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BDX-613-1453

INDUCTION SOLDERING EVALUATION

PDO 6984751, Topical Report

E. R. Friebe, Project Leader

Project Team:
C. E. Gaynor
T. J. Husby

Published August 1976

Prepared for the United States Energy Research and Development Administration Under Contract Number E(29-1)-613 USERDA

Bendix Kansas City Division

NOTICE

Printed in the United States of America

Available From the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Price: Microfiche $2.25
Paper Copy $4.00

BDX-613-1453
Distribution Category UC-38

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This investigation measured the temperature difference across the seal between the connector insert and shell on cables using EMR hardware, and determined the extent of heat damage to the shell. An induction heating coil was developed which makes a consistently air tight solder joint and minimizes heat transfer to the connector seal. An induction heating coil and processing steps were also developed to solder EMR hardware to adaptor rings and a study was made to determine the effects of subjecting the connector to a peak temperature of 600°F (316°C).

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A prime contractor for the United States Energy Research and Development Administration
Contract Number E(29-1)-613 USERDA

CONTENTS

Section	Page
SUMMARY	6
DISCUSSION	7
SCOPE AND PURPOSE	7
ACTIVITY	7
Solder Joint Criteria	7
Induction Solder Process	9
Leak Test Equipment	9
Temperature Measurement	11
Coil Analysis	12
Induction Soldering of EMR Hardware	16
ACCOMPLISHMENTS	21
APPENDICES	
A. TEMPERATURE DIFFERENCES ACROSS CONNECTOR SEALS	25
B. SOLDER LEAK TESTS	27
DISTRIBUTION	43

ILLUSTRATIONS

Figure		Page
1	Acceptable (Left) and Unacceptable Solder Joints	8
2	Assembly EMR Shell	8
3	Water Lines Attached to Coil (P-88075)	10
4	Connector on Jack and Raised Into Position in Work Coil (P-88080)	10
5	Control Box (P-88079).	11
6	Time Versus Temperature Profile.	12
7	Production Leak Test Fixture (P-88857)	13
8	Comparison of Leak Test Devices.	14
9	Temperature Monitoring and Recording Setup . .	14
10	Inside Collar Coil	15
11	Conventional Flat Coil	16
12	Tapered Flat Coil.	17
13	Step-Down Flat Coil.	17
14	Outside Collar Coil.	18
15	Top Collar Coil.	19
16	Conical Coil	19
17	Solder Being Rolled Into a Ribbon (P-88839). .	21
18	Hardware Holding Device (P-88076).	22
19	Excellent Joint (P-91409).	22
20	Cross Section of Excellent Joint (P-91412) . .	24

TABLES

Number		Page
1	Temperature Test Across Connector Seals. . . .	15
2	EMR Soldering Data	20
3	Infrared Connector Insert Temperature Monitor Data	23
4	Solder Cup Temperature Check With Thermocouple	23

SUMMARY

This project began in support of process development work on cables which use electromagnetic radiation (EMR) hardware. These cables require an air tight conductive path between the shield, the adaptor ring, and the connector shell.

Solder joint processing between the adaptor ring and connector involves installing a solder preform in the groove between ring and connector and inserting the connector in an induction heated work coil to melt the solder. A typical heat cycle lasts approximately 5 seconds and generates a peak temperature of about 500°F (260°C). The solder melts and flows into the threaded areas, making visual verification of the solder joint difficult.

This investigation measured the temperature difference across the RTV seal in the connector and determined the extent of seal damage from heat. This investigation also determined the effects of subjecting the connector to a 600°F (316°C) peak temperature.

Seven work coils were evaluated and a coil was produced which will make a consistently air tight solder joint while minimizing heat transfer to the connector seal. A process and induction heating coil were developed to solder EMR hardware to the adaptor ring while minimizing heat transfer to previously soldered terminations.

DISCUSSION

SCOPE AND PURPOSE

The induction soldering process was developed to support electromagnetic radiation (EMR) hardware cable production. At the start of this project, product specifications required that the adaptor-ring-to-connector solder joint be made with a T1 of 420°F (216°C) and a T2 of 470°F (243°C). T1 is the initial temperature, approximately 70°F (21°C) to 150°F (71°C) higher than the melting point of the solder, and should be reached in less than 5 seconds. T2 is the maximum allowable temperature (*Round Wire Multiconductor Cable Design Guide*, Sandia Laboratories, p 3.3).

An increase in the T2 was requested, but concern existed about the degradation of the RTV seal between the connector shell and insert above 480°F (249°C). Temperature gradient requirements later were relaxed to make a functional solder joint acceptable after tests showed the connector insert seal might not reach a damaging temperature during the soldering cycle. The product specification now allows a peak temperature of 600°F (316°C) because the soldering materials can be used effectively below this temperature.

ACTIVITY

Solder Joint Criteria

Solder joint acceptance originally was based on visual inspection and several cycles through the induction solder machine were required to yield a visually acceptable solder joint. These extra cycles result in a solder build-up on the inside adaptor ring lip which interferes with EMR hardware assembly.

When temperature gradient requirements were relaxed the standard was revised to allow a functional solder joint to be acceptable. An air tight, continuous 360 degree solder joint between the adaptor ring and connector that is functionally tested for air leaks and has a leakage rate of less than 20 cubic centimeters per minute is acceptable. Figure 1 shows cross sections of acceptable and unacceptable joints. In the acceptable joint, solder fill between the threads is good, no continuous air gap is present, and no solder is on the adaptor ring lip.

In the unacceptable joint excess solder has flowed onto the adaptor ring lip. This excess solder presents a problem in the installation of EMR hardware (Figure 2) because the hardware will not fit square on the adaptor ring. All solder joints are tested for air leaks on a production leak test fixture.

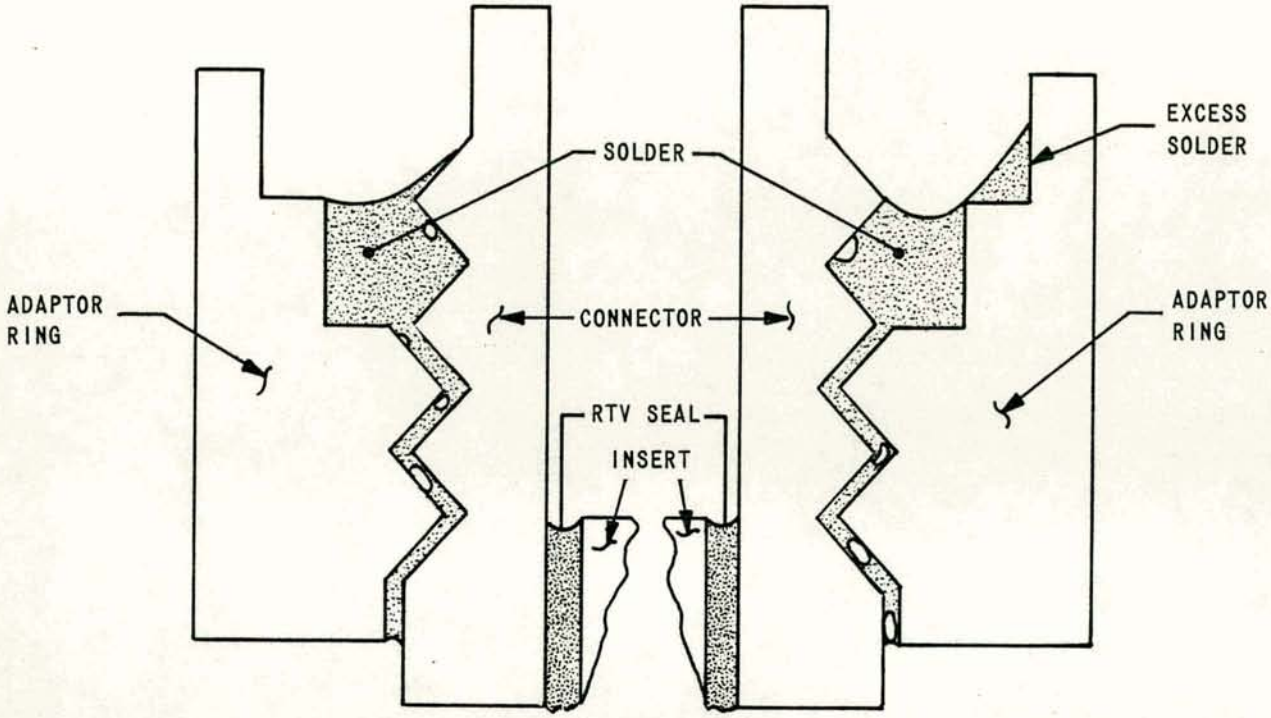

Figure 1. Acceptable (Left) and Unacceptable Solder Joints

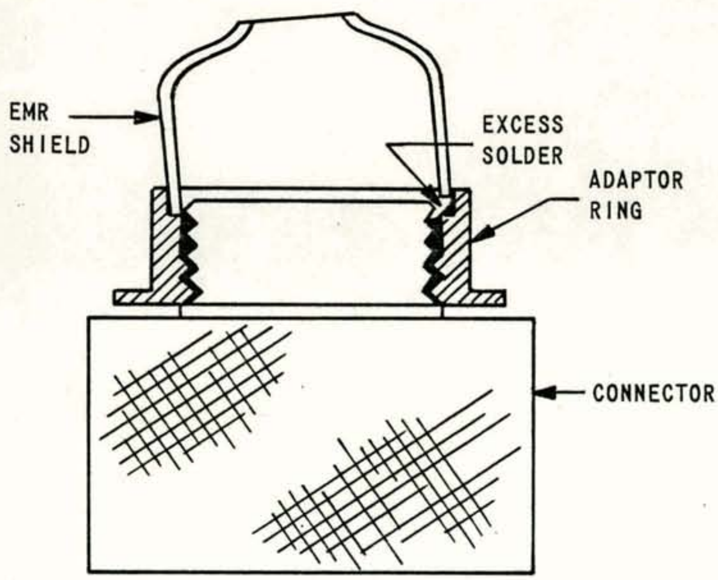

Figure 2. Assembly EMR Shell

Induction Solder Process

The following steps are performed in a typical induction solder process.

- The work coil is attached to the machine.
- Water lines to cool the coil are hooked up and activated (Figure 3).
- Flux is applied to connector and adaptor ring threads.
- The adaptor ring is screwed on the connector.
- The connector is set on a jack and raised into position in the work coil (Figure 4).
- A dag spot (liquid graphite) is painted on the inside of the connector.
- Solder is rolled into a ribbon on a wring press.
- Solder is placed between the adaptor ring and the connector.
- Machine settings are made on control boxes (Figure 5).
- The temperature recorder is started.
- A foot switch is depressed to initiate the soldering cycle.
- The work coil starts to heat up (Figure 6).
- The temperature continues to rise until T1 is reached.
- Current stops at T1, 5 seconds maximum from start of cycle.
- The temperature continues to rise until water cooling takes effect. (T2 is the maximum temperature.)
- Water is used to cool coil.
- Once the work coil cools, the soldered connector is removed, a second connector is chosen, and the cycle is repeated.

Leak Test Equipment

Leak tests are used to check both solder joint integrity and RTV insert seal damage. Determining small leak rates requires a sophisticated piece of equipment. The production leak test fixture (Figure 7) can numerically register leakage when air is

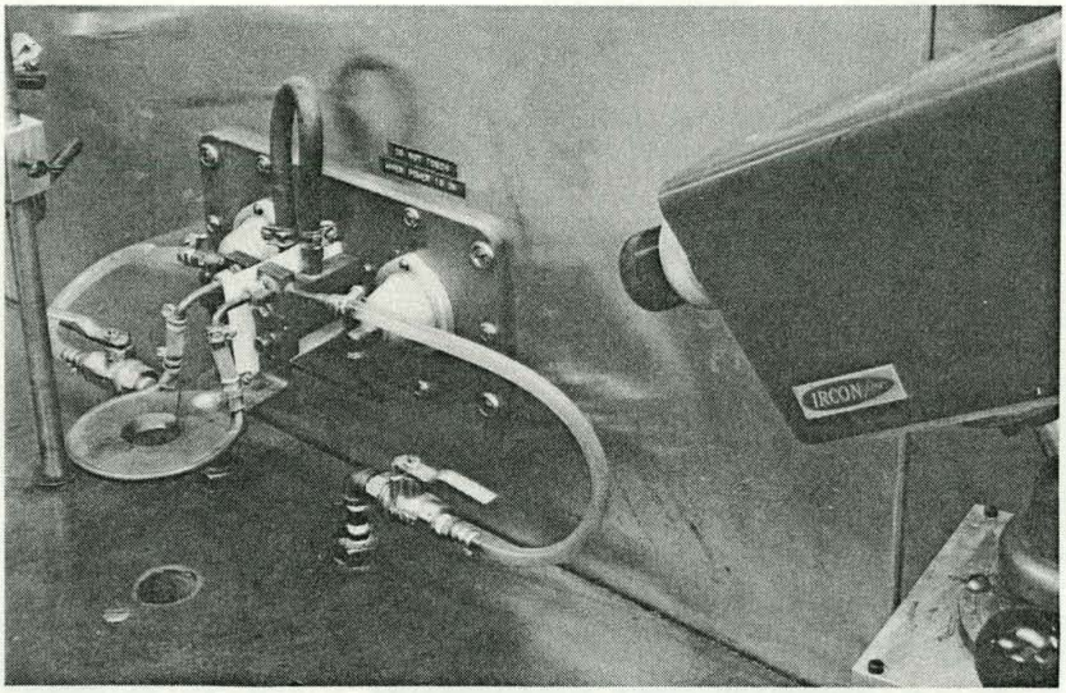

Figure 3. Water Lines Attached to Coil

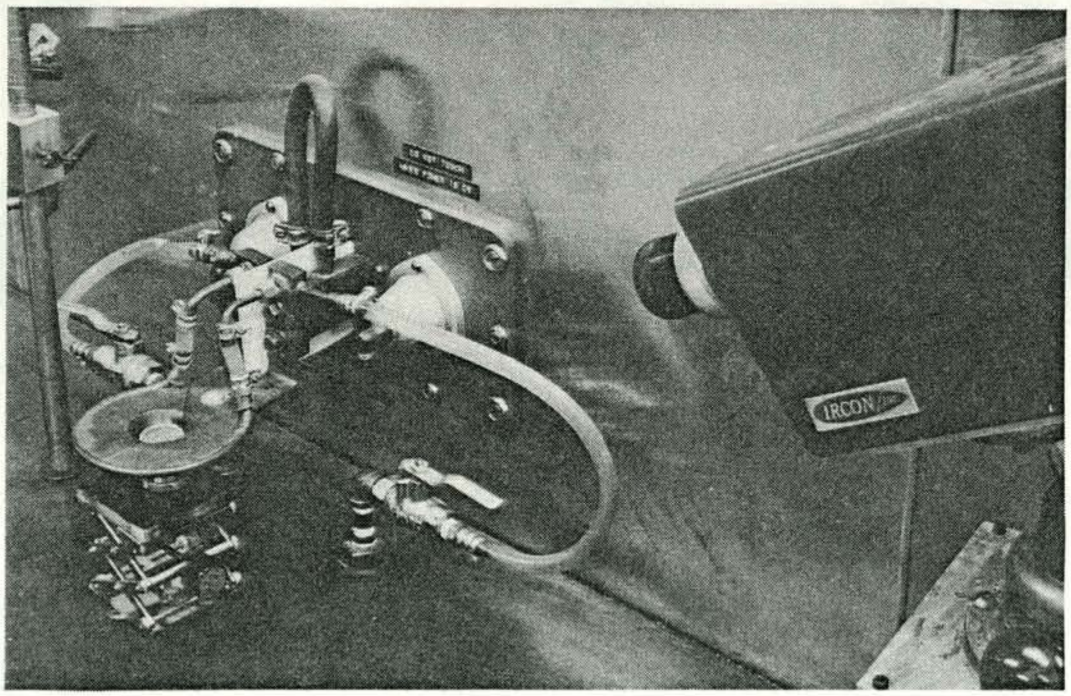

Figure 4. Connector on Jack and Raised Into Position in Work Coil

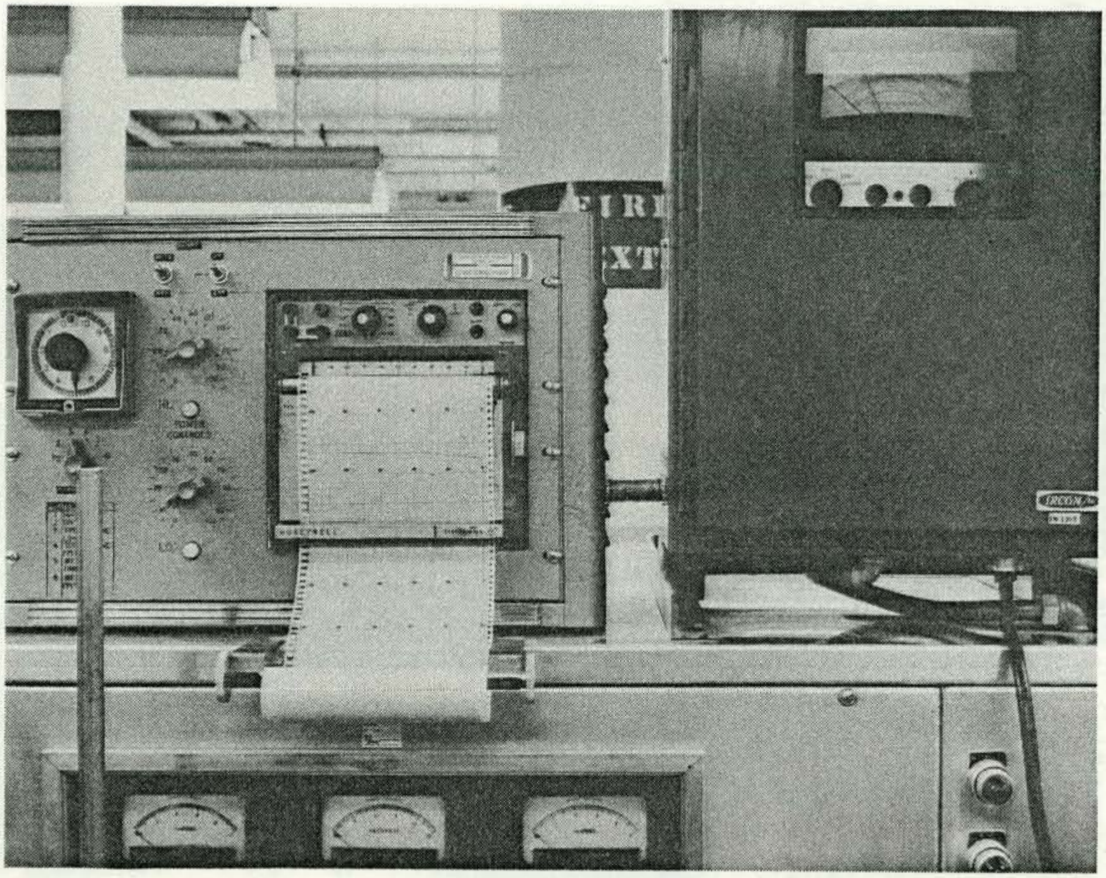

Figure 5. Control Box

generated through the connector. This particular tooling is designed to register leaks within the product specification range of 20 cubic centimeters per minute.

All of the samples made during this study were leak tested on a Veeco Mass Spectrometer which measures leaks in the range of 10^{-5} to 10^{-8} cubic centimeters per second. Figure 8 indicates the range of both the Veeco and the production fixture. The Veeco is used because the test is extreme and solder joints with leakage in this range are definitely good.

Temperature Measurement

The temperature gradient across the RTV connector insert seal is of concern, so a monitoring and recording test procedure was devised. Two infrared radiation heat sensors were used to control and monitor the temperature above and below the insert seal during the solder process. One infrared sensor was used to control

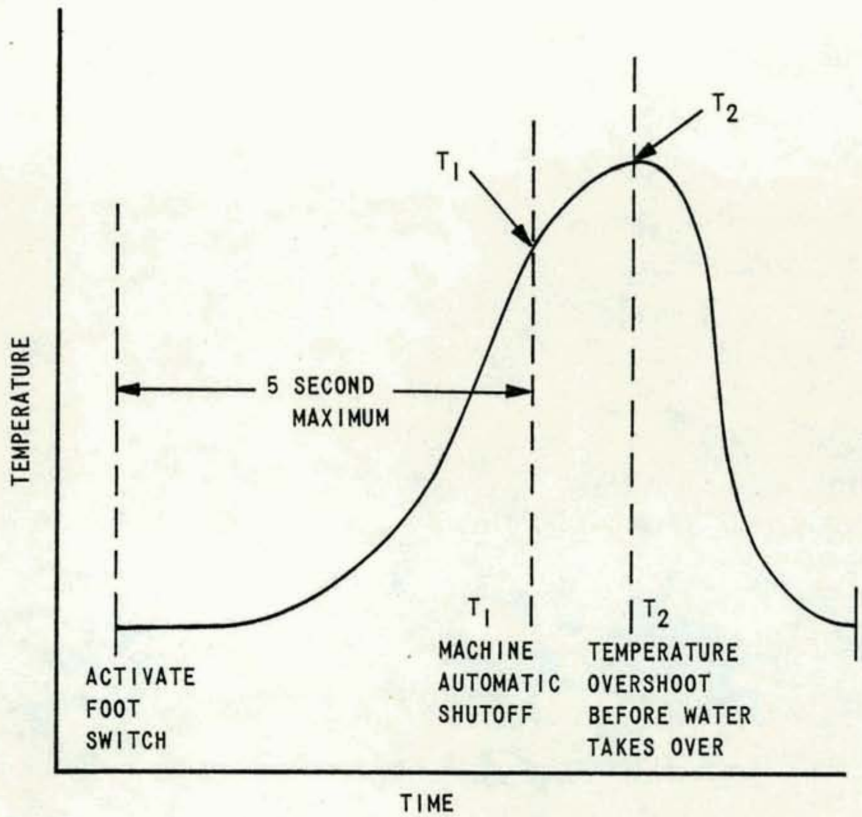

Figure 6. Time Versus Temperature Profile

the output (T_C) of the induction solder heater and the second was focused through an enlarged bayonet hole on the outside of the connector barrel (T_M) (Figure 9). Two circles of liquid graphite are painted on the connector for the focusing points.

This setup permitted simultaneous recording of temperature on both sides of the connector insert to determine the temperature gradient across the RTV seal. Five connectors were monitored in each of seven work coils. Enough data (Table 1) was collected to generate a reliable temperature profile for each coil.

<u>Coil Analysis</u>

Seven different work coils were designed to solder adaptor rings to Size 10 and 11 connectors (Figures 10 through 16). Presolder leak tests using the Veeco Mass Spectrometer defined base information on the RTV seal condition in all connectors. Twenty-five connectors were soldered on each work coil. As stated earlier, 5 of these 25 defined the temperature rise across

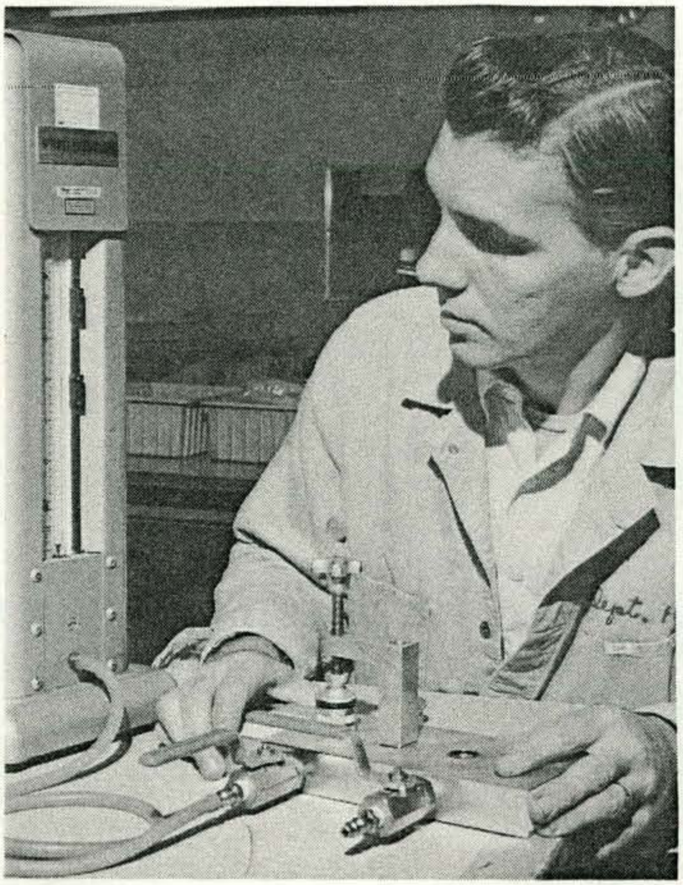

Figure 7. Production Leak Test Fixture

the connector insert seal during soldering (Table 2). In all cases, Sn60/Pb40 solder and mildly activated flux were used exclusively. Highly activated flux is not used because of potential long term corrosive problems and because the EMR hardware makes it impossible to remove.

Solid solder (Sn60/Pb40) maximized the amount of solder which could be placed in the adaptor ring groove. For a standard adaptor ring the solder must be rolled into a ribbon 0.015 inches (0.038 mm) thick on a fixture (Figure 17), permitting it to be installed in the adaptor ring-connector groove. After connectors were soldered on the work coils, each group was again leak tested on the Veeco Mass Spectrometer. Data on some connectors are inconsistant but if the leakage rate after soldering is less than full scale, (10^{-5} cubic centimeters per second) the seal and solder joint are considered good. Those indicating full scale were further tested on the production leak test

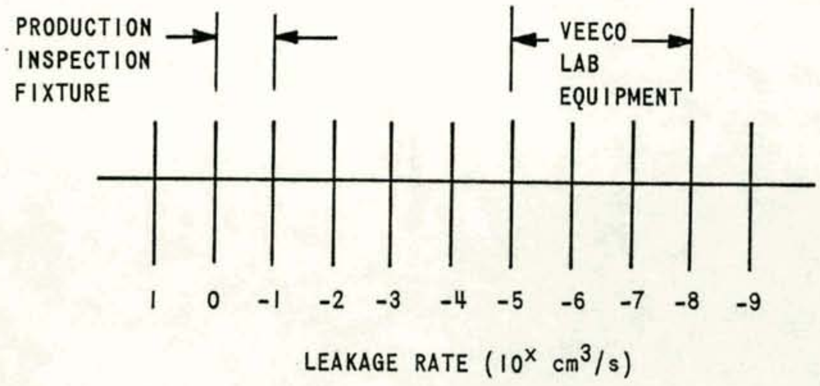

Figure 8. Comparison of Leak Test Devices

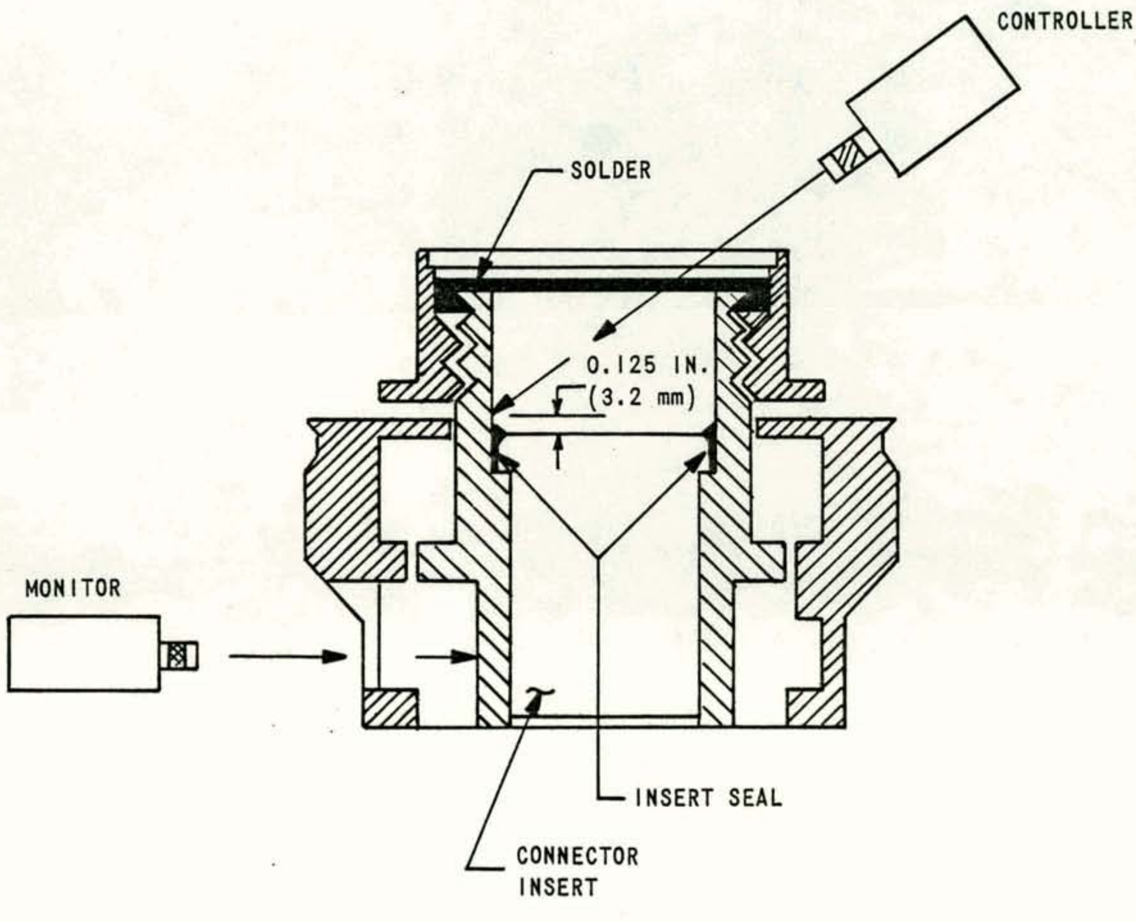

Figure 9. Temperature Monitoring and Recording Setup

Table 1. Temperature Test Across Connector Seals

Coil	Shell Size	$T_{c}-T_{m}$ Average (°F)	(°C)
1	10	+ 4.5	+ 2.5
1	11	-118.0	-65.6
2	10	- 30.8	-17.1
2	11	- 29.4	-16.3
3	10	- 57.6	-32.0
3	11	-123.2	-68.4
4	10	- 68.6	-38.1
4	11	-175.8	-97.7
5	10	- 49.0	-27.2
5	11	-125.6	-69.8
6	10	- 56.4	-31.3
6	11	- 50.6	-28.1
7	10	- 40.2	-22.3

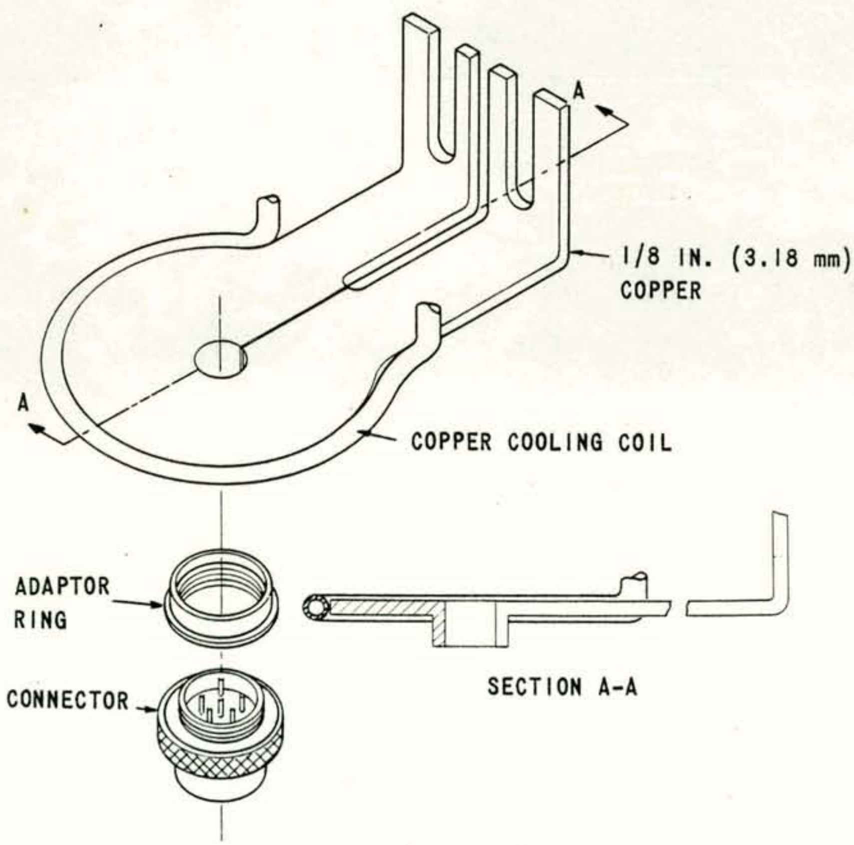

Figure 10. Inside Collar Coil

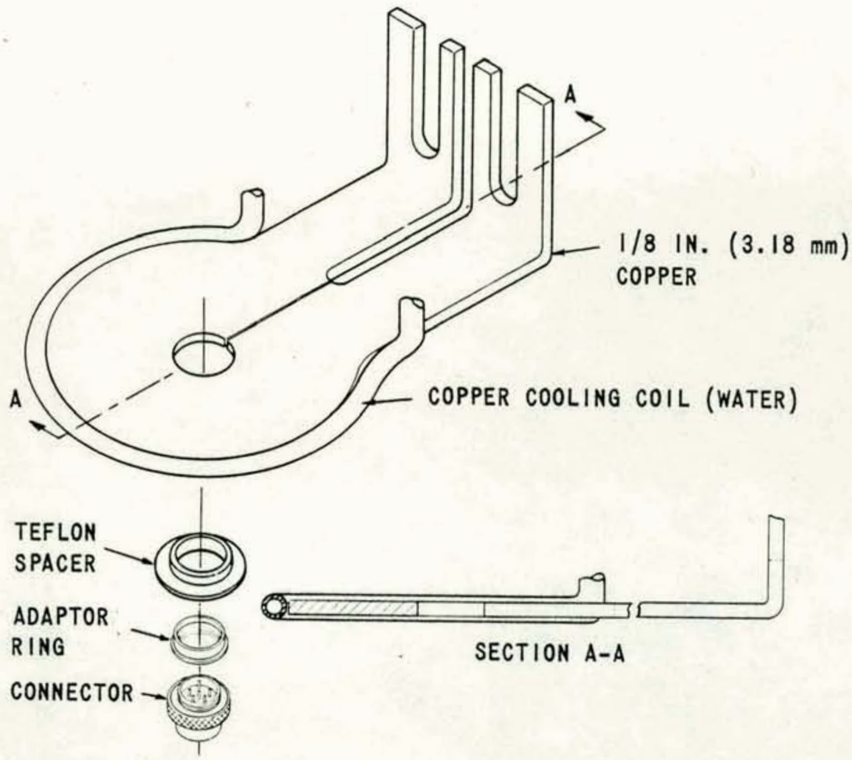

Figure 11. Conventional Flat Coil

fixture where leaks of less than 20 cubic centimeters per minute are acceptable. Several coils produced an acceptable solder joint; however, only one coil exhibited the characteristics considered most advantageous. Coil 4 was the most efficient, with a complete solder fillet, no damage to the RTV connector seal, and a low temperature gradient between the inside and outside of the connector.

Induction Soldering of EMR Hardware

EMR hardware design and assembly lends itself to induction soldering. The EMR hardware is placed inside the connector adaptor ring and a piece of round solder is formed into a circle and placed on the adaptor ring outside the EMR hardware. Next the connector, solder, and hardware set-up is placed into a holding device inside an induction solder coil similar to Coil 4 (Figure 18).

Activating the machine causes the solder to melt and flow between the hardware and adaptor ring. This process produced an excellent, continuous 360 degree fillet around the hardware once the proper

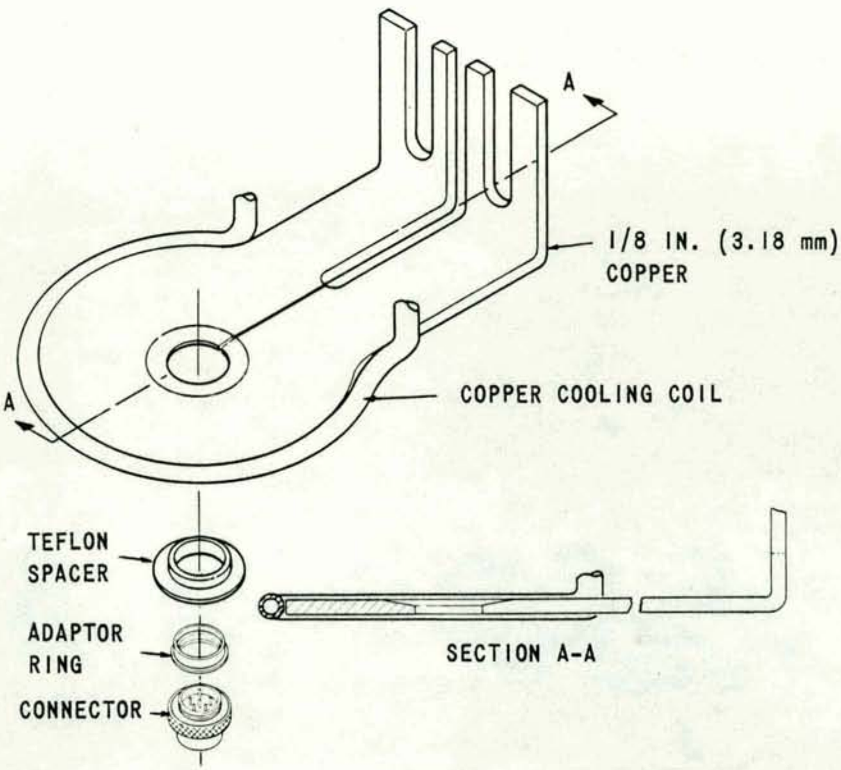

Figure 12. Tapered Flat Coil

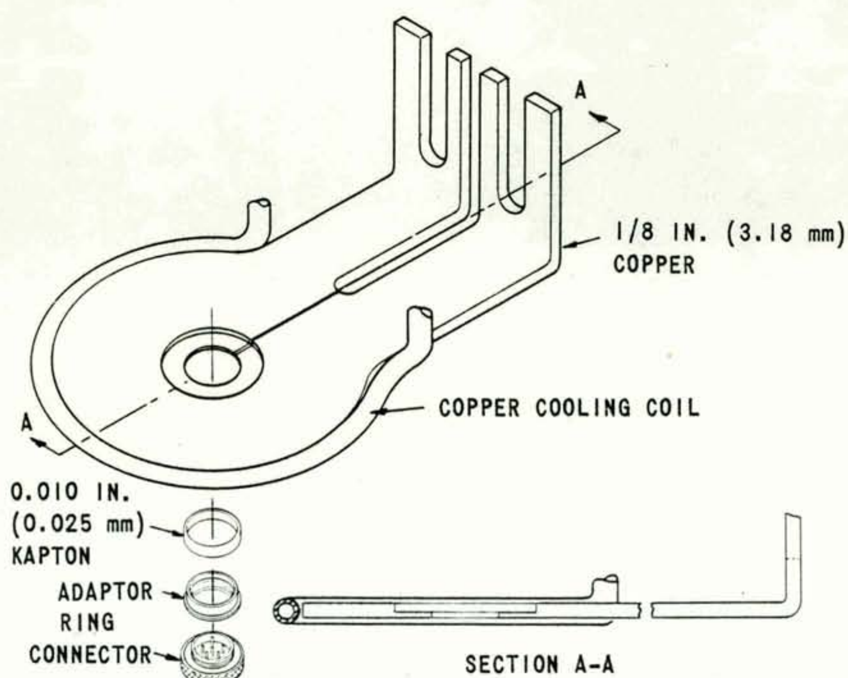

Figure 13. Step-Down Flat Coil

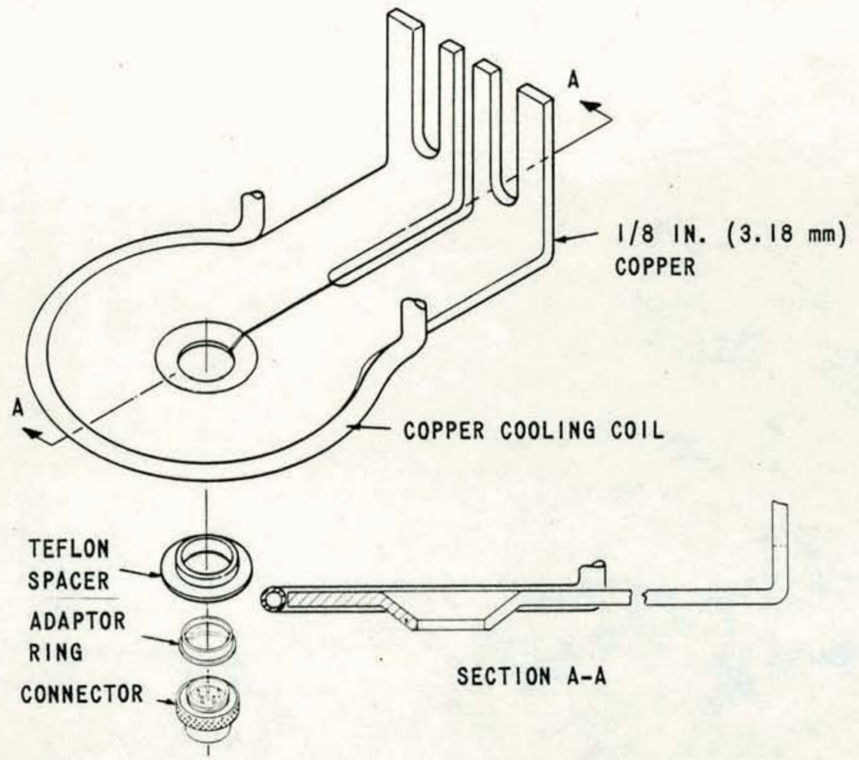

Figure 14. Outside Collar Coil

machine schedule is developed. Excellent wetting, a concave joint, and a bright and shiny joint result (Figures 19 and 20). Figure 20 is a cross section which shows an air tight seal between the connector and adaptor ring and an acceptable joint between the EMR hardware and adaptor ring.

Concern existed about the amount of heat that the soldering required and the effect of the heat on the wire-to-solder-cup joints within the hardware. Using two infrared monitors, one focused on the outside ring and the other focused on the connector insert edge inside the EMR hardware, the temperatures were monitored during soldering. Recorded temperatures on the connector insert did not exceed 310°F (154°C) which is safely below the solder melt temperature of 361°F (183°C) at the solder cup (Table 3). A second temperature test included soldering a thermocouple into a solder cup adjacent to the EMR hardware. Thermocouple readings were made during the soldering process. The peak temperature reading was 285°F (140°C), safely below the solder melt temperature (Table 4). All connectors were leak tested after soldering and this proved that the solder process neither degrades the connector seal nor the adaptor ring joint

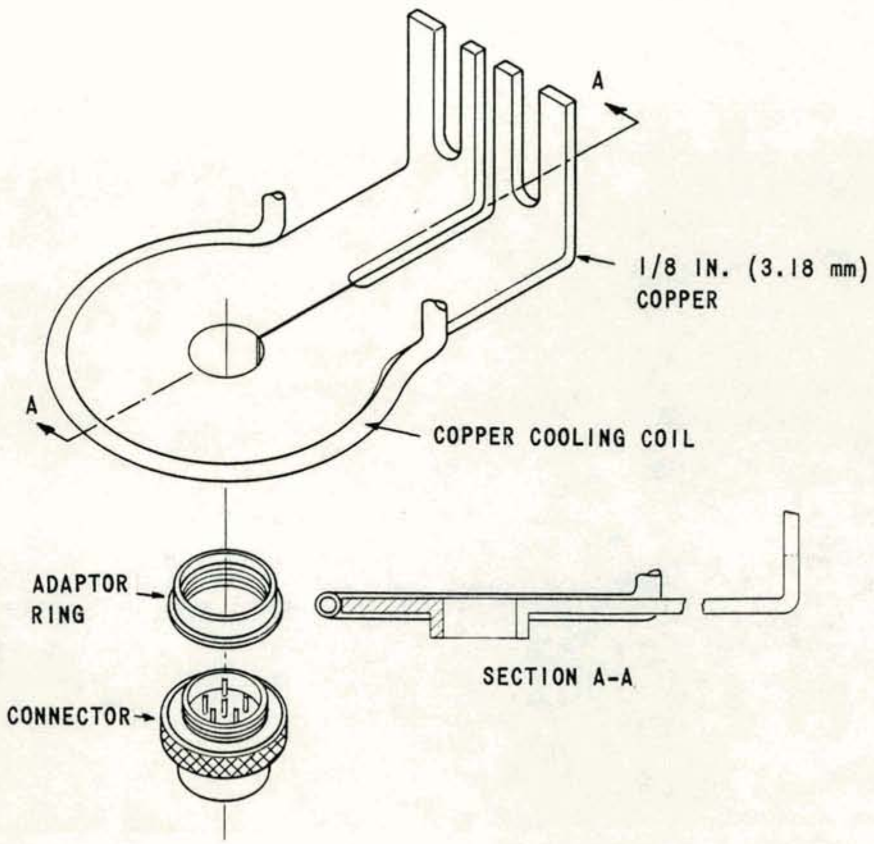

Figure 15. Top Collar Coil

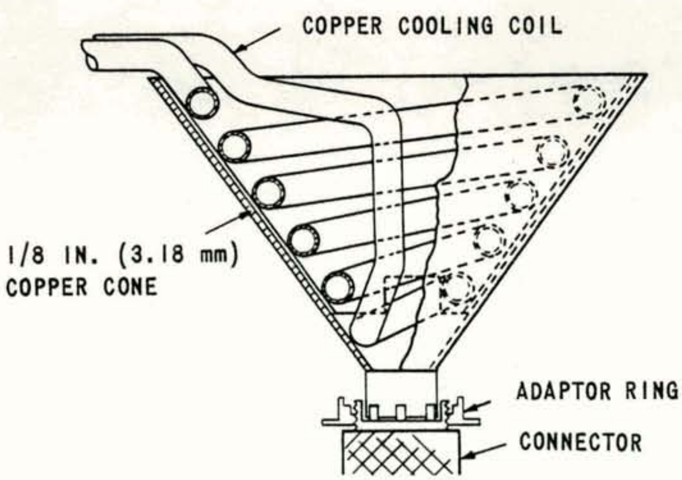

Figure 16. Conical Coil

Table 2. EMR Soldering Data

Sample	Temperatures (°F) (°C) T_m	T_c	T_c-T_m
Small Connectors			
5	295 (146)	420 (216)	125 (52)
9	305 (152)	428 (220)	123 (51)
10	308 (153)	426 (219)	118 (48)
11	310 (154)	426 (219)	116 (47)
23	310 (154)	425 (218)	115 (46)

Machine Settings: High, 3.0; Low, 1.4; Time, 1.5; Set Point, 410°F (210°C); Solder, 0.015 to 0.020
Samples 5, 19, and 10 passed visual inspection.
All five samples passed the leak test.

Sample	T_m	T_c	T_c-T_m
Large Connectors			
1	274 (134)	384 (195)	110 (43)
2	254 (123)	385 (196)	131 (55)
3	268 (131)	383 (195)	115 (46)
4	251 (122)	389 (198)	138 (59)
5	255 (124)	386 (197)	131 (55)

Machine Settings: High, 5.5; Low, 2.0; Time, 1.5; Solder, 0.032
All five samples passed the leak test.

because all connectors passed the test. Pretinning the EMR hardware proved highly advantageous to the process because it increased the wetting during induction soldering. Ultrasonic tinning displayed the best pretinning method because of smoothness and uniformity.

It was also discovered that the relationship between solder joint area and surface of induction coil was critical. Setting the EMR hardware-adaptor ring to the correct height provided an acceptable and a more accurate temperature profile with minimum heat applied to the joint.

Figure 17. Solder Being Rolled Into a Ribbon

Because of the high quality joint achieved, a definite time savings, and no adverse side effects, induction soldering of EMR hardware should be implemented.

ACCOMPLISHMENTS

From the beginning of this study, an acceptable solder joint on an EMR shielded connector was defined as a functional solder joint--meaning a continuous joint 360 degrees around and between the connector and adaptor ring, and leakage of less than 20 cubic centimeters per minute through the connector. Of all the heating coils evaluated, one, the step-down flat coil, proved superior to the other heating coils. This coil produces acceptable solder joints, good, repeatable low temperature gradients, and low leakage rates after soldering. EMR-hardware-to-adaptor-ring solder joints were successfully made. This process produced excellent quality solder joints with no adverse side effects and a definite time savings.

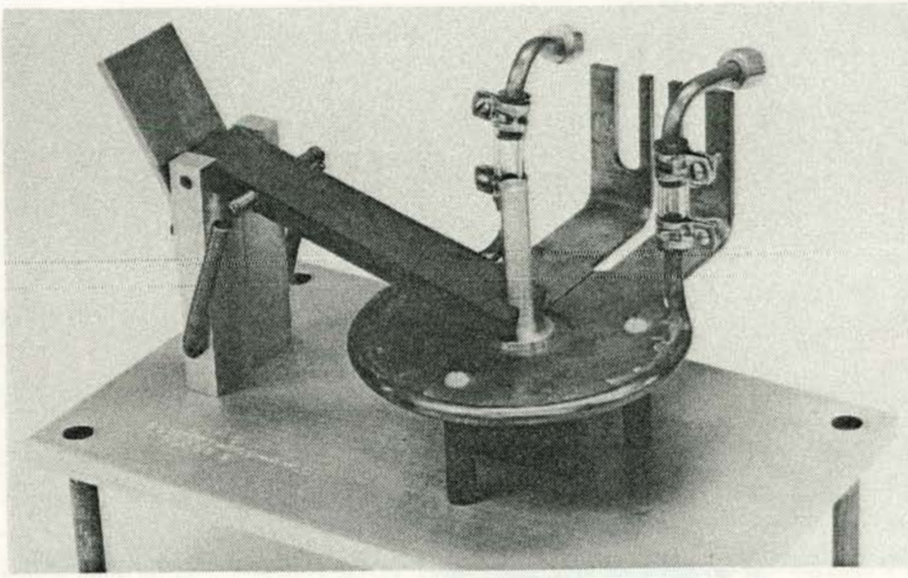

Figure 18. Hardware Holding Device

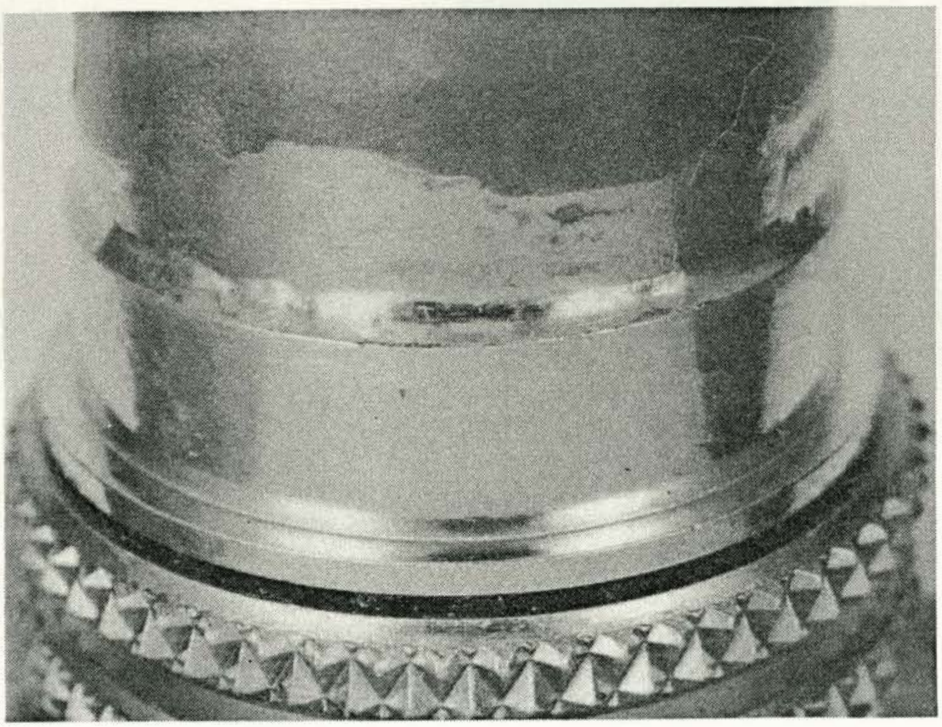

Figure 19. Excellent Joint

Table 3. Infrared Connector Insert Temperature Monitor Data

Sample	Shell Size	Temperatures (°F) (°C) T_c	T_m	Joint Quality
1	10	420 (216)	295 (146)	Excellent
2	10	426 (219)	310 (154)	Excellent
3	10	426 (219)	308 (153)	Excellent
4	10	428 (220)	305 (150)	Excellent
5	10	425 (219)	310 (154)	Excellent
6	15	384 (251)	274 (135)	Excellent
7	15	385 (252)	254 (124)	Good
8	15	383 (251)	268 (131)	Good
9	15	389 (254)	251 (121)	Excellent
10	15	386 (253)	255 (124)	Excellent

Hardware was pretinned; solder was 0.015 to 0.020; all passed post solder leak test.

Table 4. Solder Cup Temperature Check With Thermocouple

Sample	Shell Size	Temperatures (°F) (°C) EMR Solder Joint	Thermocouple Solder Cup
1	15	390 (199)	255 (124)
2	15	395 (201)	257 (126)
3	10	430 (221)	285 (140)
4	10	412 (211)	266 (130)

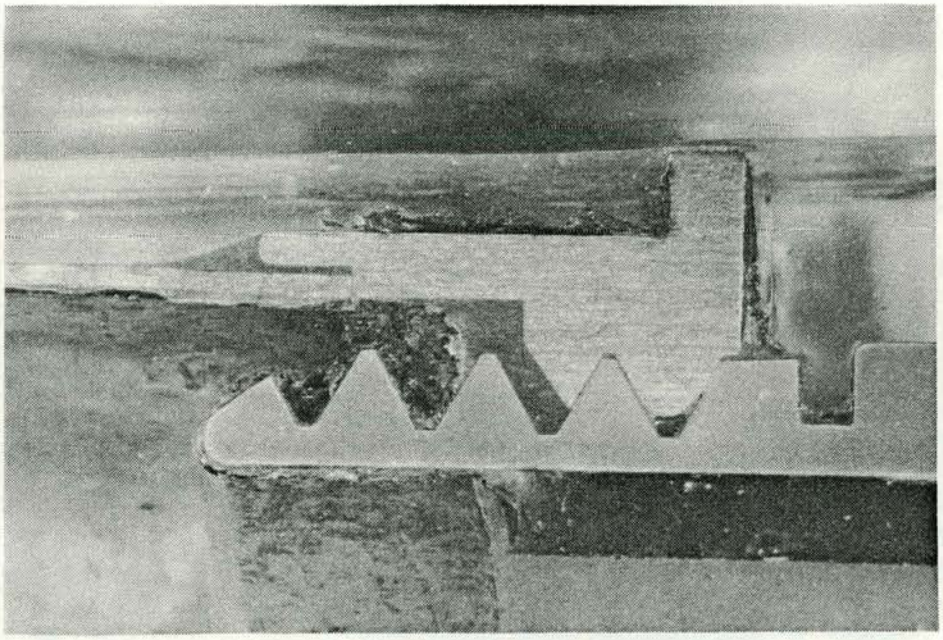

Figure 20. Cross Section of Excellent Joint

Appendix A

TEMPERATURE DIFFERENCES ACROSS CONNECTOR SEALS

		Temperatures (°F) (°C)		
Coil	Connector	T_m	T_c	T_m-T_c
1	10	440 (227)	430 (221)	+ 10 (+ 6)
1	10	419 (216)	443 (229)	- 24 (- 13)
1	10	467 (242)	452 (233)	+ 15 (+ 9)
1	10	425 (219)	408 (208)	+ 17 (+ 11)
1	11	290 (143)	395 (202)	-105 (- 59)
1	11	280 (138)	412 (211)	-132 (- 73)
1	11	312 (155)	448 (231)	-136 (- 76)
1	11	353 (179)	452 (233)	- 99 (- 54)
2	10	423 (218)	467 (242)	- 44 (- 24)
2	10	390 (199)	451 (233)	- 61 (- 34)
2	10	393 (201)	417 (214)	- 24 (- 13)
2	10	417 (214)	415 (213)	+ 2 (+ 1)
2	10	426 (219)	453 (234)	- 27 (- 15)
2	11	320 (160)	451 (233)	-131 (- 73)
2	11	312 (155)	451 (233)	-139 (- 78)
2	11	314 (156)	423 (218)	-109 (- 62)
2	11	308 (153)	447 (231)	-139 (- 78)
2	11	308 (153)	437 (225)	-129 (- 72)
3	10	380 (193)	426 (219)	- 46 (- 26)
3	10	360 (182)	419 (216)	- 59 (- 34)
3	10	380 (193)	455 (235)	- 75 (- 42)
3	10	391 (200)	435 (224)	- 44 (- 24)
3	10	371 (189)	435 (224)	- 64 (- 35)
3	11	315 (157)	430 (221)	-115 (- 64)
3	11	302 (150)	452 (233)	-152 (- 83)
3	11	308 (153)	420 (216)	-112 (- 63)
3	11	295 (146)	410 (210)	-115 (- 64)
3	11	308 (153)	430 (221)	-122 (- 68)
4	10	371 (189)	430 (221)	- 59 (- 32)
4	10	375 (192)	450 (232)	- 75 (- 40)
4	10	393 (201)	458 (236)	- 65 (- 35)
4	10	371 (189)	446 (230)	- 75 (- 41)
4	10	363 (184)	432 (222)	- 69 (- 38)
4	11	308 (153)	453 (234)	-145 (- 81)
4	11	315 (157)	473 (245)	-158 (- 88)
4	11	280 (138)	448 (231)	-168 (- 93)
4	11	267 (131)	490 (254)	-223 (-123)

Coil	Connector	Temperatures (°F) (°C) T_m	T_c	$T_m - T_c$
5	10	401 (205)	446 (230)	- 45 (- 25)
5	10	387 (197)	419 (216)	- 32 (- 19)
5	10	378 (192)	448 (231)	- 70 (- 39)
5	10	387 (197)	426 (224)	- 39 (- 27)
5	10	404 (206)	463 (240)	- 59 (- 34)
5	11	313 (156)	421 (217)	-108 (- 61)
5	11	312 (155)	421 (217)	-109 (- 62)
5	11	297 (147)	444 (229)	-147 (- 97)
5	11	325 (163)	410 (210)	- 85 (- 47)
5	11	291 (144)	470 (243)	-179 (-102)
6	10	355 (180)	531 (278)	-176 (- 98)
6	10	508 (264)	528 (275)	- 20 (- 11)
6	10	548 (286)	520 (271)	+ 28 (+ 15)
6	10	460 (238)	562 (294)	-102 (- 56)
6	10	500 (260)	512 (267)	- 12 (- 7)
6	11	476 (246)	495 (257)	- 19 (- 11)
6	11	340 (171)	508 (264)	-168 (- 93)
6	11	471 (244)	510 (266)	- 39 (- 22)
6	11	482 (250)	506 (263)	- 24 (- 13)
6	11	502 (261)	506 (263)	- 4 (- 2)
7	10	380 (193)	423 (218)	- 43 (- 25)
7	10	400 (204)	437 (225)	- 37 (- 21)
7	10	392 (200)	447 (231)	- 55 (- 31)
7	10	392 (200)	434 (223)	- 42 (- 23)
7	10	408 (208)	432 (222)	- 24 (- 14)

Appendix B

SOLDER LEAK TESTS

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 1, Connector 10		
1	$<1 \times 10^{-8}$	0.58
2	>100	0.2
3		
4	$<1 \times 10^{-8}$	3.9
5	$<1 \times 10^{-8}$	0.5
6	38	0.6
7	$<1 \times 10^{-8}$	3.8
8	$<1 \times 10^{-8}$	1.3
9	1.3	2.3
10	$<1 \times 10^{-8}$	0.13
11	$<1 \times 10^{-8}$	3.1
12	$<1 \times 10^{-8}$	6.3
13	$<1 \times 10^{-8}$	1.5
14	$<1 \times 10^{-8}$	5.0
15	$<1 \times 10^{-8}$	2.4
16	$<1 \times 10^{-8}$	7.3
17	$<1 \times 10^{-8}$	0.45
18	$<1 \times 10^{-8}$	58.0
19	$<1 \times 10^{-8}$	0.0
20	$<1 \times 10^{-8}$	1.0
21	4.4	0.24
22	13	0.055
23	$<1 \times 10^{-8}$	0.03
24	$<1 \times 10^{-8}$	0.33
25	$<1 \times 10^{-8}$	0.14

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 2, Connector 10		
26	<1 x 10^{-8}	<1 x 10^{-8}
27	<1 x 10^{-8}	<1 x 10^{-8}
28	<1 x 10^{-8}	1.4
29	<1 x 10^{-8}	2.0
30	<1 x 10^{-8}	<1 x 10^{-8}
31	<1 x 10^{-8}	<1 x 10^{-8}
32	>100	>100
33	<1 x 10^{-8}	<1 x 10^{-8}
34	57.0	>100
35	<1 x 10^{-8}	<1 x 10^{-8}
36	<1 x 10^{-8}	<1 x 10^{-8}
37	8.0	>100
38	<1 x 10^{-8}	<1 x 10^{-8}
39	2.5	2.8
40	2.6	1.1
41	22.0	22.0
42	1.2	1.6
43	1.5	3.1
44	4.8	3.2
45	2.2	1.2
46	.2	1.1
47	3.0	2.7
48	3.0	1.6
49	1.2	1.2
50	3.8	2.5

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 3, Connector 10		
51	2.0	1.8
52	1.0	1.1
53	1.0	4.4
54	1.4	2.8
55	2.8	1.2
56	1.5	1.1
57	5.5	3.1
58	3.5	1.8
59	75.0	>100
60	4.0	4.6
61	40.0	22.0
62	9.0	9.5
63	30.0	30.0
64	3.4	1.6
65	2.8	1.4
66	4.0	2.5
67	2.8	1.6
68	4.7	2.9
69	3.6	3.3
70	1.7	1.8
71	4.5	3.3
72	2.2	3.3
73	10.0	7.3
74	1.2	1.4
75	0.4	1.1

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 4, Connector 10		
76	0.4	0.3
77	1.8	<1 x 10^{-8}
78	1.4	0.8
79	2.6	0.6
80	1.5	<1 x 10^{-8}
81	15.0	17.0
82	3.2	2.2
83	5.0	4.9
84	3.6	4.2
85	1.5	2.6
86	1.5	3.1
87	1.4	4.4
88	3.6	8.0
89	2.4	2.0
90	1.6	3.0
91	1.8	7.0
92	3.4	4.5
93	2.4	3.0
94	3.6	5.0
95	10.0	12.5
96	1.7	3.2
97	10.0	11.0
98	4.0	6.0
99	3.5	3.2
100	1.2	3.0

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 5, Connector 10		
101	1.5	4.8
102	1.5	3.0
103	0.2	3.0
104	0.5	0.8
105	2.4	7.1
106	1.5	8.0
107	3.5	8.0
108	1.2	4.0
109	1.2	9.0
110	1.8	8.0
111	2.0	6.0
112	7.0	9.8
113	2.0	6.8
114	8.0	13.0
115	2.1	3.1
116	1.3	2.8
117	7.0	4.1
118	7.0	3.0
119	$<1 \times 10^{-8}$	3.2
120	2.5	3.1
121	5.5	6.0
122	4.0	9.6
123	1.5	5.8
124	2.2	2.1
125	0.6	2.8

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 6, Connector 10		
126	11.0	3.8
127	>100	2.1
128	3.0	1.5
129	4.5	4.2
130	3.2	2.3
131	3.0	1.9
132	1.6	Gross Leak Ring
133	1.6	0.8
134	6.6	Gross Leak Ring
135	$<1 \times 10^{-8}$	0.9
136	$<1 \times 10^{-8}$	2.6
137	>100	>100
138	1.5	0.99
139	0.2	3.0
140	>100	Gross Leak
141	$<1 \times 10^{-8}$	0.99
142	0.4	1.4
143	0.2	1.6
144	0.3	1.5
145	0.3	0.99
146	0.5	0.66
147	>100	0.43
148	0.3	0.80
149	$<1 \times 10^{-8}$	1.5
150	0.4	1.8

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 7, Connector 10		
151	<1 x 10^{-8}	4.2
152	0.2	3.4
153	<1 x 10^{-8}	3.3
154	0.4	3.5
155	0.3	4.8
156	>100	2.1
157	<1 x 10^{-8}	2.3
158	0.3	5.0
159	0.2	3.0
160	1.6	4.9
161	0.3	3.0
162	>100	>100
163	47.0	40.0
164	0.2	4.2
165	0.4	4.1
166	0.2	3.4
167	<1 x 10^{-8}	4.4
168	<1 x 10^{-8}	4.0
169	0.4	4.1
170	<1 x 10^{-8}	3.2
171	0.3	4.7
172	0.4	3.1
173	0.2	4.1
174	30.0	>100
175	0.4	Gross Leak

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 8, Connector 10		
176	<0.1	
177	<0.1	
178	<0.1	
179	>100	
180	>100	
181	<0.1	
182	<0.1	
183	13.0	
184	<0.1	
185	<0.1	
186	<0.1	
187	<0.1	
188	<0.1	
189	>100	
190	<0.1	
191	40.0	
192	>0.1	
193	0.15	
194	>0.1	
195	>0.1	
196	>0.1	
197	>0.1	
198	>0.1	
199	>0.1	
200	>0.1	

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 9, Connector 10		
201	50.0	
202	<0.1	
203	<0.1	
204	30.0	
205	50.0	
206	<0.1	
207	>100	
208	>100	
209	<0.1	
210	<0.1	
211	13.0	
212	7100	
213	10.0	
214	<0.1	
215	<0.1	
216	10.0	
217	<0.1	
218	30.0	
219	<0.1	
220	<0.1	
221	<0.1	
222	>100	
223	<0.1	
224	<0.1	
225	1.0	

Serial Number	Test Results (10^{-7} cm^3/s) Pre-Solder	Post Solder
Coil 1, Connector 11		
1	<1 x 10^{-8}	4.7
2	>100	7.4
3	<1 x 10^{-8}	1.4
4	<1 x 10^{-8}	Damaged Threads
5	<1 x 10^{-8}	8.4
6	<1 x 10^{-8}	Gross Leak
7	<1 x 10^{-8}	2.8
8	80.0	11.0
9	<1 x 10^{-8}	1.1
10	<1 x 10^{-8}	0.45
11	60.0	4.5
12	<1 x 10^{-8}	0.35
13	>100	5.0
14	>100	44.0
15	<1 x 10^{-8}	3.0
16	<1 x 10^{-8}	4.5
17	<1 x 10^{-8}	0.4
18	<1 x 10^{-8}	0.5
19	<1 x 10^{-8}	3
20	<1 x 10^{-8}	0.3
21	<1 x 10^{-8}	3.5
22	80.	1.2
23	<1 x 10^{-8}	3.0
24	<1 x 10^{-8}	4.9
25	<1 x 10^{-8}	0.7

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 2, Connector 11		
26	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
27	$<1 \times 10^{-8}$	4.8
28	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
29	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
30	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
31	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
32	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
33	$<1 \times 10^{-8}$	2.3
34	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
35	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
36	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
37	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
38	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
39	$<1 \times 10^{-8}$	10.0
40	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
41	40.0	>100
42	1.0	20.0
43	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
44	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
45	$<1 \times 10^{-8}$	3.0
46	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
47	>100	>100
48	>100	>100
49	>100	>100
50	$<1 \times 10^{-8}$	>100

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 3, Connector 11		
51	45.0	80.0
52	<1 x 10^{-8}	<1 x 10^{-8}
53	<1 x 10^{-8}	<1 x 10^{-8}
54	<1 x 10^{-8}	<1 x 10^{-8}
55	<1 x 10^{-8}	<1 x 10^{-8}
56	<1 x 10^{-8}	<1 x 10^{-8}
57	20.0	>100
58	<1 x 10^{-8}	>100
59	<1 x 10^{-8}	60.0
60	1.8	46.0
61	<1 x 10^{-8}	<1 x 10^{-8}
62	<1 x 10^{-8}	<1 x 10^{-8}
63	<1 x 10^{-8}	<1 x 10^{-8}
64	<1 x 10^{-8}	80.0
65	<1 x 10^{-8}	39.0
66	<1 x 10^{-8}	0.1
67	<1 x 10^{-8}	70.0
68	80.0	>100
69	70.0	>100
70	<1 x 10^{-8}	95.0
71	<1 x 10^{-8}	<1 x 10^{-8}
72	>100	>100
73	>100	<1 x 10^{-8}
74	<1 x 10^{-8}	<1 x 10^{-8}
75	<1 x 10^{-8}	<1 x 10^{-8}

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 4, Connector 11		
76	>100	>100
77	>100	>100
78	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
79	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
80	$<1 \times 10^{-8}$	1.5
81	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
82	0.25	>100
83	>100	>100
84	80.0	>100
85	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
86	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
87	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
88	$<1 \times 10^{-8}$	2.4
89	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
90	>100	>100
91	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
92	$<1 \times 10^{-8}$	3.8
93	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
94	$<1 \times 10^{-8}$	3.0
95	$<1 \times 10^{-8}$	2.9
96	$<1 \times 10^{-8}$	1.2
97	$<1 \times 10^{-8}$	1.6
98	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
99	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
100	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 5, Connector 11		
101	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
102	$<1 \times 10^{-8}$	2.8
103	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
104	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
105	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
106	70.0	>100
107	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
108	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
109	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
110	18.0	>100
111	>100	>100
112	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
113	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
114	$<1 \times 10^{-8}$	4.0
115	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
116	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
117	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
118	>100	>100
119	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
120	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
121	$<1 \times 10^{-8}$	25.0
122	$<1 \times 10^{-8}$	>100
123	$<1 \times 10^{-8}$	70.0
124	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
125	$<1 \times 10^{-8}$	26.0

Serial Number	Test Results (10^{-7} cm^3/s) Pre-Solder	Post Solder
Coil 6, Connector 11		
126	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
127	55.0	>100
128	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
129	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
130	>100	>100
131	$<1 \times 10^{-8}$	5.0
132	>100	>100
133	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
134	1.0	38.0
135	40.0	4.1
136	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
137	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
138	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
139	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
140	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
141	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
142	40.0	7.0
143	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
144	>100	>100
145	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
146	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
147	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
148	2.0	$<1 \times 10^{-8}$
149	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$
150	$<1 \times 10^{-8}$	$<1 \times 10^{-8}$

Serial Number	Test Results (10^{-7} cm^3/s)	
	Pre-Solder	Post Solder
Coil 7, Connector 11		
151	7.0	
152	$<1 \times 10^{-8}$	
153	$<1 \times 10^{-8}$	
154	$<1 \times 10^{-8}$	
155	$<1 \times 10^{-8}$	
156	$<1 \times 10^{-8}$	
157	$<1 \times 10^{-8}$	
158	$<1 \times 10^{-8}$	
159	$<1 \times 10^{-8}$	
160	$<1 \times 10^{-8}$	
161	>100	
162	$<1 \times 10^{-8}$	
163	$<1 \times 10^{-8}$	
164	$<1 \times 10^{-8}$	
165	$<1 \times 10^{-8}$	
166	$<1 \times 10^{-8}$	
167	$<1 \times 10^{-8}$	
168	$<1 \times 10^{-8}$	
169	$<1 \times 10^{-8}$	
170	$<1 \times 10^{-8}$	
171	$<1 \times 10^{-8}$	
172	>100	
173	$<1 \times 10^{-8}$	
174	$<1 \times 10^{-8}$	
175		

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