacing are included as Appendix E. The proposed wire for this application is 34 AWG nickel with 0.02 mm of FEP Teflon insulation.

While a number of problems were encountered during this development, a large amount of valuable information potentially useful for future applications was obtained relative to (1) the design and operation of the welder, (2) the requirements for preparation of numerically controlled tape programs, and (3) the criticality of breakthrough and weld parameters, as derived from mechanical tests, visual inspection, and metallurgical sections of representative welds. The total data has been recorded and preserved by the author.

REFERENCES

1. Katzin, L., Through Insulation Welding System, U.S. Patent 3,596,044 (assigned to the California Institute of Technology). U.S. Department of Commerce, July 27, 1971.

2. Katzin, L., "Simplifying Complex Miniature Interconnections", Supporting Research and Advanced Development, Space Programs Summary 37-52, Vol. III, pp. 80-84. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 31, 1968.

Table 1. Control program for test board

Block	Rate[a]	Command[b]	Function[c]
1		EOR	
2	f4	x1.750y.750	ml
3	f1	x.150	ml
4		x.150	ml
5		x-.075y.050	ml
6		x-.150	ml
7		x-.075y.050	ml
8		x.150	ml
9		x.150	ml
10		x-.075y.050	ml
11		x-.150	m2
12	f4	x-1.77y-.950	
13		EOR	

[a]f1, f4 define table rates which are held until changed.

[b]Command is expressed in incremental steps; each step is equivalent to 0.001 in. EOR signals start or end of program.

[c]Function ml signals start of weld cycle; next line will not be read until cycle is complete. Function m2 signals wire cut-off; same function interrupt as ml.

Table 2. Composite concentric electrode welding program, module sample by rows

Row A, Terminals 1 through 12		Row C, Terminals 25 through 36	
1 fl	x89y650 ml	25 fl	x747y271 ml
2	x-2y154 ml	26	x-1y157 ml
3	x2y591 ml	27	x3y595 ml
4	y156 ml	28	x1y154 ml
5	x1y605 ml	29	x-1y601 ml
6	y149 ml	30	x1y150 ml
7	y596 ml	31	x1y597 ml
8	x2y150 ml	32	x3y148 ml
9	x-3y596 ml	33	x1y601 ml
10	y154 ml	34	x-2y150 ml
11	x2y600 ml	35	x-4y602 ml
12	y154 ml	36	x2y153 ml
	y500 m2		y500 m2
fl	x-91y-5055	fl	x-751y-4679

Row B, Terminals 13 through 24		Row D, Terminals 37 through 48	
13 fl	x166y274 ml	37 fl	x823y654 ml
14	x-2y151 ml	38	x2y150 ml
15	x2y604 ml	39	x2y592 ml
16	x4y147 ml	40	x-4y154 ml
17	x-6y596 ml	41	y604 ml
18	x-3y155 ml	42	x3y149 ml
19	y596 ml	43	x1y595 ml
20	x2y153 ml	44	x2y153 ml
21	x-1y594 ml	45	x-2y599 ml
22	y155 ml	46	y152 ml
23	y599 ml	47	x-2y601 ml
24	y152 ml	48	x2y153 ml
	y500 m2		y500 m2
fl	x-162y-4676	fl	x-827y-5056

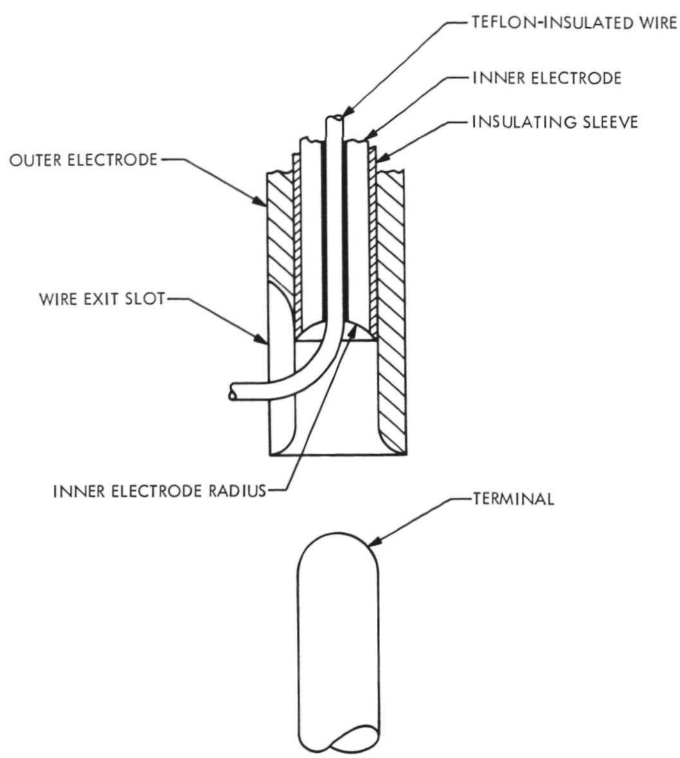

Fig. 1. Cross section view of concentric electrode configuration

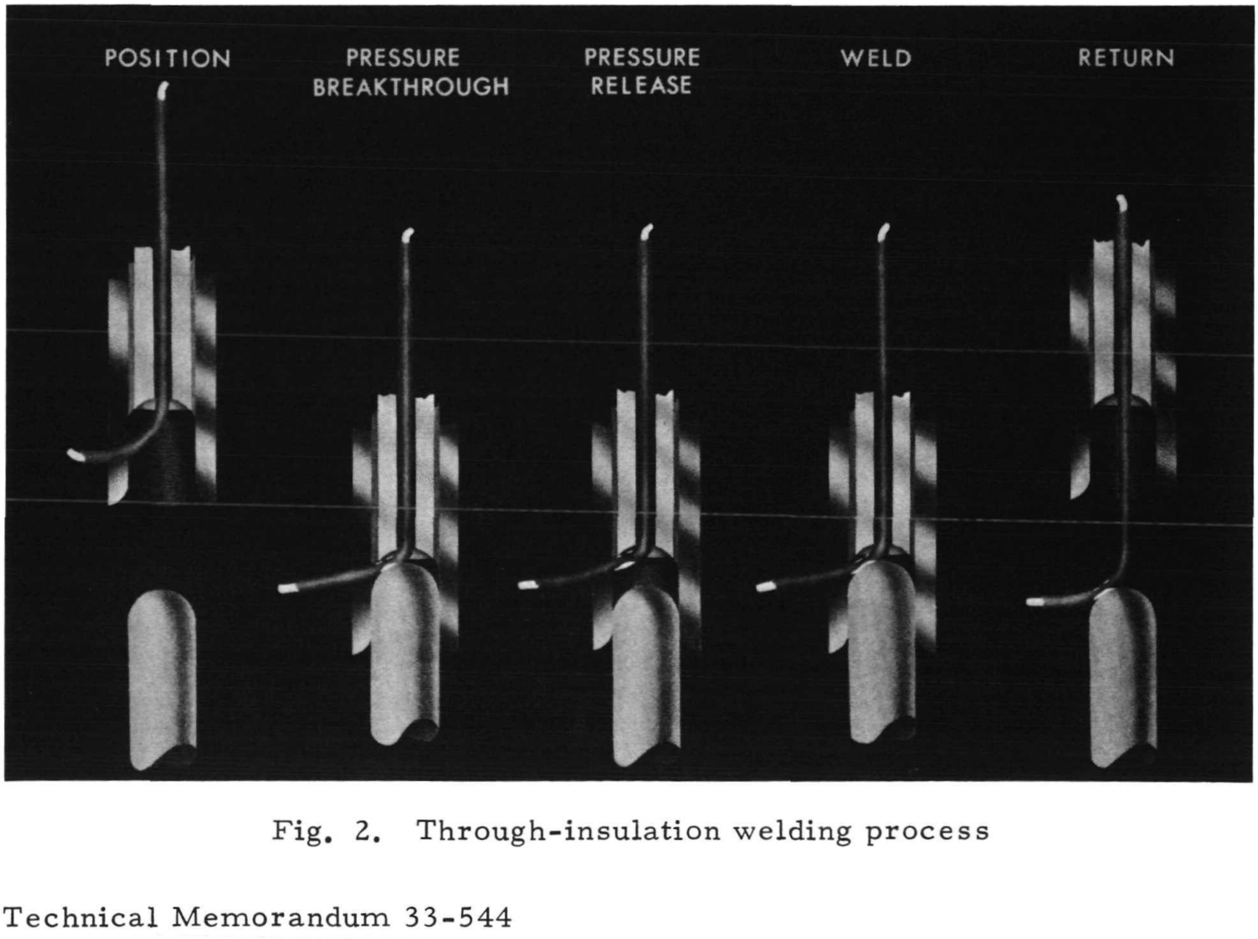

Fig. 2. Through-insulation welding process

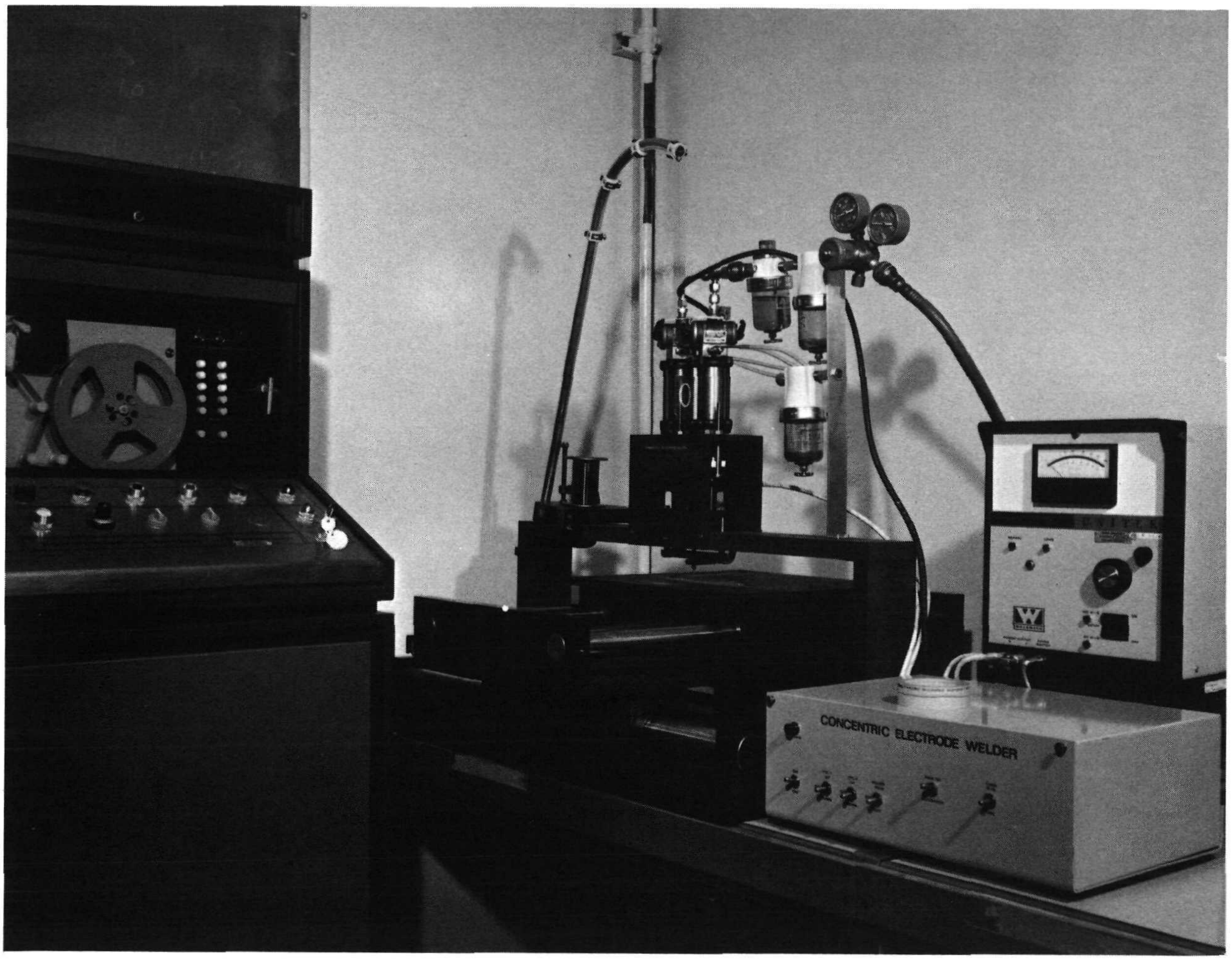

Fig. 3. CEW machine

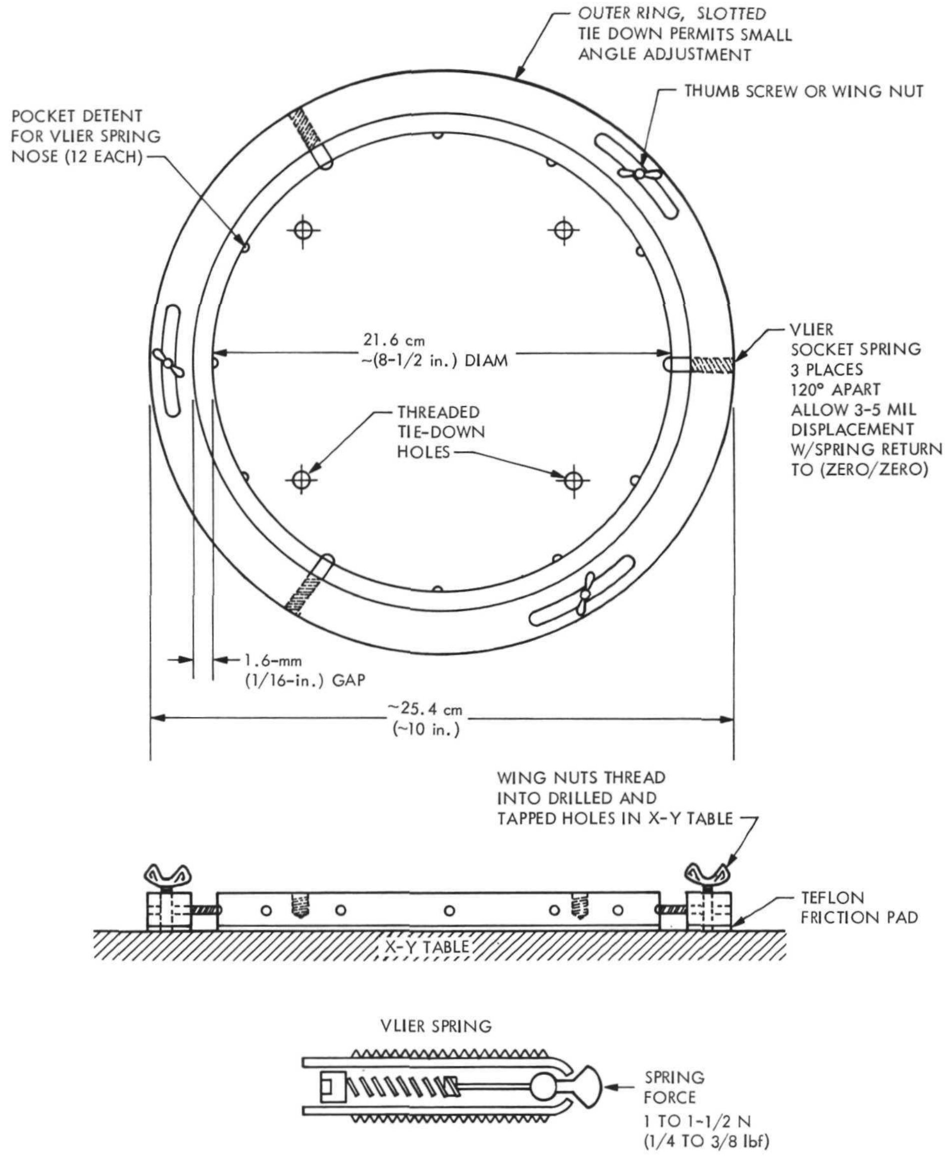

Fig. 4. Compliant work piece holder concept

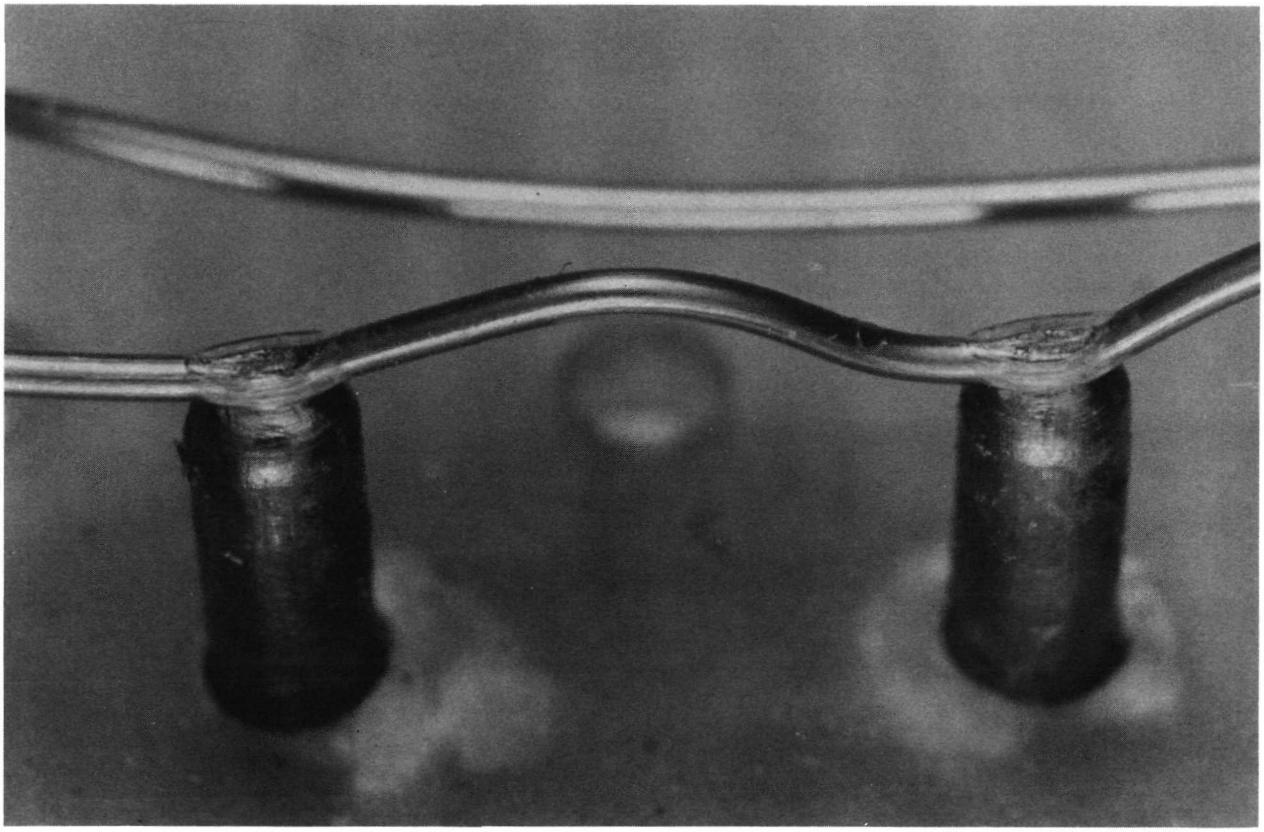

Fig. 5. Automatically connected terminals (magnification 40×)

APPENDIX A

THROUGH INSULATION WELDING SYSTEM
DISCLOSURE NO. 30-1487, DATED SEPTEMBER 30, 1968

NEW TECHNOLOGY REPORT
DISCLOSURE SHEET

1487
CASE NO.

TITLE: THROUGH INSULATION WELDING SYSTEM

DESCRIPTION AND EXPLANATION (REFER TO SKETCH)

Summary of the Innovation:

Complex electronic assemblies using integrated circuit modules as components have large numbers of closely spaced, miniature terminals which must be interconnected to function. Such interconnections are made using continuous, insulated magnet wire. Because of spatial limitations, wire wrap techniques cannot be utilized. Sequential welding of interconnecting insulated wire to terminals is accepted industry practice but requires removal of selected portions of insulation prior to welding wire to terminal. The previously utilized technique employed in-line, top and bottom welding electrodes, with either the top or both electrodes heated. Heat softens the wire insulation so that it can be displaced to expose bare wire for making suitable physical contact with terminal and top electrode during welding. In the extremely crowded confines of complex assemblies, this hot electrode technique involves hazard of heat damage to insulation of adjacent wire interconnections.

The novel technique disclosed herein employs cold welding electrodes and utilizes pressure to displace wire insulation immediately prior to welding. Insulated wire is fed through a hollow inner electrode and a concentric outer electrode fits around the terminal and fixes both wire and inner electrode over the terminal in position for insulation displacement and subsequent welding of exposed wire to the terminal.

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JPL 2688-3 (7-68)

NEW TECHNOLOGY REPORT
SUPPLEMENTARY DISCLOSURE SHEET

1487
CASE NO.

TITLE:
THROUGH INSULATION WELDING SYSTEM

A machine has been designed and built at JPL to facilitate making interconnections by this technique. Greater pressure is required to break through the insulation than for welding. The machine accordingly is provided with two independently applicable pressure cycles to accommodate the different requirements.

Description and Explanation:

Complex electronic assemblies such as that typically shown in Figure 1 and which are often fabricated on a short run basis for spacecraft use, frequently utilize interconnections made by an earlier insulated magnet wire welding technique which involves use of a conventional, opposed electrode welder in which the upper or both electrodes are heated to a temperature which plasticizes the insulation and allows it to flow until physical contact is established between upper electrode, exposed wire and terminal for welding. The main shortcomings of this approach are that it requires that both electrodes, the terminal and the wire be aligned on a single axis, and that the heated electrode is capable of burning insulation from adjacent wires in confined areas such as that shown in Figure 1. Another disadvantage is that because insulation thickness on wire often varies, the amount of heat needed to melt the insulation also varies, and this affects wire temperature and accordingly, its electrical conductivity. This requires adjustment of the weld schedule to accommodate different insulation thicknesses.

The new machine shown in Figure 2 overcomes these disadvantages and also makes it possible to utilize the new technique in a fully automated short run production system. A study has shown that "TEFLON" insulation on a hard wire can be neatly split to each side of the conductor when compressed between two properly designed opposed members. Hence, it is possible to use pressure rather than heat for local displacement of insulation.

Figure 3 shows a series of views which illustrate the insulation displacement and weld sequence utilized in the new machine. A length of insulated wire 10 coming from a supply spool threads through hollow inner electrode 11 and passes out of concentric outer electrode 12 through slit 12a to the previously made connection. When the concentric electrode assembly carrying wire 10 is lowered toward terminal 15, outer electrode encircles the shank of the terminal and positions wire 10 over the top of the terminal which is rounded as shown. The lower end of electrode 11 has a matching concave geometry.

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JPL 2688-4 (7-68)

NEW TECHNOLOGY REPORT
SUPPLEMENTARY DISCLOSURE SHEET

1487
CASE NO.

TITLE:
THROUGH INSULATION WELDING SYSTEM

The photographs designated Figures 4 and 5 respectively, show the concentric electrodes disassembled, and assembled but removed from the machine shown in Figure 2.

Since the amount of pressure required to rupture the insulation is considerably greater than the welding pressure, the machine has mechanisms which apply two different pressure cycles, in sequence. The mechanisms are independent, both in operation and in adjustment.

When the machine is operated, electrode 11 is first forced downwardly with sufficient pressure and at a suitable rate so that the "TEFLON" insulation on wire 10 is initially ruptured and subsequently displaced as the bare wire is forced into contact with the top of the terminal by the concave surface 11a of electrode 11. Pressure is then reduced to that required to hold the bared wire in place on terminal 15 while the welding pulse is applied between electrodes 11 and 12.

Sleeve 16 is utilized to insulate the electrodes from each other during application of the welding pulse. A typical weld to a terminal is shown in the photograph designated Figure 6, in which a #34 AWG nickel wire (.0063" diameter) with "TEFLON" insulation has been welded to a gold plated, type 302 stainless steel terminal having a .036" diameter.

Electrode 12 serves a triple function; it makes good electrical contact with the terminal shank for application of the welding pulse; it pilots the electrode assembly onto the terminal which lessens the alignment problem and also prevents deflection of the inner electrode 11 during pressure cycles; and it clears the top of the terminal of all previously routed wires. As electrode 12 descends it pushes all adjacent wires out of the way prior to enveloping the terminal shank. This eliminates the possibility of a previously routed wire interfering with the current weld. Figure 1 gives an indication of the environment in which such welds are made.

Since wire 10 feeds through hollow inner electrode 11, the arrangement can be used to rout the wire from terminal to terminal between welding operations. A series of

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1487
CASE NO.

TITLE:
THROUGH INSULATION WELDING SYSTEM

connections can therefore be produced using a single length of wire. The insulated wire emerges from the center of the inner electrode and trails in the direction of the previous weld. Before the electrode assembly descends to make a weld, the wire is moved by a mechanical finger (not shown) into slit 12a of the outer electrode to eliminate the possibility of wire pinching between electrode 12 and the terminal shank. By moving the wire into the slit, all welds would be made with wire 10 approaching the terminals from the same direction. This has the advantage that an extra service loop can be provided in most point-to-point connections which will make automatic wire cutoff (still to be added to the machine shown) much easier. Wire cutoff is mandatory if production of interconnections is to be further automated.

Further automation will be accomplished by addition of a numerically controlled X-Y table for transporting the circuit component being fabricated from position to position between successive welding operations. While such automation would clearly be of advantage for large scale production, it would also be desirable for interconnection of spacecraft components on a small scale basis because of elimination of positioning errors in welding interconnect wires.

Since interconnections are point-to-point, programming time would be very low. There would be no art work, no laminating, and no alignment problem. Successive units being made from the same tape or cards would be identical. Repairs or modifications could be quickly, simply and reliably effected because changes can easily be programmed into punched tape or stacks of cards. Short run automation of this character is therefore within reach.

It is believed that the technique could also be applied to interconnections between blind terminals by suitably modifying a parallel gap concentric welder.

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1487
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TITLE: THROUGH INSULATION WELDING SYSTEM

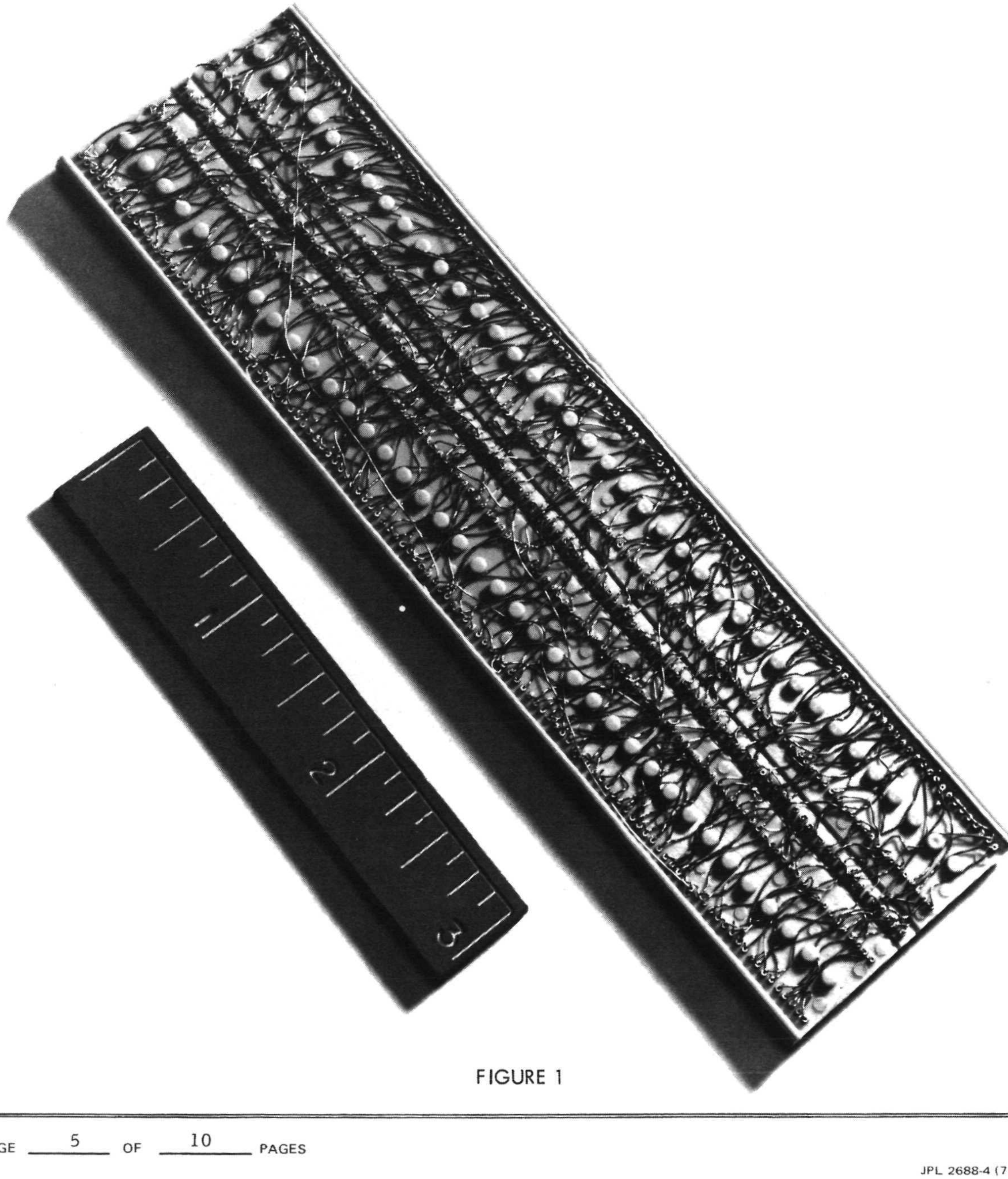

FIGURE 1

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1487
CASE NO.

TITLE:
THROUGH INSULATION WELDING SYSTEM

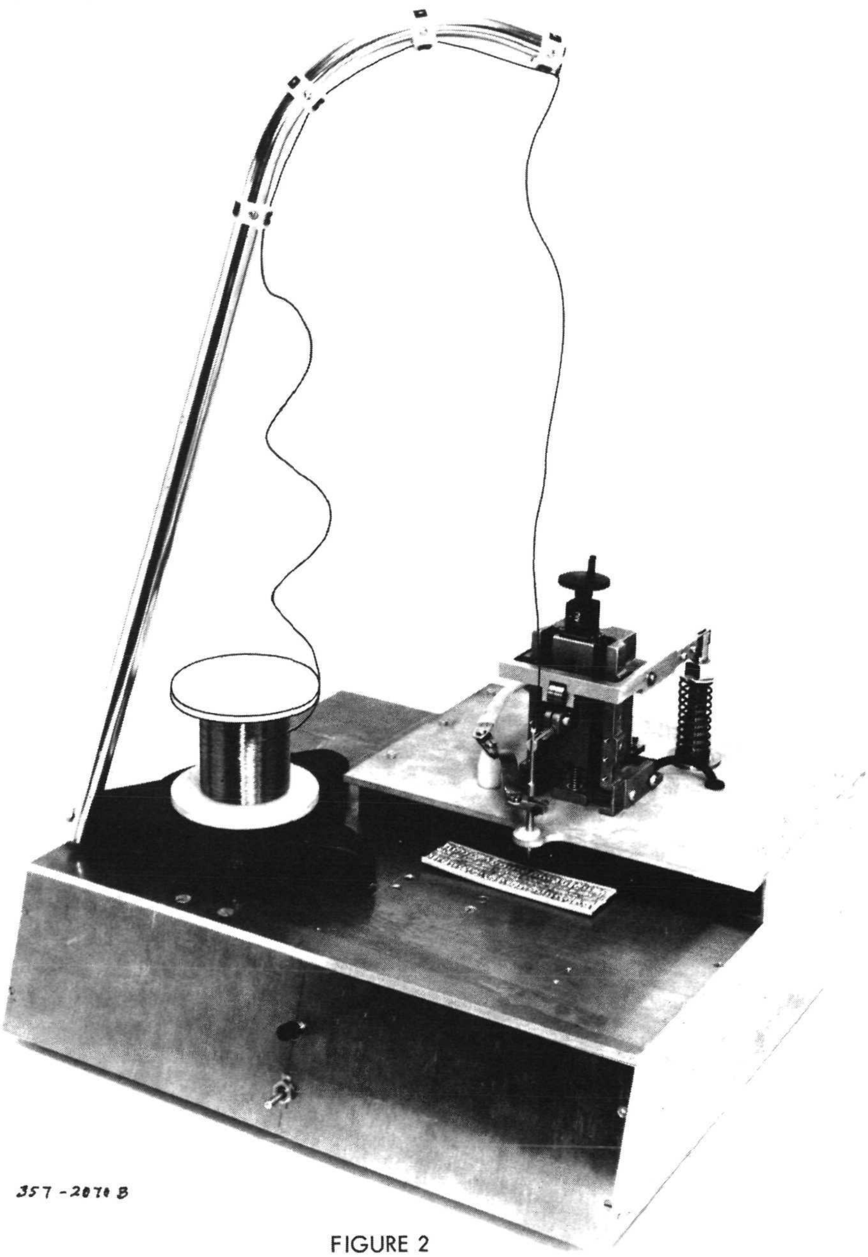

FIGURE 2

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TITLE: THROUGH INSULATION WELDING SYSTEM

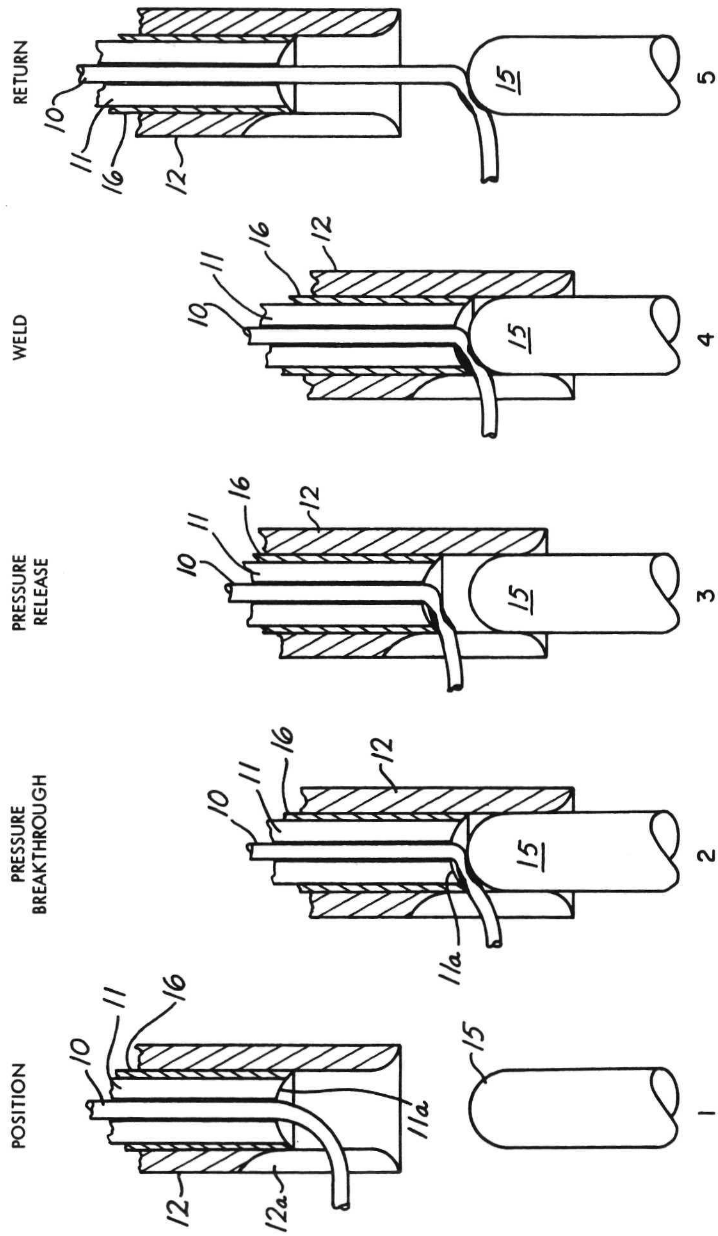

FIGURE 3

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CASE NO.

TITLE: THROUGH INSULATION WELDING SYSTEM

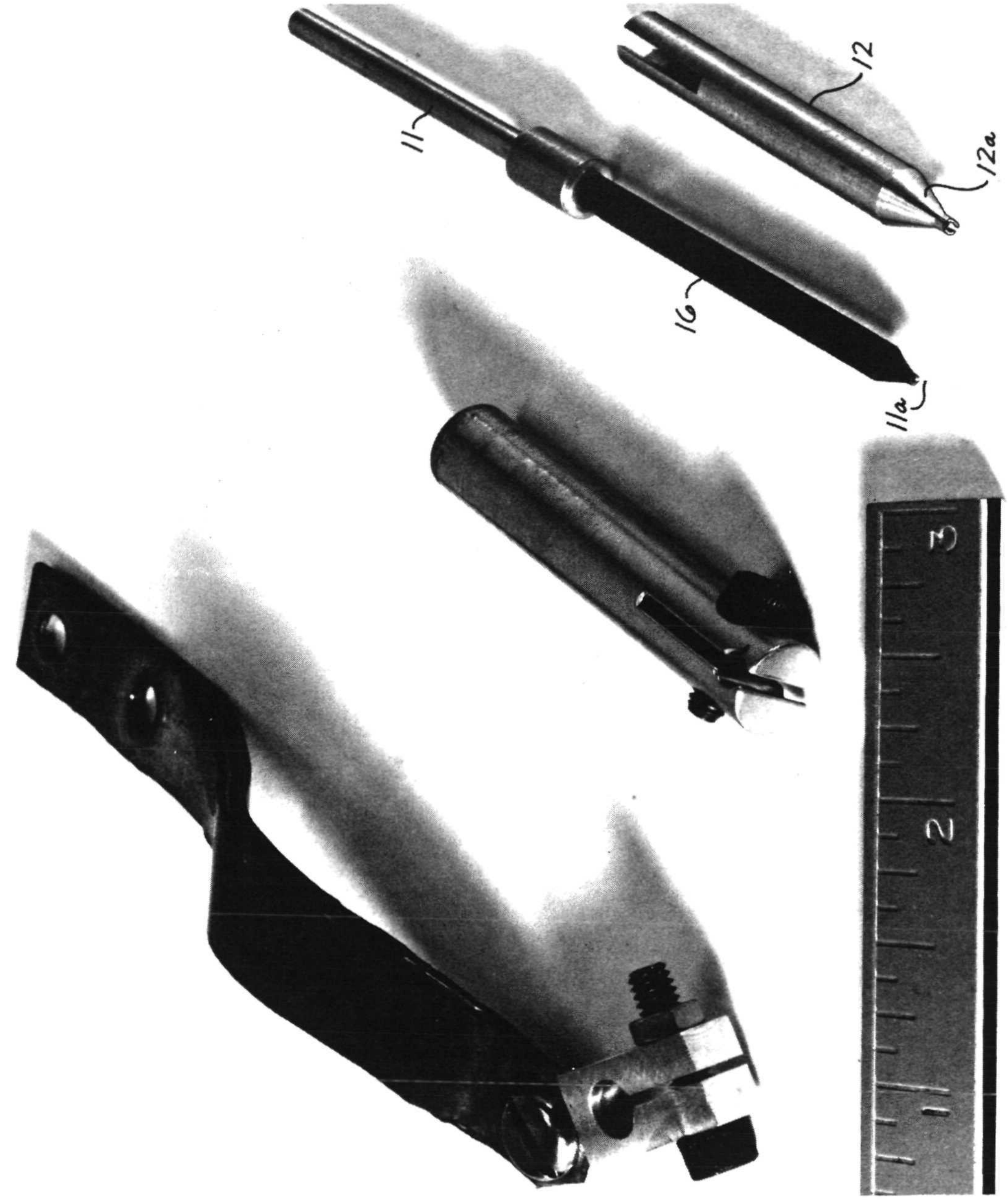

FIGURE 4

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1487
CASE NO.

TITLE:
THROUGH INSULATION WELDING SYSTEM

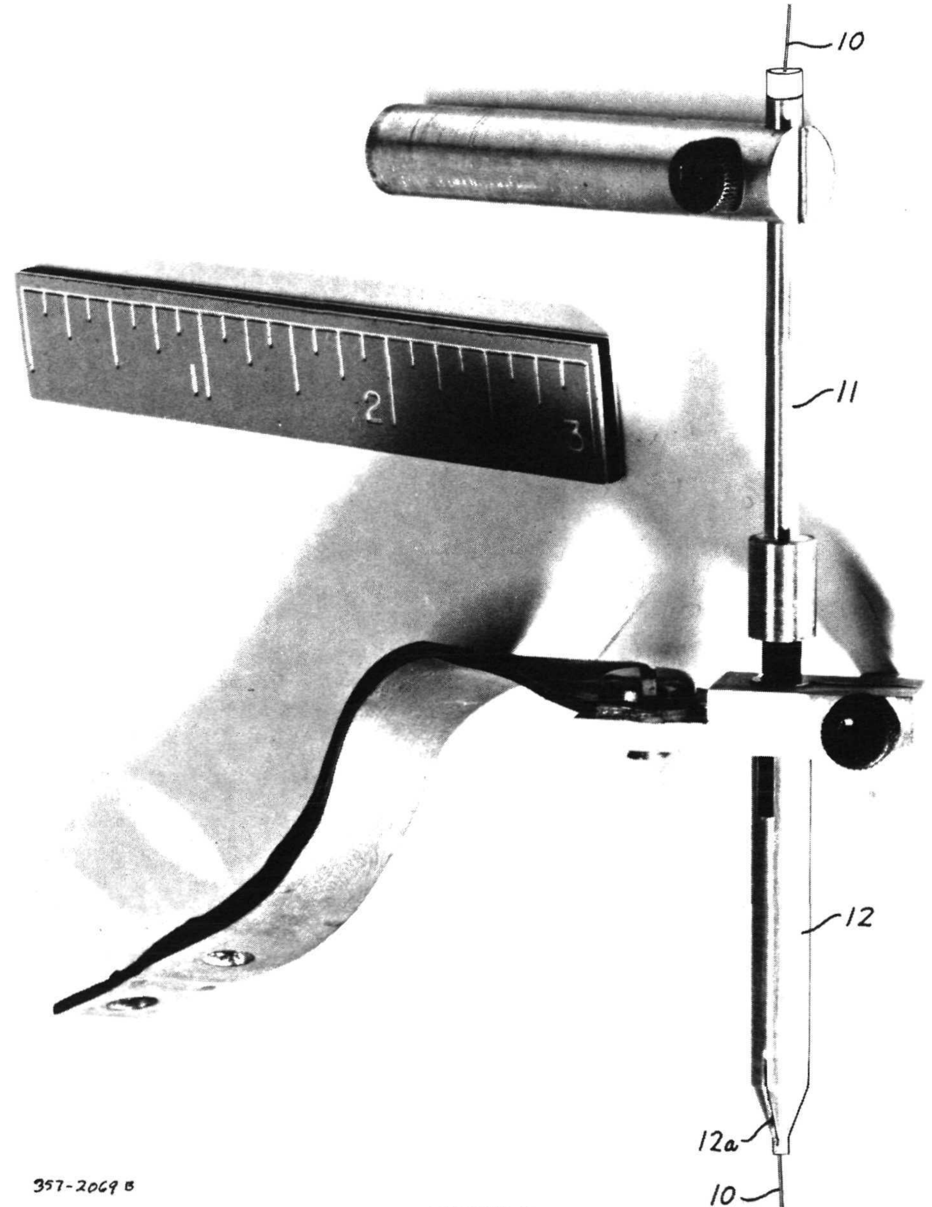

FIGURE 5

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NEW TECHNOLOGY REPORT
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1487
CASE NO.

TITLE: THROUGH INSULATION WELDING SYSTEM

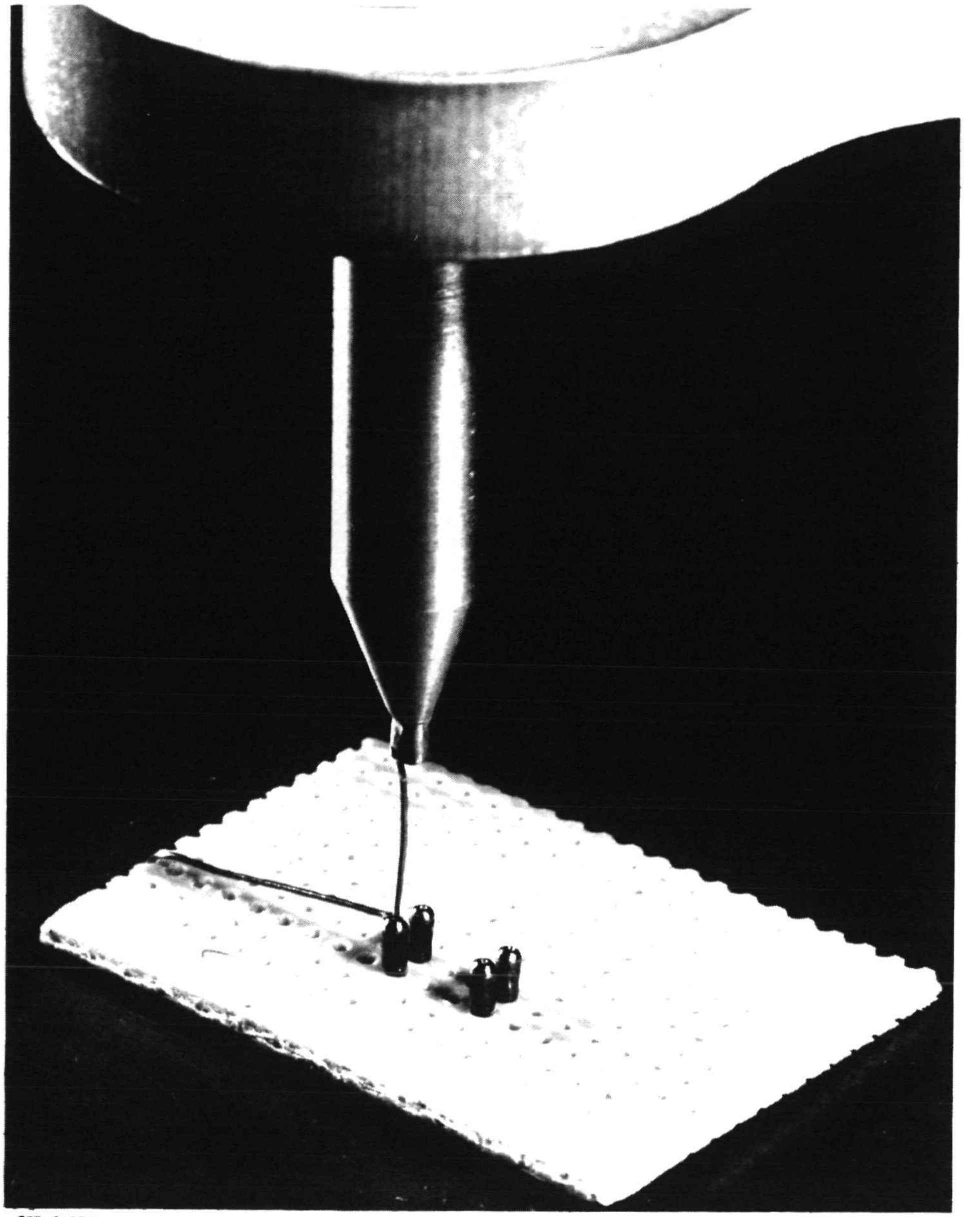

FIGURE 6

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APPENDIX B

CONCENTRIC ELECTRODE WELDER DRAWING LIST

Table B-1. Drawing list, concentric electrode welder, JPL drawing No. 10036552

Drawing dash number	Title[a]
101	Supporting cross bar
102	Extended support for X-Y table
103	Air cylinder retaining plate
104	Lower guide plate
105	Upper guide plate
106	Guide post
107	Plunger
108	Side plate
109	Adjustable plunger retainer
110	Stop plate
111	Coil spring, weld pressure
112	Return spring
113	Adjustment screw
114	Knurl nut
115	Coil spring, breakthrough
116	Lower electrode holder
117	Upper electrode holder
118	Extender tube
119	Inner electrode
120	Inner electrode holder
121	Inner electrode guide
122	Outer electrode
123	Shoulder bushing
124	Shoulder bushing
125	Washer
126	Washer

[a] In addition to the above-listed dash-numbered parts, the top assembly drawing, No. 10036552-100, also specifies appropriate quantities of miscellaneous nuts, screws, washers, pins, and commercially procured bronze bearings.

Table B-1 (contd)

Drawing dash number	Title[a]
127	Shoulder bushing
128	Shoulder bushing
129	Washer, flat
130	Shoulder bushing

APPENDIX C

CONCENTRIC ELECTRODE WELDER TIMING/SEQUENCE CONTROLLER

The electrical schematic of the controller appears in Fig. C-1. This unit (1) controls the sequence and duration of the breakthrough and weld force application and the weld pulse initiation, (2) prevents motion of the X-Y table until the weld head has retracted, and (3) provides both manual and automatic control of all functions. Provision for incorporation of a wire cutoff function was also made in the design.

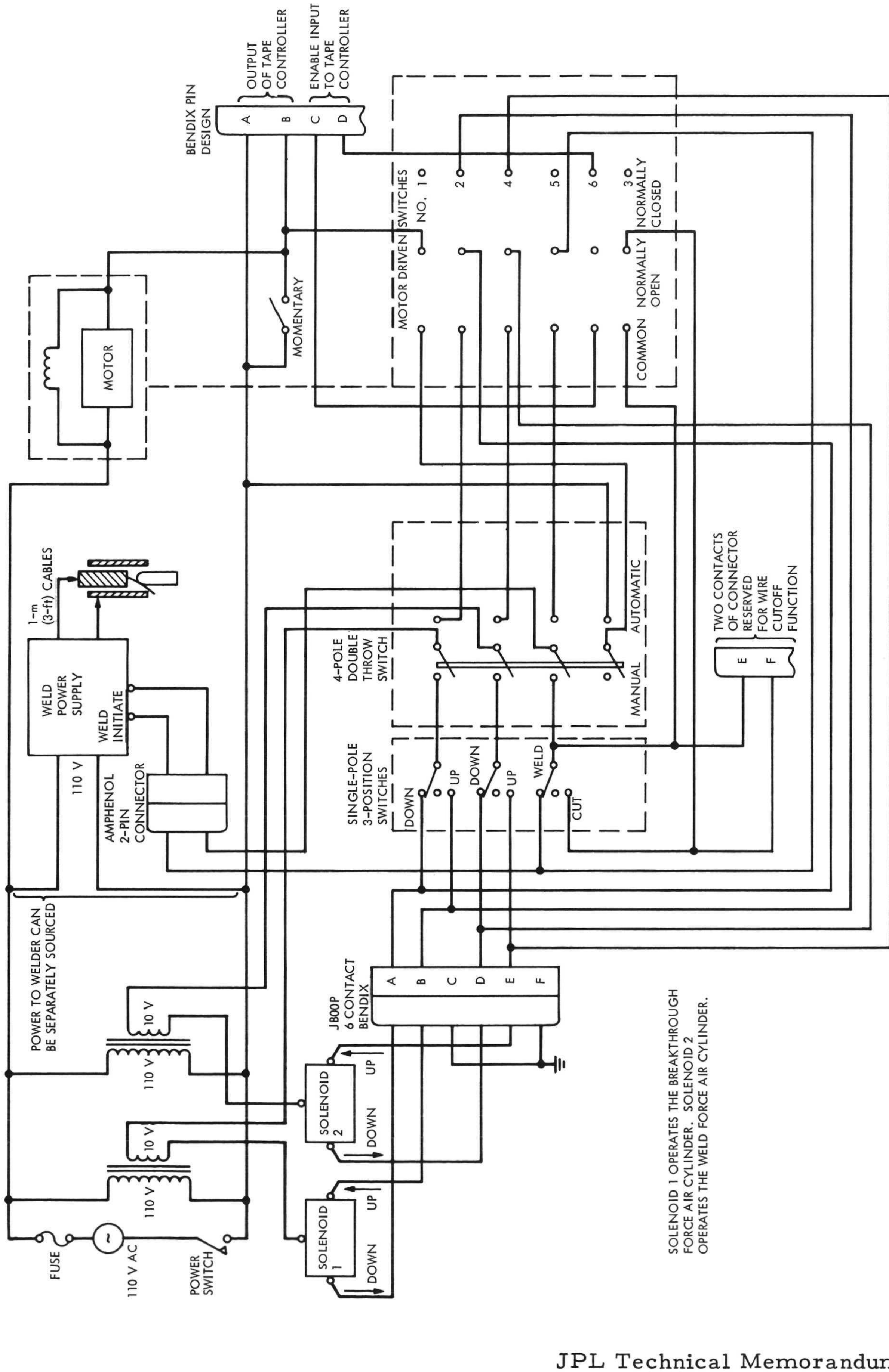


Fig. C-1. CEW electronic controller schematic

APPENDIX D

TEST DATA, DEVELOPMENT OF BREAKTHROUGH AND WELD FORCE PARAMETERS

Tables D-1 and D-2, along with Figs. D-1 through D-19, present data on breakthrough and weld force parameters. Column headings in Table D-1 represent machine operational settings for the Micropoint MP-1201 machine used for the breakthrough tests. Figures D-1 through D-9 are typical of the breakthrough tests, and Figs. D-10 through D-19 represent weld force parameter development tests. Magnification in the figures of this Appendix is 50X.

Table D-1. Results of breakthrough force tests

Sample number	Gap		Dial setting	Number of counter-clockwise turns	Applied force		Remarks
	cm	in.			N	lbf	
10-1	0.9	0.4	008	0	26.7	6	Some small distortion of wire.
10-2	0.9	0.4	016	0	28.9	6.5	Similar to sample 10-1.
10-3	0.9	0.4	024	0	31.1	7	Slightly larger electrode print; well broken.
10-4	0.9	0.4	032	0	33.4	7.5	Similar to sample 10-3.
10-5	0.9	0.4	008	1	26.7	6	Similar to sample 10-1. Teflon was pushed aside.
10-6	1.2	0.5	008	9	20.9	4.7	Width of set-down print was ~ 20% of diameter.
10-7	1.2	0.5	016	9	24.0	5.4	Difficult to tell whether Teflon was being affected. Similar to sample 10-1.
10-8	1.2	0.5	024	9	25.4	5.7	Very similar to samples 10-1 and 10-5.
10-9	1.2	0.5	032	9	28.5	6.4	Similar to sample 10-2.
10-10	1.5	0.6	008	9	8.9	2.0	This is the maximum machine travel at this gap setting, so load was not increased. No apparent breakthrough
10-11	1.5	0.6	016	9	8.9	2.0	Same results as sample 10-10.

Table D-1 (contd)

Sample number	Gap cm	Gap in.	Dial setting	Number of counter-clockwise turns	Applied force N	Applied force lbf	Remarks
10-12	1.5	0.6	024	9	8.9	2	Same results as sample 10-10.
10-13	1.5	0.6	032	9	8.9	2	No apparent breakthrough or wire distortion.[a]
10-14	1.4	0.55	008	9	17.8	4	Teflon appeared split, no apparent wire flattening.
10-15	1.4	0.55	016	9	17.8	4	Teflon appeared split, but there was no obvious wire flattening.
10-16	1.1	0.45	008	0	24.9	5.6	Small airfoil-shaped breakthrough. the lowest at this spacing.
10-17	1.1	0.45	016	0	27.1	6.1	Similar to others in this breakthrough range.
10-18	1.1	0.45	024	0	29.4	6.6	Similar to samples 10-2 and 10-9.
10-19	1.1	0.45	032	0	31	~7	Similar to sample 10-3. An appreciable dent in wire was beginning to show.
10-20	1.1	0.45	032	9	31	~7	Same results as sample 10-19. It was apparent that the number of turns did not affect the maximum force.

[a] Because of the machine travel limit, it was decided to try a gap that would provide some lower force data between 8.9 and 22.2 N (2 and 5 lbf) loads.

Table D-2. Typical weld parameter tests

Sample[a]	Figure number	Breakthrough force		Weld force		Weld energy, W-s	Load at failure, 90-deg peel	
		N	Lbf	N	Lbf		N	Lbf
1	D-10	35.2	8	17.6	4	3	8.8	2.0
2	D-11	35.2	8	17.6	4	2	7.5	1.7
3	D-12	35.2	8	17.6	4	2	7.0	1.6
4	D-13	26.4	6	13.2	3	1.5	8.4	1.9
5	D-14	26.4	6	13.2	3	1.5	8.8	2.0
6	D-15	26.4	6	13.2	3	2	9.7	2.2
7	D-16	26.4	6	13.2	3	2	9.7	2.2
8	D-17	26.4	6	13.2	3	2.5	11.9	2.7
9	D-18	26.4	6	13.2	3	3	14.1	3.2
10	D-19	26.4	6	13.2	3	3	14.1	3.2

[a]These tests are keyed to Figs. D-10 through D-19 in this Appendix.

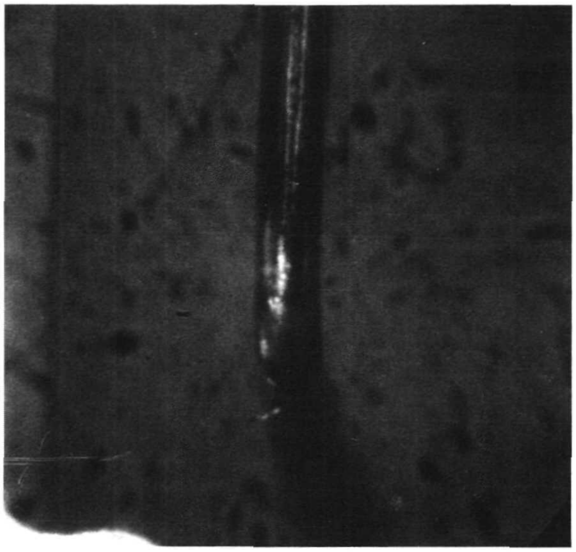


Fig. D-1. Breakthrough force test run at a gap of 3.81 mm (0.15 in.) and a force of 4.4 N (1 lbf). This load barely distorts the Teflon; there is no effect on the wire nor any apparent breakthrough

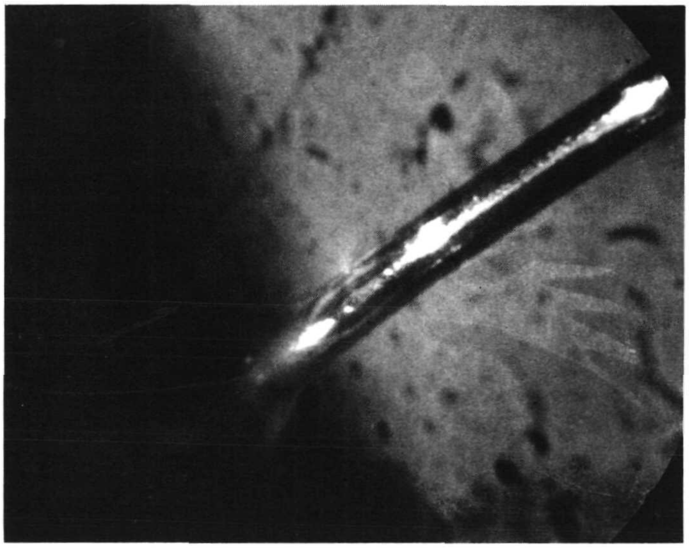


Fig. D-2. Breakthrough force test run at a gap of 3.81 mm (0.15 in.) and a force of 8.8 N (2 lbf). There is apparently a slight impression on the wire, but no obvious squeeze-out of the Teflon

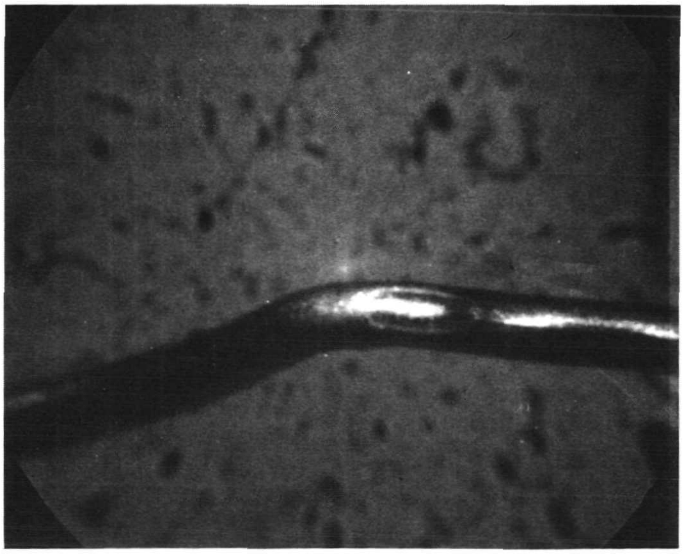


Fig. D-3. Breakthrough force test run at a gap of 3.81 mm (0.15 in.) and a force of 13.2 N (3 lbf). The set-down print appears somewhat larger, but it is still difficult to tell whether a breakthrough has been made, although the Teflon has obviously been squeezed to the sides

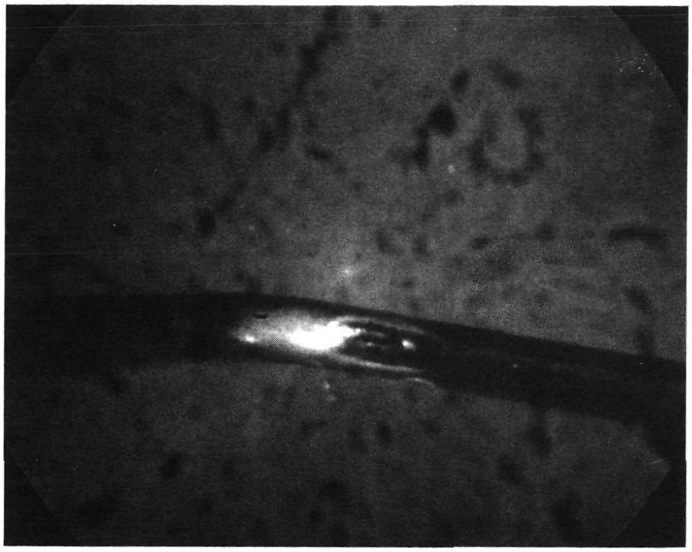
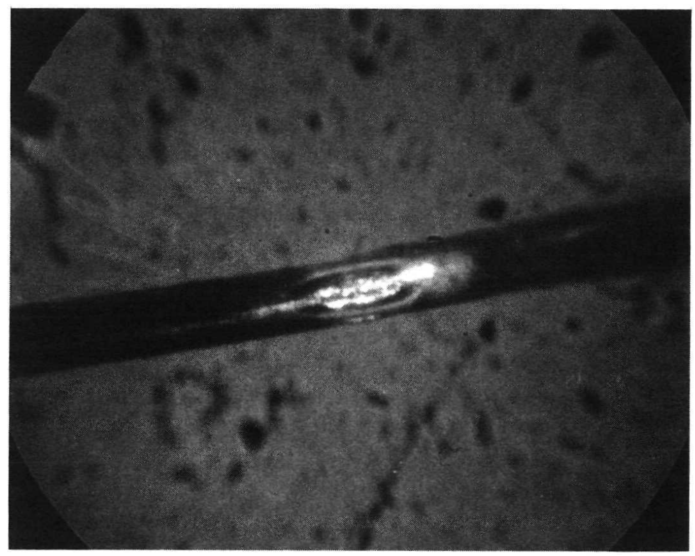


Fig. D-4. Breakthrough force test run at a gap of 3.81 mm (0.15 in.) and a force of 17.6 N (4 lbf). Decidedly more Teflon has been squeezed out and a fairly prominent set-down print is now visible

Fig. D-5. Breakthrough force test run at a gap of 3.81 mm (0.15 in.) and a force of 22.0 N (5 lbf). This is the first load at which the Teflon is obviously squeezed beyond the outline of the wire. There is a definite set-down print, and a trace of the electrode surface finish was transferred. However, the light reflections give an apparent image of a thin Teflon film on the wire



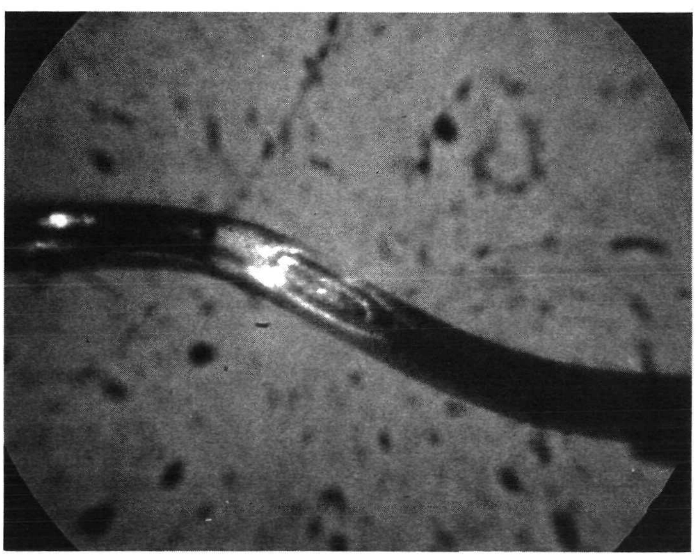


Fig. D-6. Breakthrough force test run at a gap of 3.81 mm (0.15 in.) and a force of 26.4 N (6 lbf). The size of the set-down print is definitely larger, and there is more squeeze-out of the Teflon

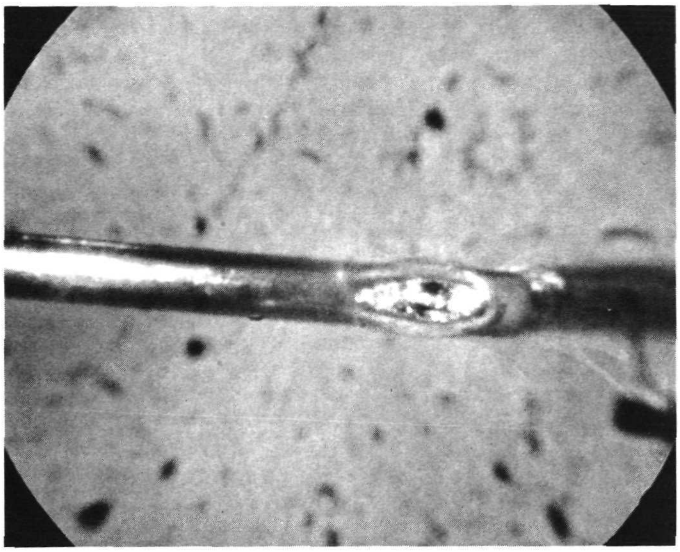


Fig. D-7. Breakthrough force test run at a gap of 3.81 mm (0.15 in.) and a force of 30.8 N (7 lbf). The wire is beginning to be badly mashed at this force level; from the side, the deformation indicates a 15 to 20% reduction in diameter

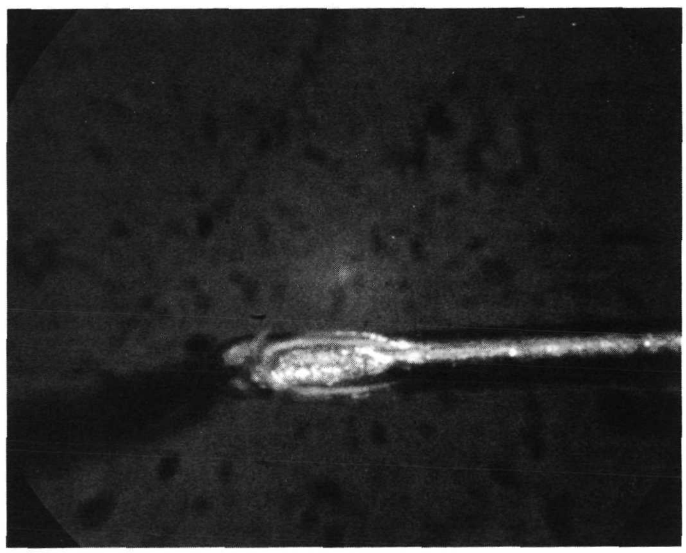


Fig. D-8. Breakthrough force test run at a gap of 3.81 mm (0.15 in.) and a force of 35.2 N (8 lbf). It is apparent that this force level is too high for the CEW application

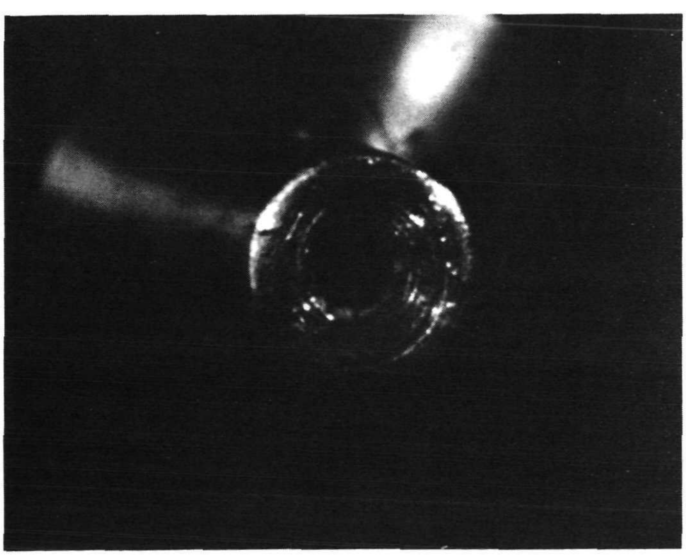


Fig. D-9. Electrode tip used for breakthrough development

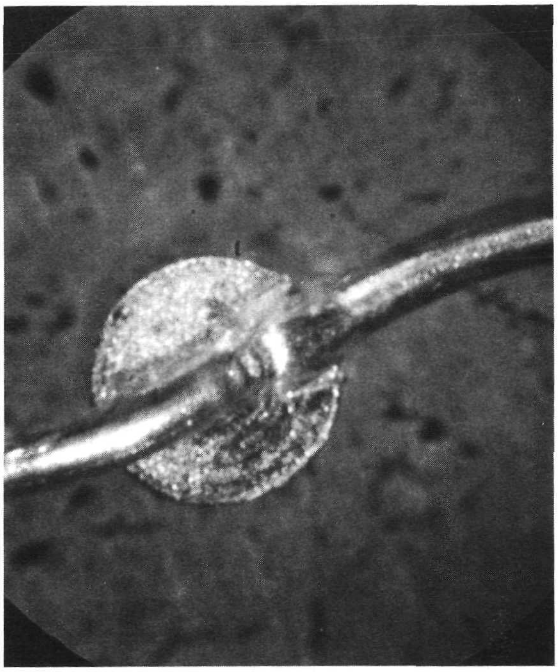


Fig. D-10. Weld force test sample 1. Test was run at a breakthrough force of 35.2 N (8 lbf), a weld force of 17.6 N (4 lbf), and a power level of 3 W/s

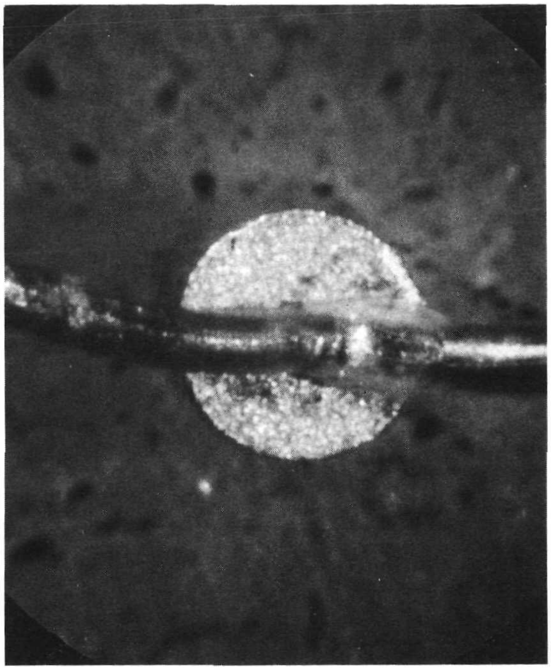


Fig. D-11. Weld force test sample 2. Test was run at a breakthrough force of 35.2 N (8 lbf), a weld force of 17.6 N (4 lbf), and a power level of 2 W/s

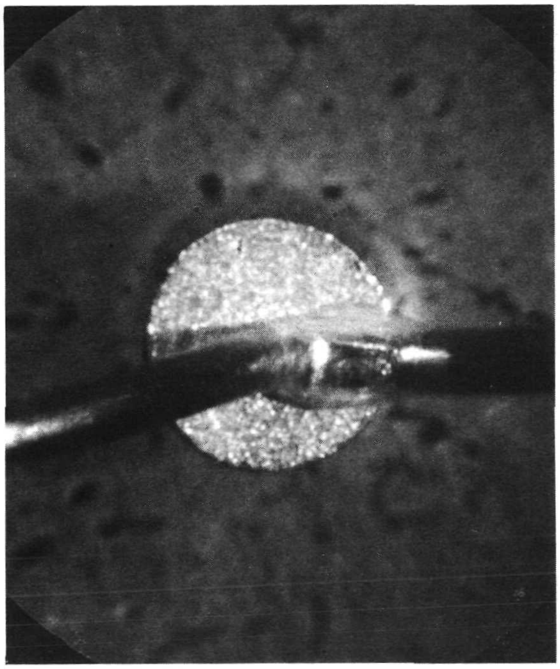


Fig. D-12. Weld force test sample 3. Test was run at a breakthrough force of 35.2 N (8 lbf), a weld force of 17.6 N (4 lbf), and a power level of 2 W/s

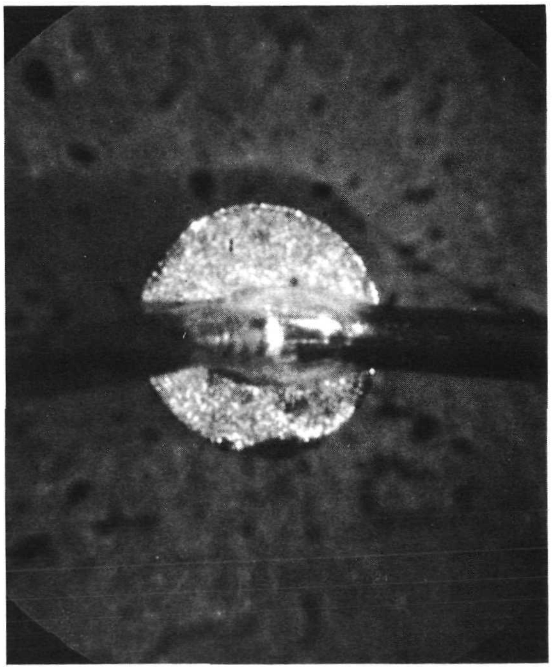


Fig. D-13. Weld force test sample 4. Test was run at a breakthrough force of 26.4 N (6 lbf), a weld force of 13.2 N (3 lbf), and a power level of 1.5 W/s

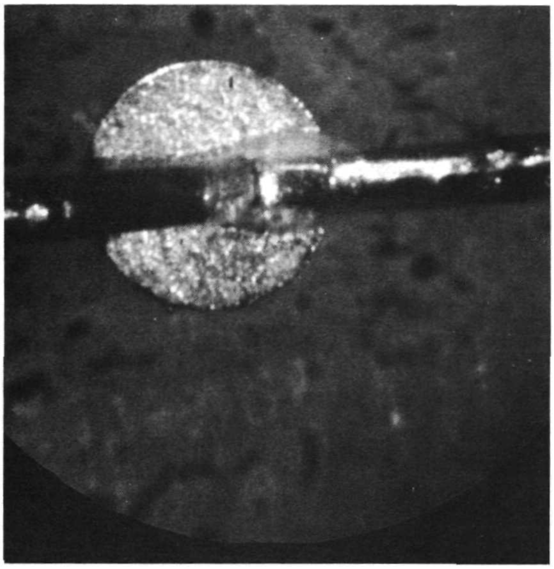


Fig. D-14. Weld force test sample 5. Test was run at a breakthrough force of 26.4 N (6 lbf), a weld force of 13.2 N (3 lbf), and a power level of 1.5 W/s

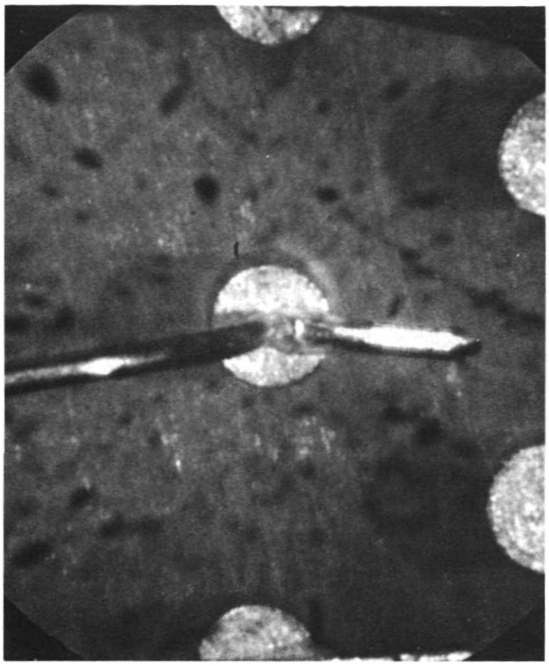


Fig. D-15. Weld force test sample 6. Test was run at a breakthrough force of 26.4 N (6 lbf), a weld force of 13.2 N (3 lbf), and a power level of 2 W/s

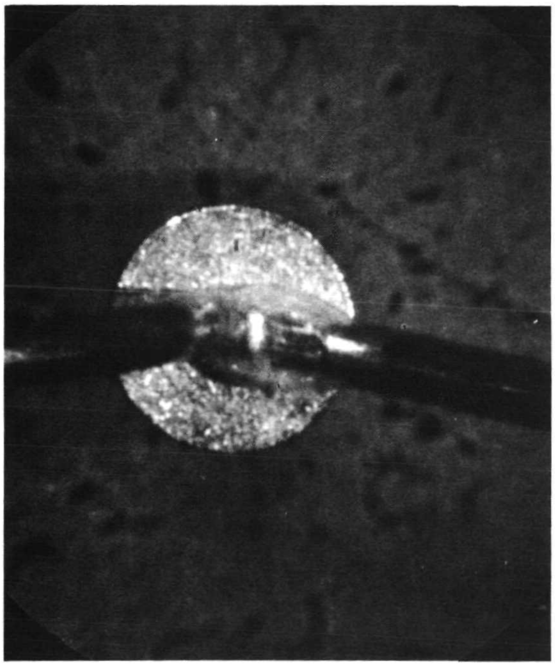


Fig. D-16. Weld force test sample 7. Test was run at a breakthrough force of 26.4 N (6 lbf), a weld force of 13.2 N (3 lbf), and a power level of 2 W/s

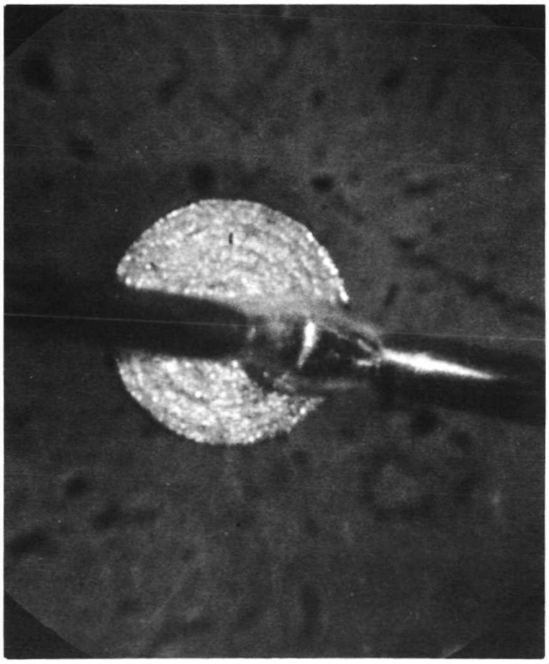


Fig. D-17. Weld force test sample 8. Test was run at a breakthrough force of 26.4 N (6 lbf), a weld force of 13.2 (3 lbf), and a power level of 2.5 W/s

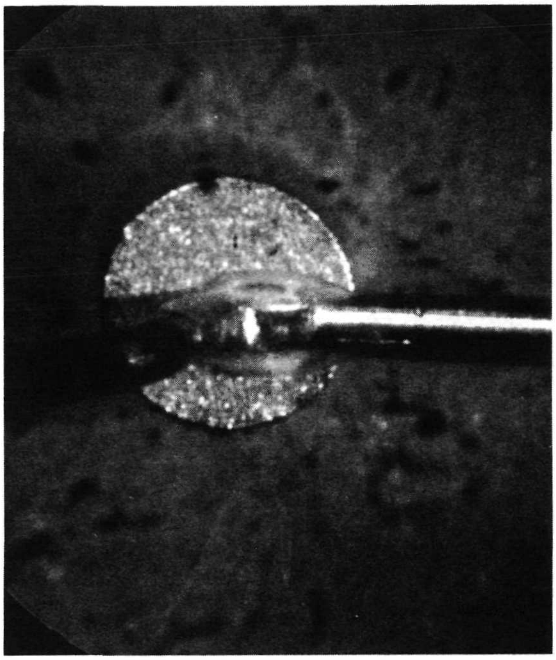


Fig. D-18. Weld force test sample 9. Test was run at a breakthrough force of 26.4 N (6 lbf), a weld force of 13.2 (3 lbf), and a power level of 3 W/s

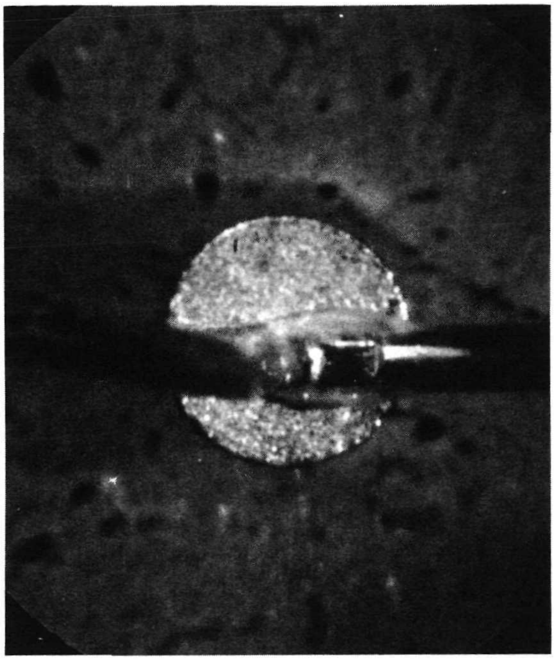


Fig. D-19. Weld force test sample 10. Test was run at a breakthrough force of 26.4 N (6 lbf), a weld force of 13.2 (3 lbf), and a power level of 3 W/s

APPENDIX E

ENGINEERING SKETCH FOR A 1.27-mm (0.050-in.) SPACED ELECTRODE/TERMINAL CEW SYSTEM

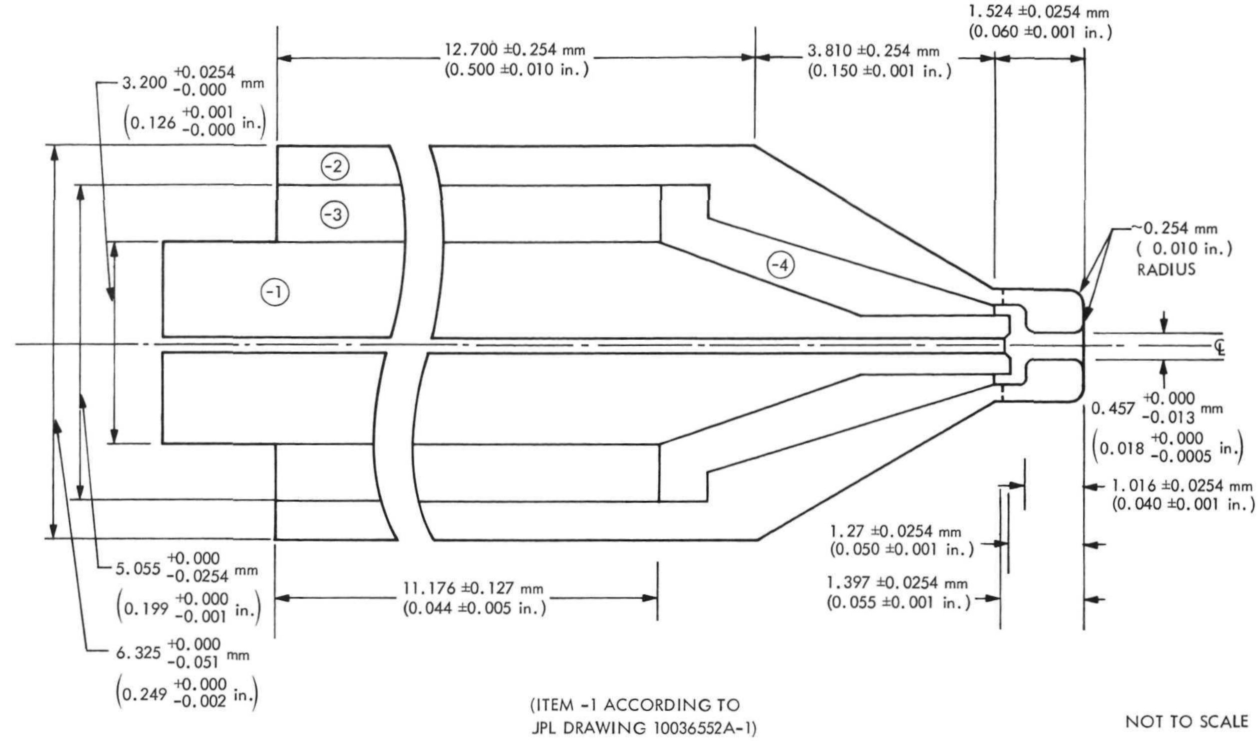


Fig. E-1. CEW assembly

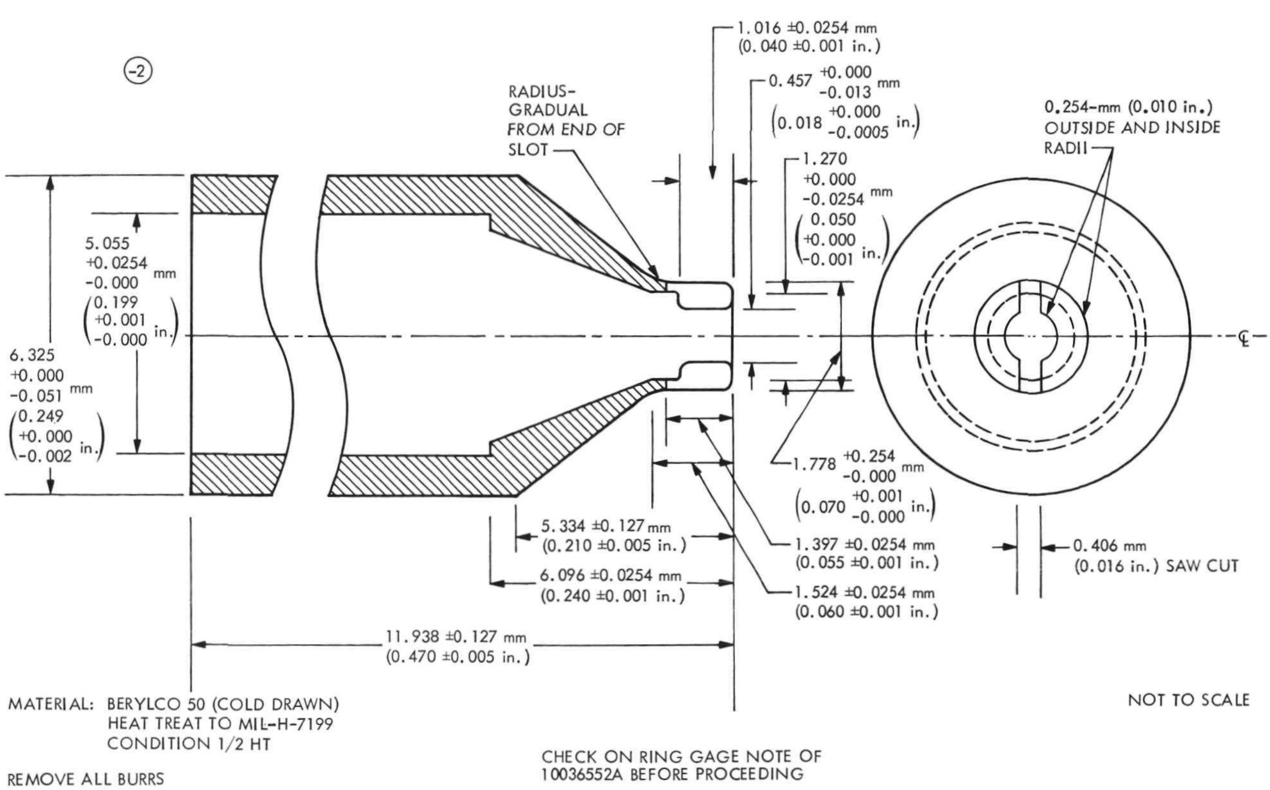


Fig. E-2. CEW outer electrode

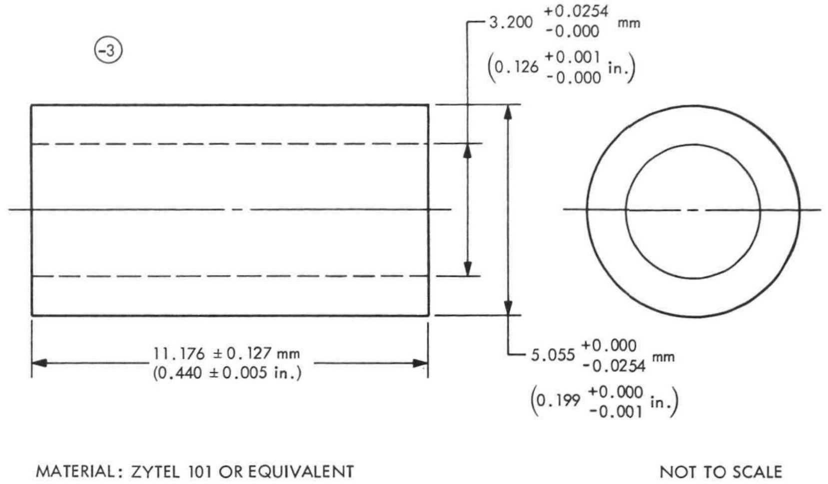


Fig. E-3. CEW insulating sleeve

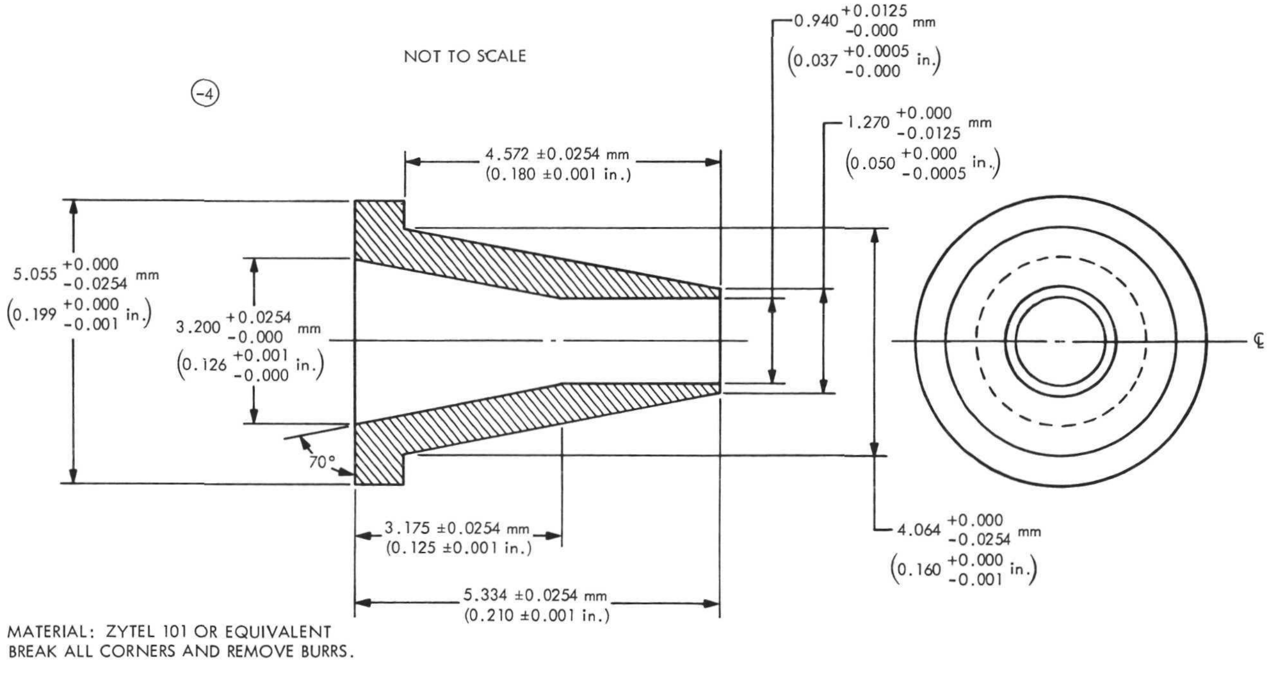


Fig. E-4. CEW position sleeve

APPENDIX F

NEW TECHNOLOGY REPORT, SIDE WIRE FEED FOR WELDING APPARATUS

NEW TECHNOLOGY REPORT

2873
CASE NO.

30-13148
IR NO.

TITLE:
SIDE WIRE FEED FOR WELDING APPARATUS

I. The Novelty

A coaxial electrode arrangement for a wire welder including a solid central electrode, an insulated outer electrode surrounding the inner electrode, and a transverse wire feed channel through the tip of the electrode assembly, can be utilized for sequentially welding either uninsulated or insulated wire to terminals in confined areas of electronic assemblies. When insulation such as "TEFLON" is to be removed, the pressure displacement arrangement previously reported in NTR-1487/NPO-10867 may be utilized.

II. The Disclosure

The Problem

Complex electronic assemblies using integrated circuit modules as components have large numbers of closely spaced, miniature terminals which must be interconnected to function. Such interconnections are made using continuous, magnet wire. Because of spatial limitations, wire wrap techniques cannot be utilized. Sequential welding of the interconnecting wire to terminals is accepted industry practice but often requires removal of selected portions of insulation prior to welding wire to terminal. One previously utilized technique employed in-line, top and bottom welding electrodes, with either the top or both electrodes heated. Heat softens the wire insulation (when used) so that it can be displaced to expose bare wire for making suitable physical contact with terminal and top electrode during welding. In the extremely crowded confines of complex assemblies, this hot electrode technique involves hazard of heat damage to adjacent wire interconnections.

PAGE 1

JPL 2688-2 (REV 5-69)

NEW TECHNOLOGY REPORT

2873 CASE NO.

30-13148 IR NO.

TITLE: SIDE WIRE FEED FOR WELDING APPARATUS

The Solution

The novel technique disclosed herein employs cold welding electrodes and utilizes pressure to displace wire insulation (when used) immediately prior to welding. Wire is fed to an inner electrode and a concentric outer electrode fits around the terminal and fixes both wire and inner electrode over the terminal in position for insulation displacement (when necessary) and subsequent welding of exposed wire to the terminal.

A machine has been designed and built at JPL to facilitate making interconnections by this technique. Greater pressure is required to break through the insulation (when used) than for welding. The machine accordingly is provided with two independently selectable pressure cycles to accommodate different requirements. In a previously reported case (NTR 1487, NPO 10867) the inner electrode had a hollow configuration so that the wire could be fed through the electrode. This report is directed to a version in which the inner electrode is solid and wire is fed under the electrode from one side.

Description and Explanation

The machine shown in Figure 2 of NTR-1487/NPO-10867, was designed for use with "TEFLON" insulation on a hard wire. The insulation is split to each side of the conductor when compressed between two properly designed opposed members. Hence, it is possible to use pressure rather than heat for local displacement of insulation.

Figure 3 of NTR-1487/NPO-10867, illustrates the insulation displacement and weld sequence utilized in that machine. A length of insulated wire coming from a supply spool threads through a hollow inner electrode and

PAGE 2

JPL 2688-2 (REV 5-69)

NEW TECHNOLOGY REPORT

2873 30-13148

CASE NO. IR NO.

TITLE: SIDE WIRE FEED FOR WELDING APPARATUS

passes out of a concentric outer electrode through a slit to a previously made connection. The concentric electrode assembly carrying a wire is lowered toward a terminal and the outer electrode then encircles the shank of the terminal and positions the wire over the round top of the terminal. The lower end of the hollow electrode has a matching concave geometry.

Since the amount of pressure required to rupture the insulation is considerably greater than the welding pressure, that machine has mechanisms which apply two different pressure cycles, in sequence. The mechanisms are independent, both in operation and in adjustment. This is described more fully in NTR-1487/NPO-10867.

In the new electrode version shown in Figure 2, a length of wire 10 coming from the supply reel is threaded through outer electrode 12, passing through transverse opening 12a and slot 12b to a previously made connection. Electrode 12 is provided with an axial opening 12c which encircles the shank of the terminal or pin 15 to which the wire is to be welded.

The inner electrode 11 is coaxially disposed within outer electrode 12, and suitably insulated therefrom by insulation sleeve 16a and insulation washer 16b. Electrode 11 which is made of a suitable metal which can withstand the erosion effect of welding, is press fitted into shank 11a which may be fabricated from a brass rod.

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Both electrodes are secured to a mechanism which lowers the welding assembly over pin 15 either by manual operation or automatically in a programmed setup. The mechanism provides the required welding pressure. As shown, this arrangement is suited for welding of non-insulated wire to terminals in sequence.

When the device is to be used with "TEFLON" insulated wire, displacement of the insulation by pressure may be effected by means of the arrangement and in the manner disclosed in the earlier case NTR-1487/NPO-10867. In that event, rod 11a would be provided with means by which it could be moved independently of the general movement of the electrode assembly. Such movement could be accommodated if insulating washer 16b is fabricated of a resilient material such as one of the heat resistant silicone rubbers.

Use of the electrode assembly in this manner is indicated in Figure 3.

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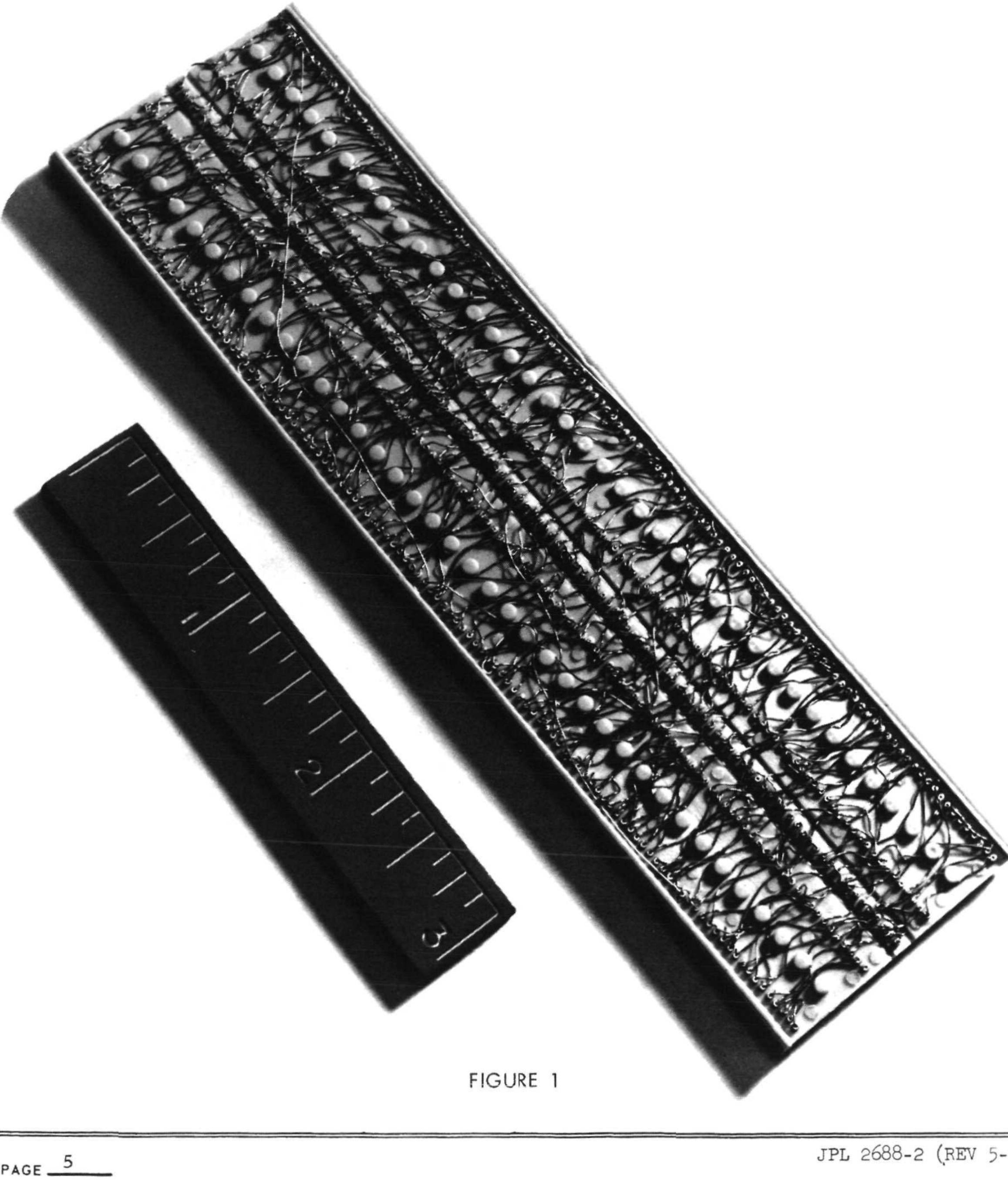

FIGURE 1

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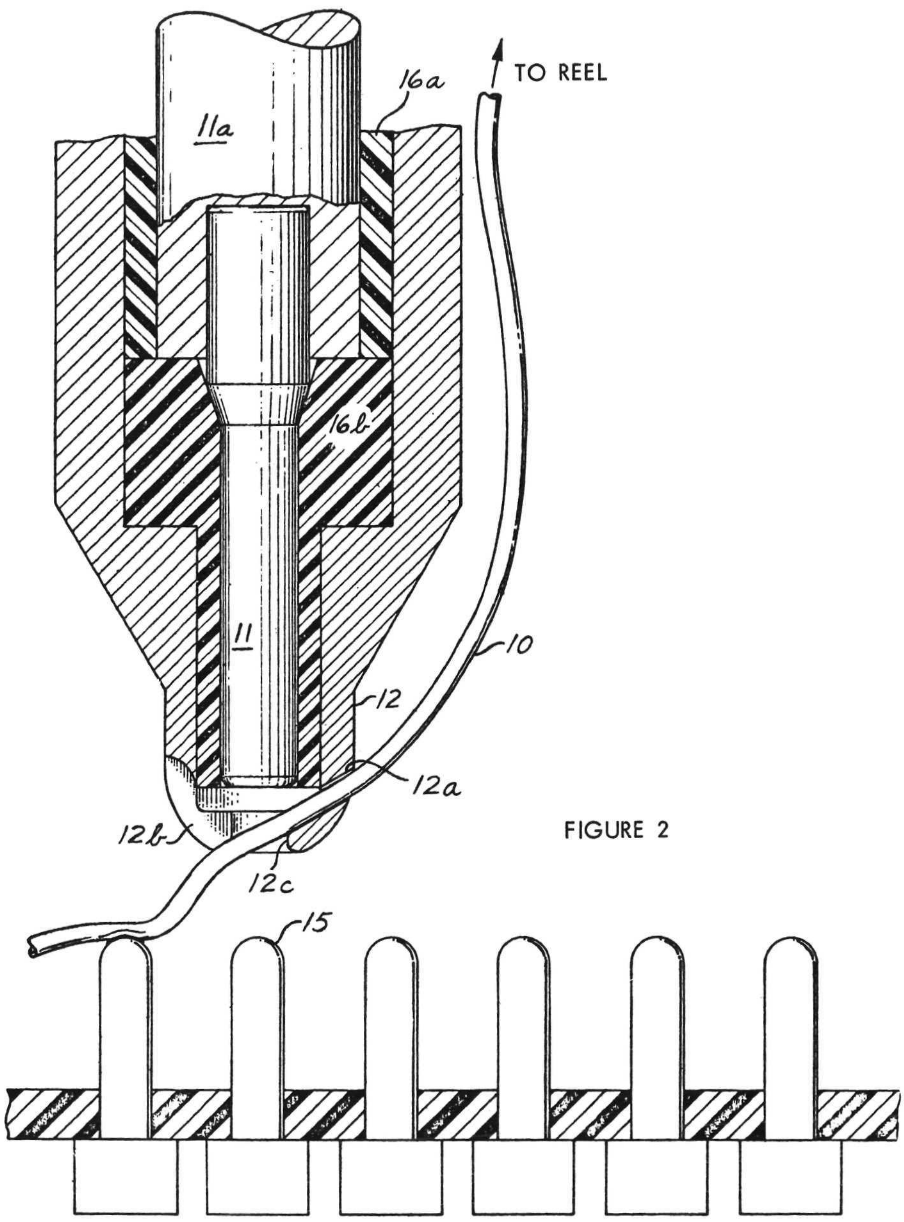

FIGURE 2

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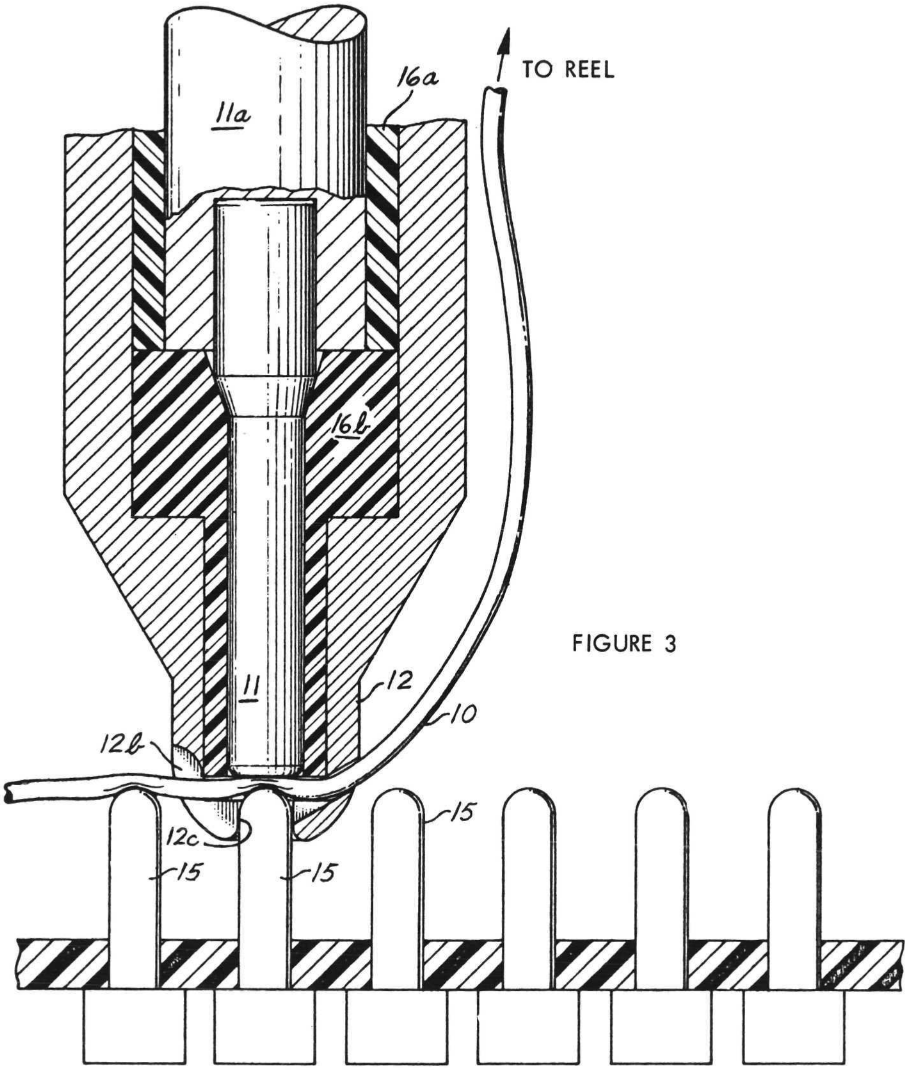

FIGURE 3

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