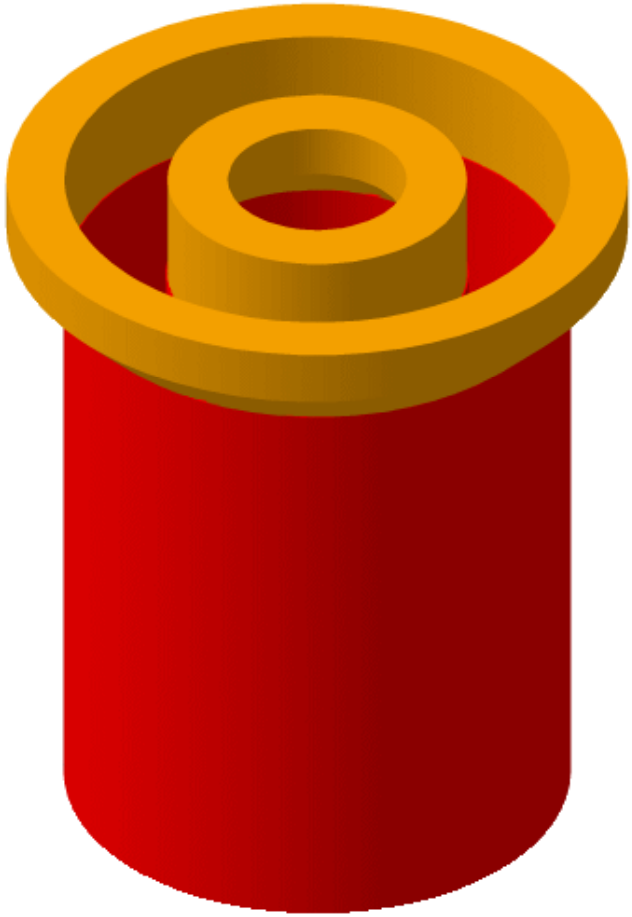
APUL – Current Lead Remote Soldering Test Report

Ten Full Test Cycles
(Twenty Heat Cycles)

Solder Volume Analysis

- Min Weight = 32.6 g
- Max Weight = 43.9 g
- Maximum overflow allowed = 112.6 g
- Specify 44 g Solder
  - Maximum overflow produced = 11 g
  - Overflow 10% filled
  - 20% filled if all solder flows into (1) groove



Indalloy 1E Solder Wire Used

Solder Wire (52In/48Sn)

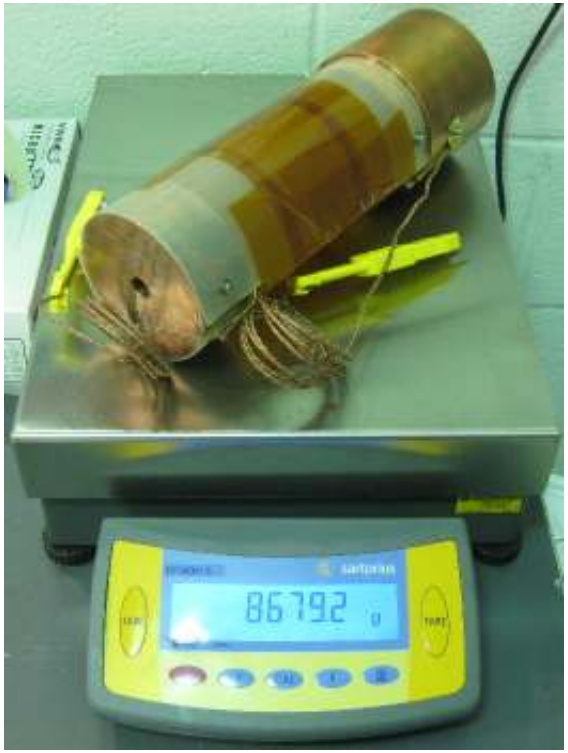
Formed to Fit

Starting System Data

Starting System: 4,605.4 + 8,679.2 + 44.0 = 13,328.6 g

Upper Assembly

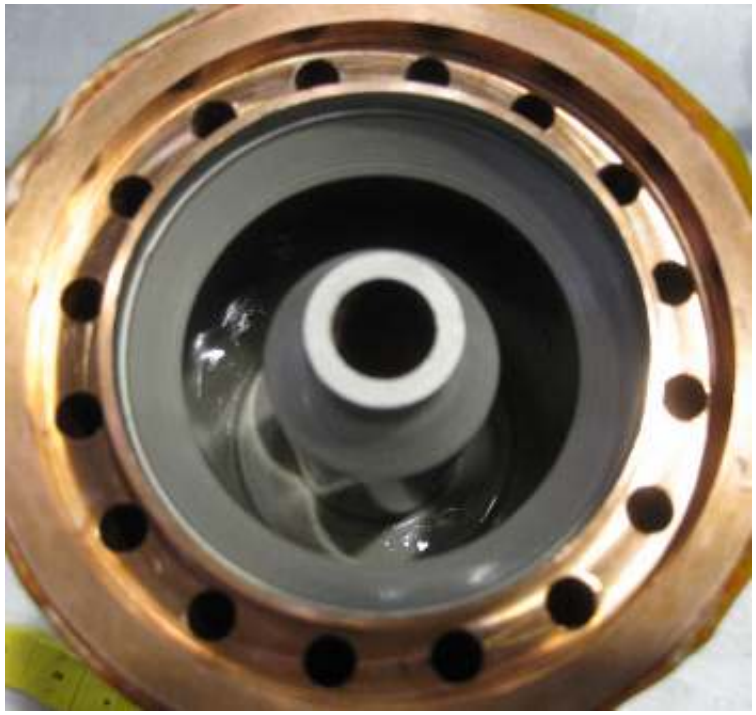
Lower Assembly



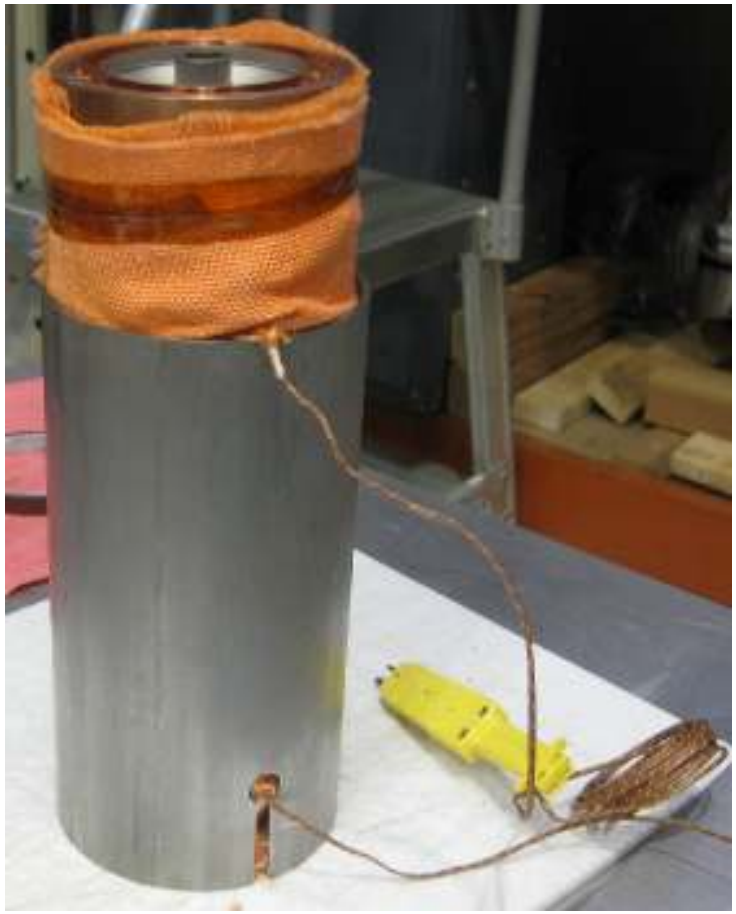
Starting Diameter: 53.44 mm avg. (plated)

Assemblies Cleaned and Fluxed

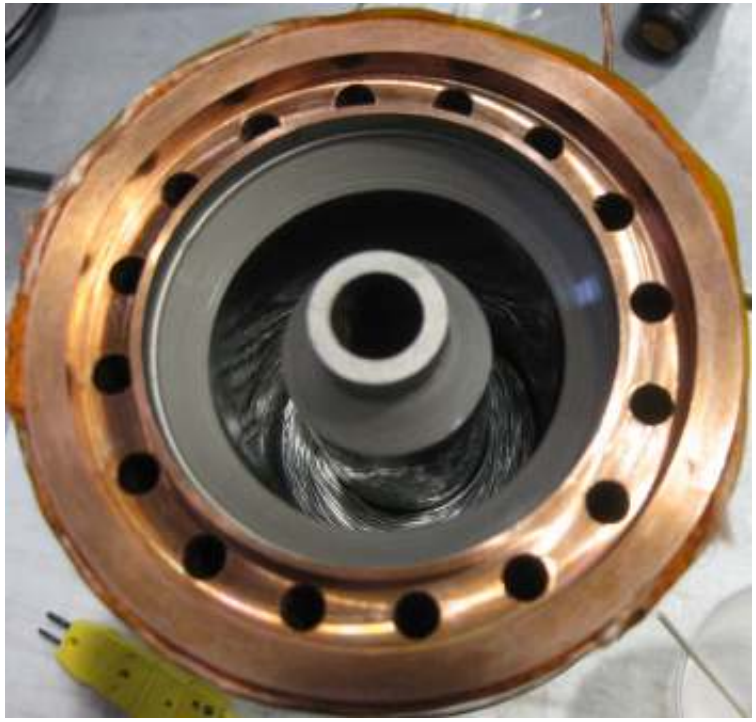
Indalloy 4OA, organic liquid resin, water soluble



Lower Assembly Ready

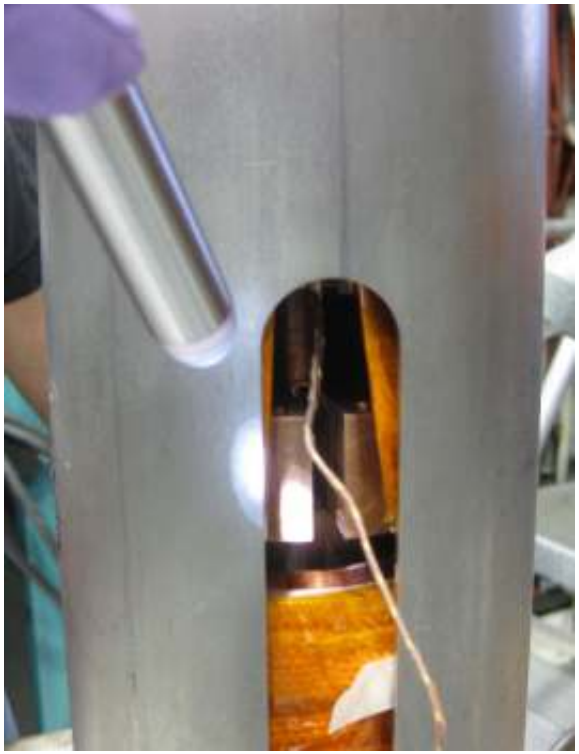


Two layers of insulation simulates G-10 tube – solder a snug fit



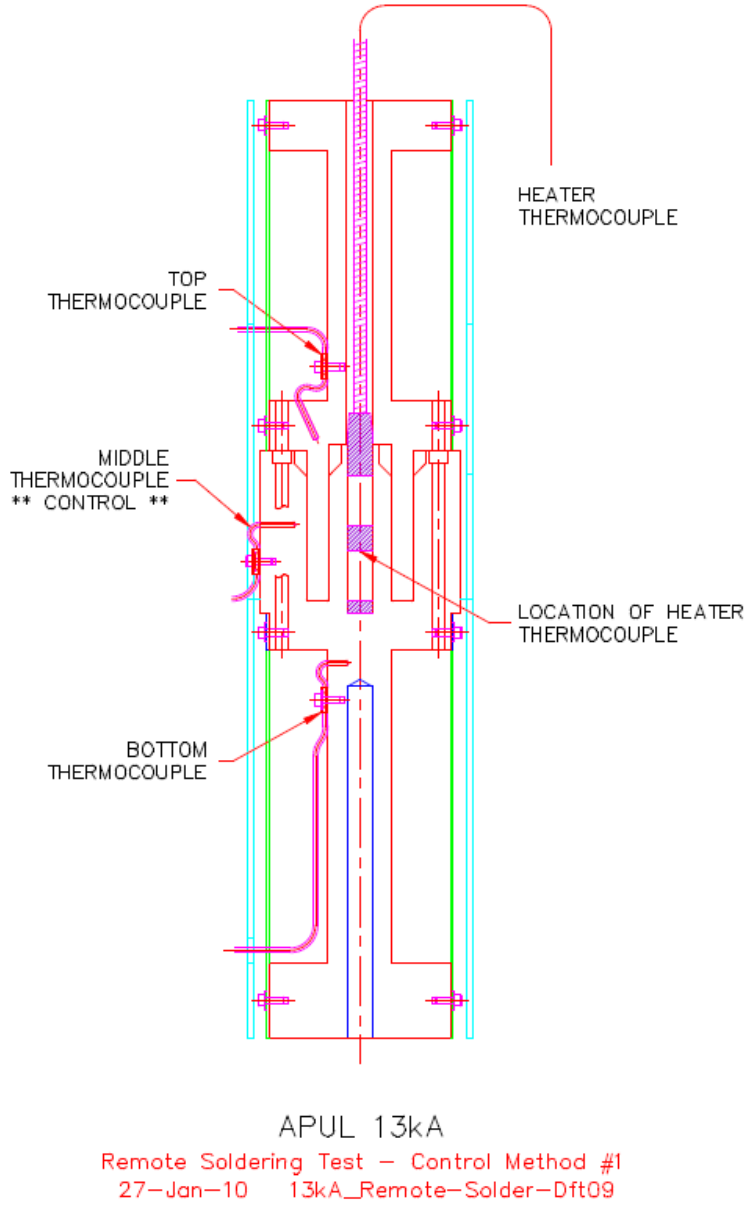
Upper Assembly Insertion

Easy sliding fit, bottomed out on solder, ~10mm gap



Control Method #1

- Surest result
- Heater temperature not restricted
- Shortest time cycle
- Most efficient
- Safest – copper temperature will never go above set point



Heat Cycle #1 / 1st Separate Cycle

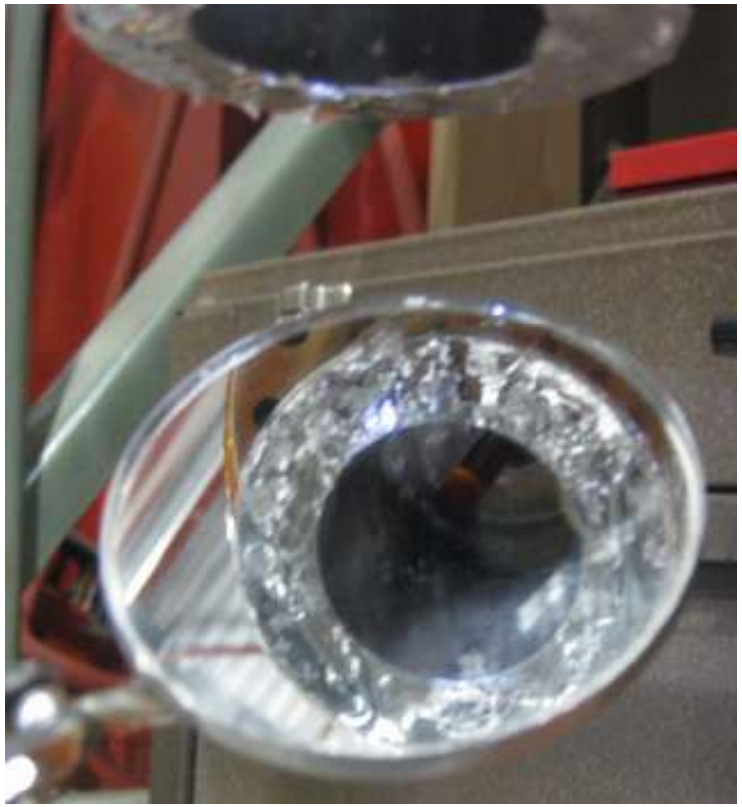
Time	Control	Heater	Bott Tc	Top Tc	Comment
12:53	22	22	22	21	Heater on
12:58	72	316	73	51	
1:02	108	345	107	85	Flux visible
1:03	119	310	111	104	Liquidus
1:07	150	329	138	141	
1:11	160	275	150	154	Heater off
1:14	150	160	143	147	Remove heater
1:15	145	135	140	143	Separate
1:28	115	43	113	106	Solidus

18 min @ 311 °C Pre-Tin, Control Method #1 25-Jan-10

First Separation

Solder molten

Solder molten



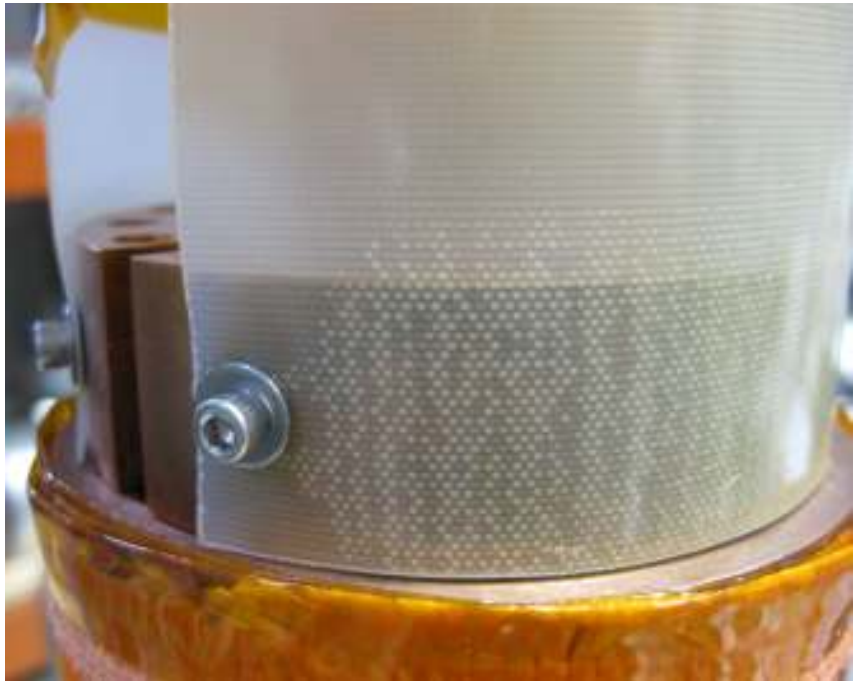
First Separation

Solder solidified
flux cleaned

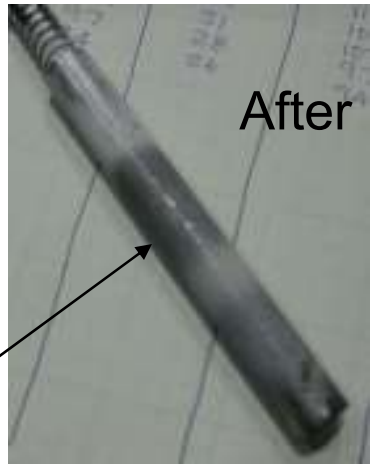
Solder solidified
flux not cleaned

First Separation

G-10 discoloration,
but no scorching



Boron Nitride spray coating



At 160° C, heater easily removed

First Separation – System Data

System: 4,607.3 + 8,721.3 = 13,328.6 - 13,328.6 = 0.0 g loss

4607.3 - 4605.4 = 1.9 g Solder

8721.3 - 8679.2 = 42.1 g Solder

Diameter: 53.48 avg. - 53.44 plated = 0.020 mm (.0008”) / side

Fluxless Soldering – First Join Cycle

- Fixture re-assembled
  - Flux residue thoroughly cleaned
  - Minimal force and slight rocking to bottom out
  - ~5 mm gap (previously ~10 mm gap with wire)
- Same heat cycle
  - Gap closed at 114 - 118° C
  - Molten solder visible
- All subsequent cycles are Fluxless using the original solder volume over and over

Heat Cycle #2 / 1st Join Cycle

Time	Control	Heater	Bott Tc	Top Tc	Comment
9:21	20	19	19	20	Heater on
9:24	44	319	47	37	
9:28	88	351	86	75	
9:31	114	371	109	99	Liquidus
9:35	149	361	136	141	
9:40	160	305	148	153	Heater off
9:42	150	160	142	147	Remove heater
9:50	131	73	127	129	
10:00	117	40	114	115	Solidus

18 min @ 335 °C Control Method #1 26-Jan-10

Heat Cycle #3 / 2nd Separate Cycle

Time	Control	Heater	Bott Tc	Top Tc	Comment
8:13	19	19	19	18	Heater on
8:16	49	270	43	44	
8:20	90	299	81	83	
8:23	117	321	105	108	Liquidus
8:27	148	345	134	139	
8:31	160	285	148	154	Heater off
8:33	153	159	144	149	Remove heater
8:35	146	136	139	143	Separate
8:46	117	56	114	107	Solidus

18 min @ 302 °C Control Method #1 28-Jan-10

Second Separation

No change in G-10 discoloration, some solder degradation?

Second Separation – System Data

System: 4,607.8 + 8,720.4 = 13,328.2 - 13,328.6 = 0.4 g loss

4607.8 - 4605.4 = 2.4 g Solder

8720.4 - 8679.2 = 41.2 g Solder

Diameter: 53.53 avg. - 53.44 plated = 0.045 mm (.0018”) / side

Heat Cycle #4 / 2nd Join Cycle

Time	Control	Heater	Bott Tc	Top Tc	Comment
1:40	20	19	20	19	Heater on
1:43	46	330	51	30	
1:47	92	361	92	62	
1:50	120	340	113	100	Liquidus
1:54	148	354	139	139	
1:58	160	294	152	153	Heater off
2:01	151	154	145	147	Remove heater
2:06	138	108	134	136	
2:15	121	57	118	120	Solidus

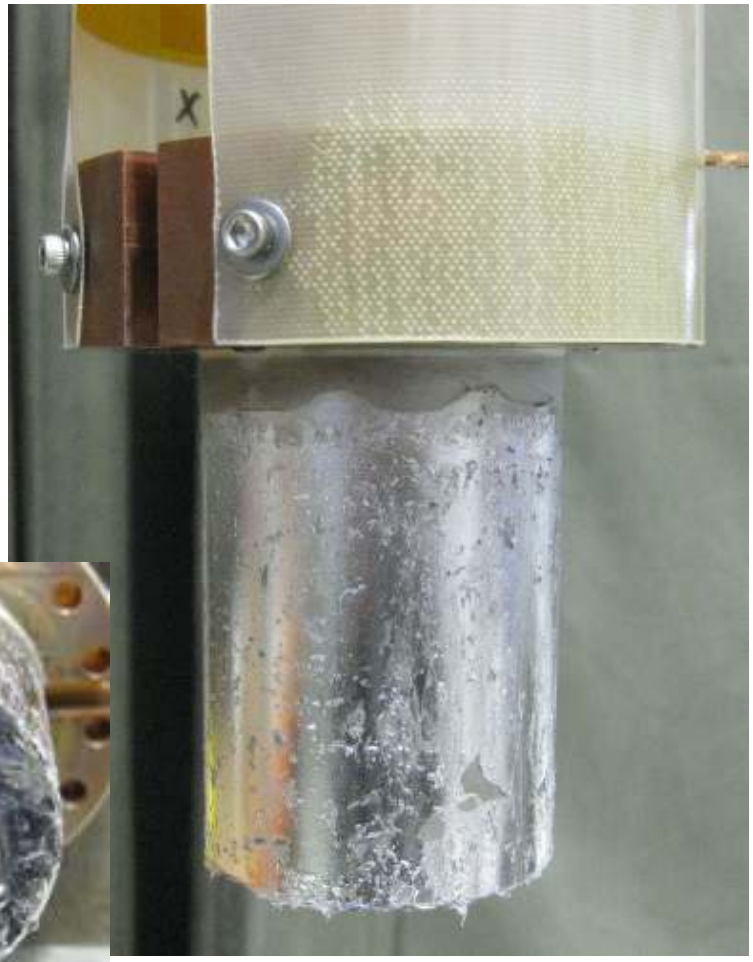
18 min @ 335 °C Control Method #1 28-Jan-10

Heat Cycle #5 / 3rd Separate Cycle

Time	Control	Heater	Bott Tc	Top Tc	Comment
8:20	19	19	19	18	Heater on
8:23	52	260	48	46	
8:27	90	291	83	83	
8:30	117	314	109	109	Liquidus
8:34	148	336	138	139	
8:38	160	280	151	154	Heater off
8:40	155	161	147	151	Remove heater
8:46	137	90	133	135	Separate
9:00	112	35	111	100	Solidus

18 min @ 294 °C Control Method #1 29-Jan-10

Third Separation



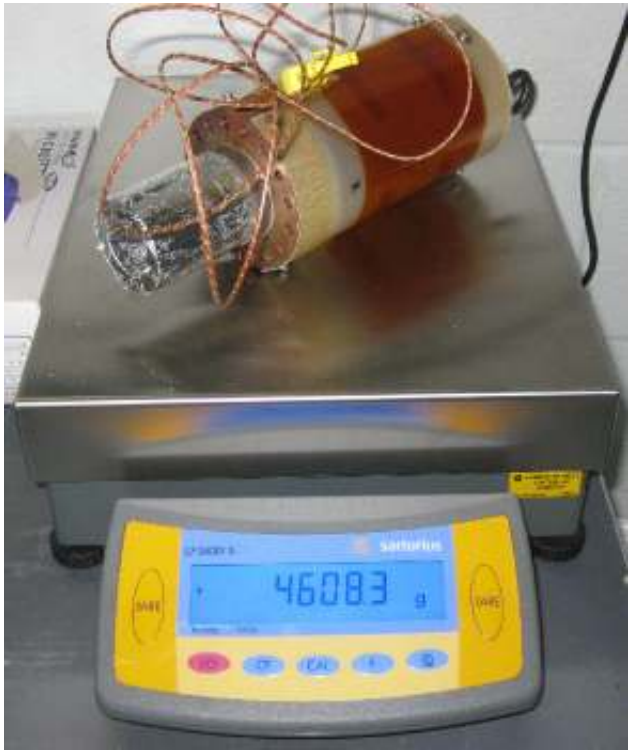
No change in G-10 discoloration, no change in solder degradation

Third Separation – System Data

System: 4,608.3 + 8,719.9 = 13,328.2 - 13,328.6 = 0.4 g loss

4608.3 - 4605.4 = 2.9 g Solder

8719.9 - 8679.2 = 40.7 g Solder



Diameter: 53.55 avg. - 53.44 plated = 0.055 mm (.0022”) / side

Heat Cycle #6 / 3rd Join Cycle

Time	Control	Heater	Bott Tc	Top Tc	Comment
1:32	21	20	20	20	Heater on
1:35	49	326	53	37	
1:39	91	356	90	70	
1:42	121	341	112	104	Liquidus
1:46	150	354	137	140	
1:50	160	287	150	154	Heater off
1:53	152	156	145	149	Remove heater
2:00	134	79	131	132	
2:11	119	39	117	117	Solidus

18 min @ 333 °C Control Method #1 29-Jan-10

Heat Cycle #7 / 4th Separate Cycle

Time	Control	Heater	Bott Tc	Top Tc	Comment
8:03	19	19	19	18	Heater on
8:06	50	281	45	45	
8:10	91	308	82	83	
8:13	117	329	107	108	Liquidus
8:17	149	350	136	139	
8:21	160	290	149	154	Heater off
8:23	154	161	146	150	Remove heater
8:26	144	116	138	141	Separate
8:40	117	42	115	104	Solidus

18 min @ 311 °C Control Method #1 01-Feb-10

Fourth Separation

No change in G-10 discoloration, little change in solder degradation

Fourth Separation – System Data

System: 4,608.0 + 8,720.2 = 13,328.2 - 13,328.6 = 0.4 g loss

4608.0 - 4605.4 = 2.6 g Solder

8720.2 - 8679.2 = 41.0 g Solder

Diameter: 53.47 avg. - 53.44 plated = 0.015 mm (.0006”) / side

Heat Cycle #8 / 4th Join Cycle

Time	Control	Heater	Bott Tc	Top Tc	Comment
1:51	21	21	21	20	Heater on
1:54	48	347	52	36	
1:58	92	361	90	72	
2:01	121	349	112	106	Liquidus
2:05	150	359	138	140	
2:09	160	295	150	154	Heater off
2:11	155	163	147	151	Remove heater
2:19	133	84	129	130	
2:38	118	48	117	116	Solidus

18 min @ 343 °C Control Method #1 01-Feb-10

CM#1 Heat Cycle Analysis

Join Cycles

- 18 Data Points (17 min.)
  - #1 = 334.8
  - #2 = 334.2
  - #3 = 332.7
  - #4 = 343.3
  - Average = 336 °C

Use in CM#2 Heat cycles #9 and #10

Separate Cycles

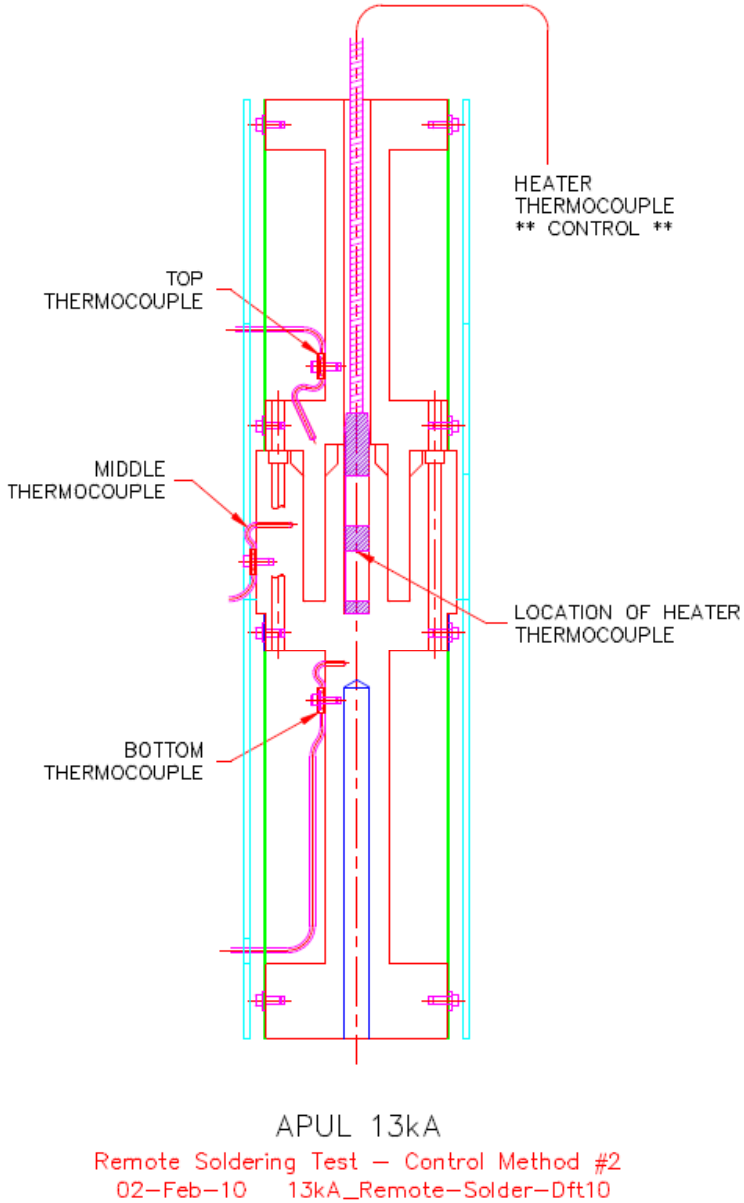
- 18 Data Points (17 min.)
  - #1 = 311.1
  - #2 = 302.1
  - #3 = 293.9
  - #4 = 310.6
  - Average = 305 °C

Use in CM#2 Heat cycles #11 and #12

- Use 330 °C for heat cycles #13 and #14
  - Based on times for heat cycles #9 thru #12, interpolated between highlighted values

Control Method #2

- Attempt to mimic CM#1 using thermocouple in heater as the control
- Attempt to maintain CM#1 cycle time
- Heater temperature set to CM#1 average
- More risky – cycle time must be controlled



Heat Cycle #9 / 5th Separate Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
8:23	20	19	19	19	Heater on
8:26	252	46	42	41	
8:30	277	88	79	80	
8:34	303	121	111	113	Liquidus
8:37	320	143	133	136	
8:39:30	330	160	149	152	Heater off
8:41	220	165	155	158	Max. overshoot
8:45	130	148	142	146	Separate
9:00	46	117	116	100	Solidus

Control @ 336 °C for 16.5 min Control Method #2 02-Feb-10

Fifth Separation

No change in G-10 discoloration.
Little change in solder degradation.
Removal doesn't feel as smooth.

Fifth Separation – System Data

System: 4,608.7 + 8,719.5 = 13,328.2 - 13,328.6 = 0.4 g loss

4608.7 - 4605.4 = 3.3 g Solder

8719.5 - 8679.2 = 40.3 g Solder

Diameter: 53.50 avg. - 53.44 plated = 0.030 mm (.0012”) / side

Heat Cycle #10 / 5th Join Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
1:40	22	22	22	21	Heater on
1:43	307	43	47	34	
1:48	332	96	94	77	
1:51	321	119	112	104	Liquidus
1:55	335	148	140	140	
1:57:30	336	160	152	152	Heater off
1:59	178	165	157	158	Max. overshoot
2:09	80	132	130	131	
2:20	43	118	117	117	Solidus

Control @ 336 °C for 17.5 min Control Method #2 02-Feb-10

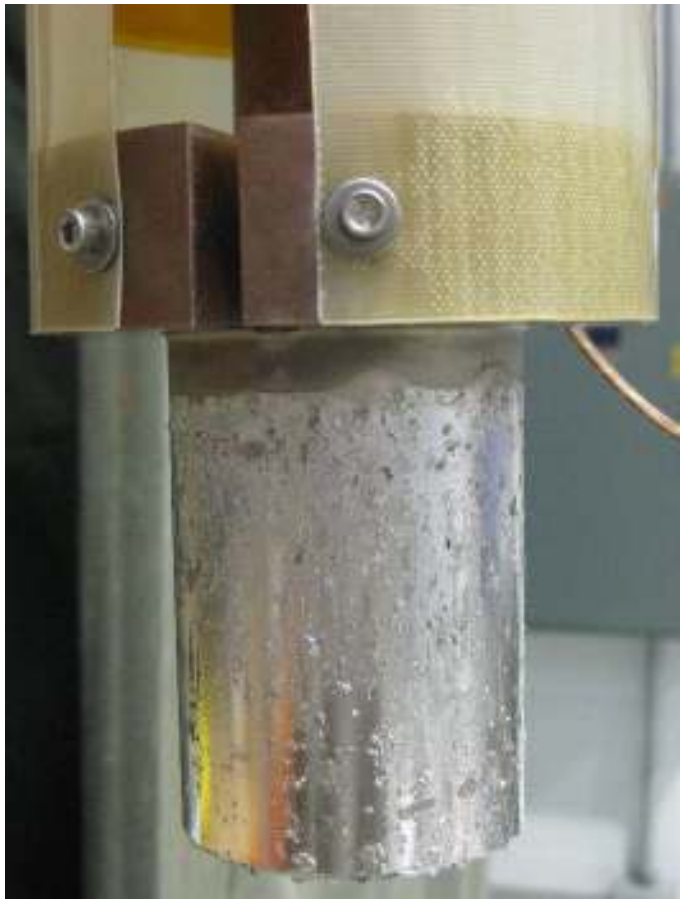
Heat Cycle #11 / 6th Separate Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
8:06	20	19	19	19	Heater on
8:09	269	46	43	41	
8:13	290	87	81	81	
8:17	302	118	111	111	Liquidus
8:22	305	143	136	136	
8:27:15	305	160	154	155	Heater off
8:28	256	161	156	156	Max. overshoot
8:31	141	151	147	149	Separate
8:46	42	118	118	100	Solidus

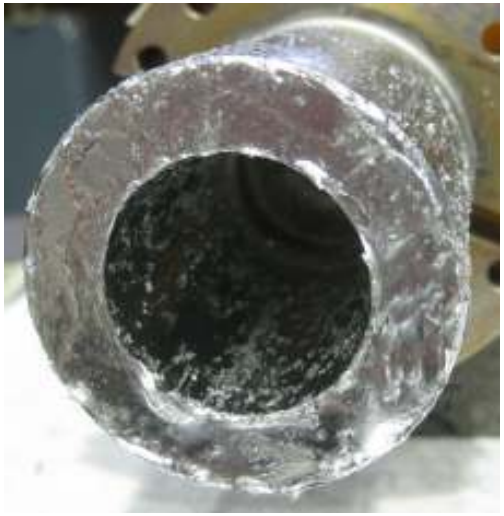
Control @ 305 °C for 21.3 min Control Method #2 04-Feb-10

Sixth Separation

No change in G-10 discoloration.
Solder degradation becoming
more pronounced.



Sixth Separation



More solder sticking to end of upper section. Gritty feel upon removal. Scoring in upper section film. Dark deposits on rim of cup.

Sixth Separation – System Data

System: 4,609.5 + 8,718.7 = 13,328.2 - 13,328.6 = 0.4 g loss

4609.5 - 4605.4 = 4.0 g Solder

8718.7 - 8679.2 = 39.5 g Solder

Diameter: 53.49 avg. - 53.44 plated = 0.025 mm (.0010”) / side

Heat Cycle #12 / 6th Join Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
1:32	21	21	21	20	Heater on
1:36	297	53	55	37	
1:42	304	97	95	74	
1:47	297	119	112	109	Liquidus
1:54	310	148	139	142	
1:58:00	298	160	151	155	Heater off
1:59	178	165	157	158	Max. overshoot
2:08	93	140	137	139	
2:24	37	118	117	117	Solidus

Control @ 305 °C for 26.0 min Control Method #2 04-Feb-10

Heat Cycle #13 / 7th Separate Cycle

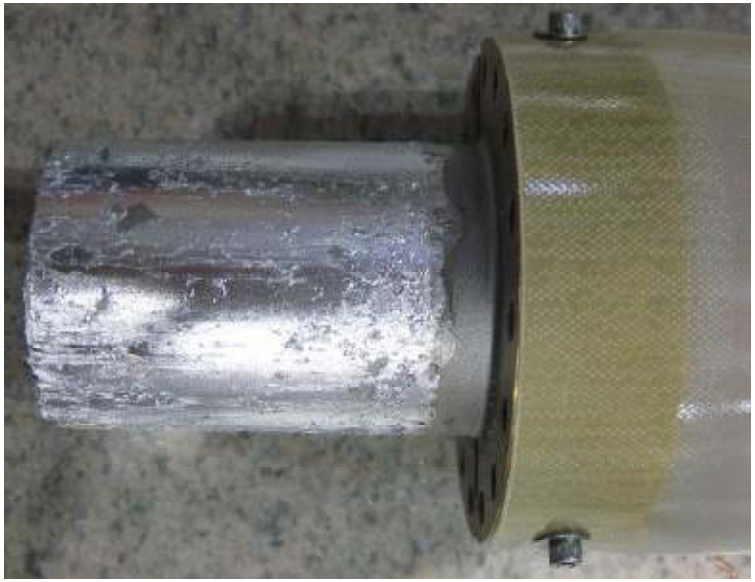
Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
8:10	20	20	20	19	Heater on
8:13	273	47	43	41	
8:17	288	89	80	81	
8:21	314	122	112	115	Liquidus
8:24	325	144	132	136	
8:27:00	329	160	149	153	Heater off
8:28	226	161	151	156	Max. overshoot
8:31	139	149	142	147	Separate
8:43	51	118	117	108	Solidus

Control @ 330 °C for 17.0 min Control Method #2 05-Feb-10

Seventh Separation

Did NOT experience gritty feel. Solder film looks as good as much earlier separations. Fewer dark deposits on rim of cup.

Seventh Separation



No change in G-10 discoloration. Scoring in upper section film less pronounced. Same amount of solder sticking to end of upper section.

Seventh Separation – System Data

System: 4,609.3 + 8,718.7 = 13,328.0 - 13,328.6 = 0.6 g loss

4609.3 - 4605.4 = 3.9 g Solder

8718.7 - 8679.2 = 39.5 g Solder

Diameter: 53.48 avg. - 53.44 plated = 0.022 mm (.0008”) / side

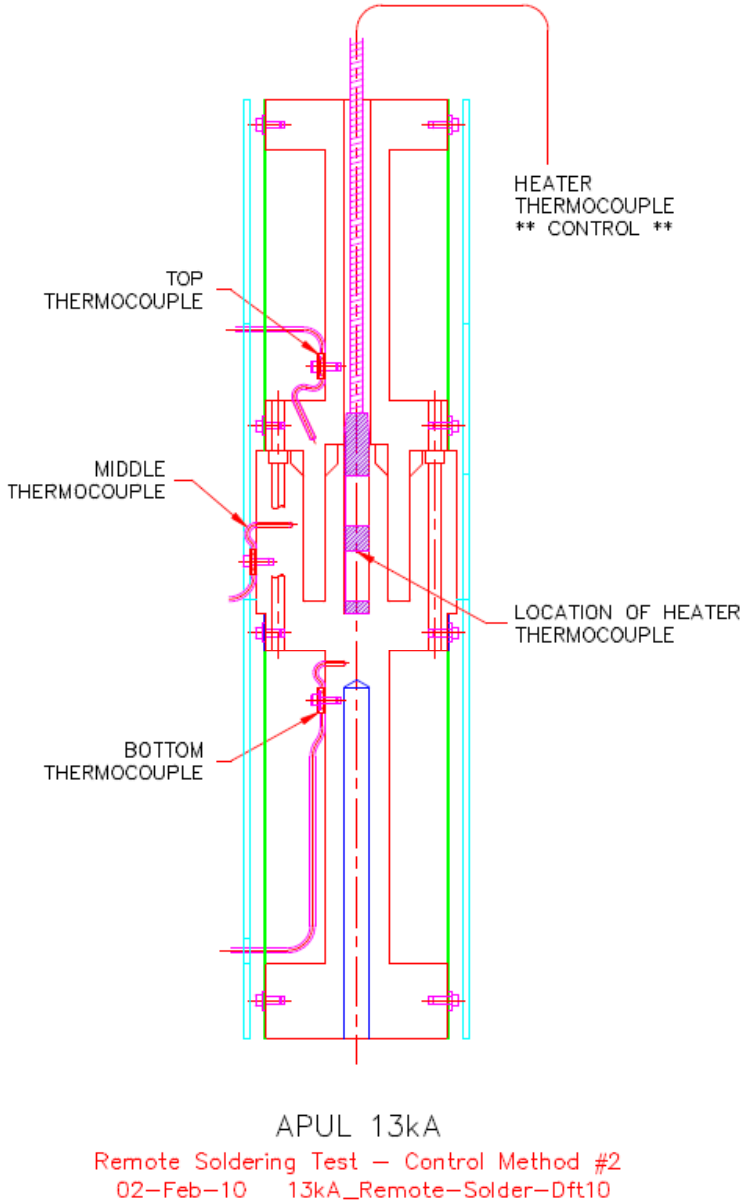
Heat Cycle #14 / 7th Join Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
1:30	22	21	21	21	Heater on
1:34	323	58	60	38	
1:38	329	94	93	67	
1:42	327	119	112	104	Liquidus
1:45	329	138	128	130	
1:49:30	330	160	150	153	Heater off
1:50	230	162	153	156	Max. overshoot
2:01	84	139	131	133	
2:14	41	118	116	117	Solidus

Control @ 330 °C for 19.5 min Control Method #2 05-Feb-10

Control Method #3

- Like CM#2, uses thermocouple in heater as the control
- Heater temperature set to 170 °C
- Eliminates risk of melting SC solder
- Will it produce a usable cycle time?

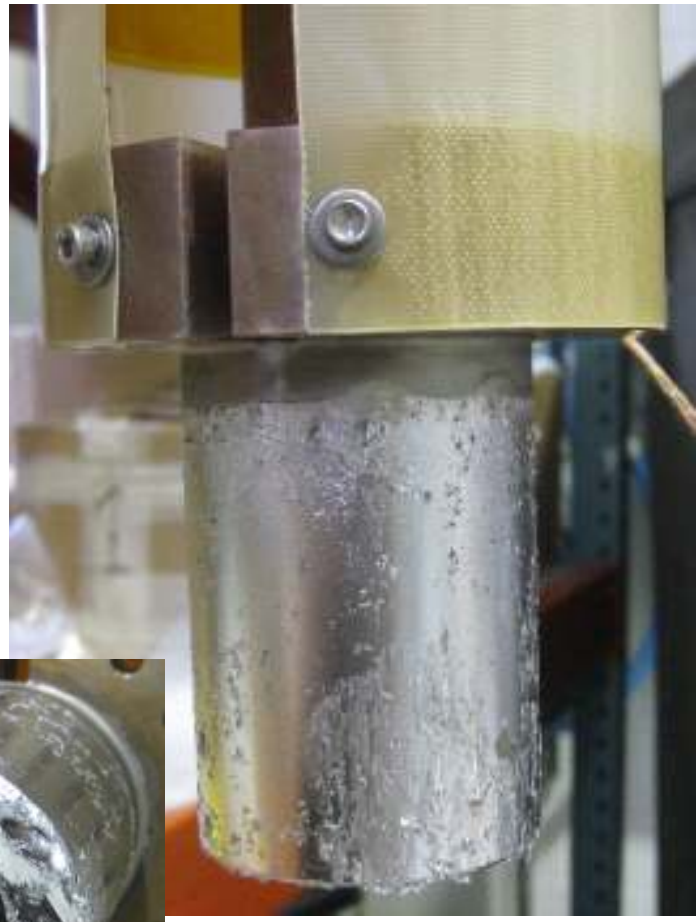


Heat Cycle #15 / 8th Separate Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
8:41	19	19	19	18	Heater on
8:59	172	82	78	79	
9:17	272	107	103	104	
9:34	170	118	115	116	Liquidus
10:01	172	127	124	125	Add insulation
10:31	176	133	131	132	
10:51	176	136	133	135	
11:12	170	137	134	136	Heater off
11:13	172	136	134	135	Separate

Control @ 170 °C for 151 min Control Method #3 10-Feb-10

Eighth Separation



Not gritty, no change in G-10 discoloration, little change in solder degradation, joint did not reach target temperature

Eighth Separation – System Data

System: 4,609.8 + 8,718.2 = 13,328.0 - 13,328.6 = 0.6 g loss

4609.8 - 4605.4 = 4.4 g Solder

8718.2 - 8679.2 = 39.0 g Solder

Diameter: 53.49 avg. - 53.44 plated = 0.025 mm (.0010”) / side

Control Method #4, Iteration #1

CM #3 Not Usable!

- Uses thermocouple in heater as the control
- Safe as possible
  - Controller programmed
  - Automatic operation
  - Automatic profile end
- Most efficient
  - Attempt to mimic CM#1

- Profile #1, Iteration #1
  - Ramp 0 to 330 °C in 5 sec.
  - Soak 330 °C, 16 min.
  - Ramp 330 to 170 °C in 5 seconds
  - Soak 170 °C, 4 min.
  - Ramp 170 to 0 °C in 5 seconds
  - End, heater off

Heat Cycle #16 / 8th Join Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
9:09	20	19	19	19	Profile start
9:12	291	49	53	35	
9:16	318	93	93	67	
9:19	296	120	113	106	Liquidus
9:22	312	142	131	133	
9:25:30	200	165	156	157	Max. overshoot
9:29	178	151	151	148	Profile end
9:38	72	128	126	127	
9:47	43	117	115	116	Solidus

Controller Profile #1, It. #1 Control Method #4 11-Feb-10

Control Method #4, Iteration #2

Refine Ramp and Soak Durations

- Uses thermocouple in heater as the control
- Safe as possible
  - Controller programmed
  - Automatic operation
  - Automatic profile end
- Most efficient
  - Attempt to mimic CM#1

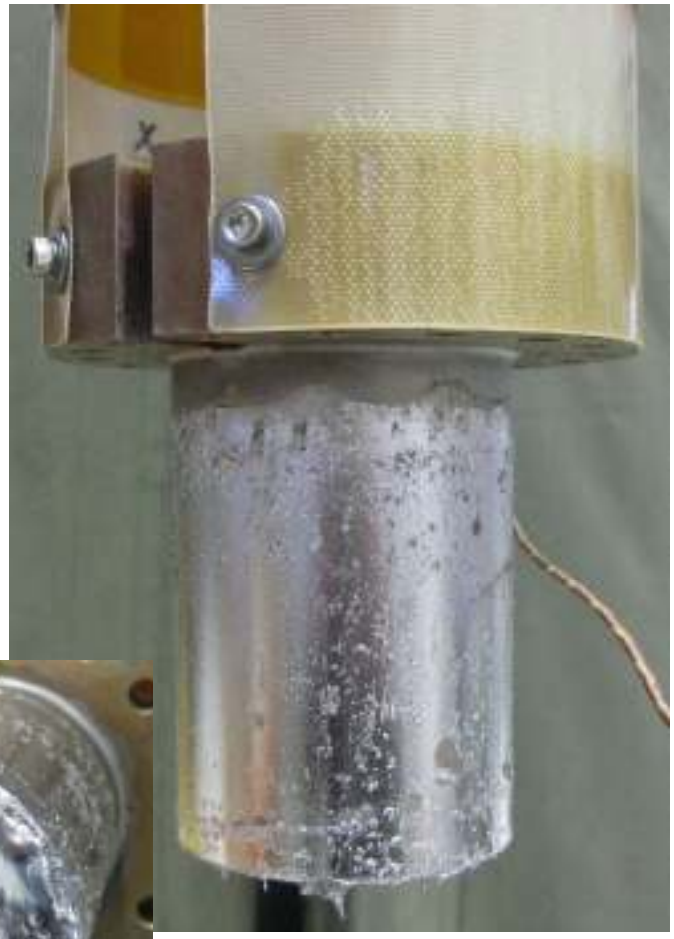
- Profile #1, Iteration #2
  - Ramp 0 to 330 °C in 30 seconds
  - Soak 330 °C, 14.5 min.
  - Ramp 330 to 170 °C in 2 minutes
  - Soak 170 °C, 2 min.
  - Ramp 170 to 0 °C in 5 seconds
  - End, heater off

Heat Cycle #17 / 9th Separate Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
8:10	19	18	18	18	Profile start
8:13	265	50	47	46	
8:17	287	92	85	85	
8:20	304	117	111	110	Liquidus
8:22	315	133	126	125	
8:25:45	250	157	150	150	Max. temp.
8:29	178	146	141	143	Profile end
8:30	154	143	139	141	Separate
8:41	62	117	117	109	Solidus

Controller Profile #1, It. #2 Control Method #4 12-Feb-10

Ninth Separation



Not gritty, no change in G-10 discoloration, little change in solder degradation, joint did not reach target temperature

Ninth Separation – System Data

System: 4,609.4 + 8,718.7 = 13,328.1 - 13,328.6 = 0.5 g loss

4609.4 - 4605.4 = 4.0 g Solder

8718.7 - 8679.2 = 39.5 g Solder

Diameter: 53.48 avg. - 53.44 plated = 0.020 mm (.0008”) / side

Heat Cycle #18 / 9th Join Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
1:30	22	21	21	20-00	Profile start
1:33	316	48	52	41	
1:37	328	89	88	76	
1:41	322	119	111	109	Liquidus
1:43	329	134	124	126	
1:46	247	149	139	143	Max. temp.
1:49	174	140	134	137	Profile end
1:54	99	127	123	126	
2:00	62	117	115	117	Solidus

Controller Profile #1, It. #2 Control Method #4 12-Feb-10

Control Method #4, Iteration #3

Refine Ramp and Soak Durations

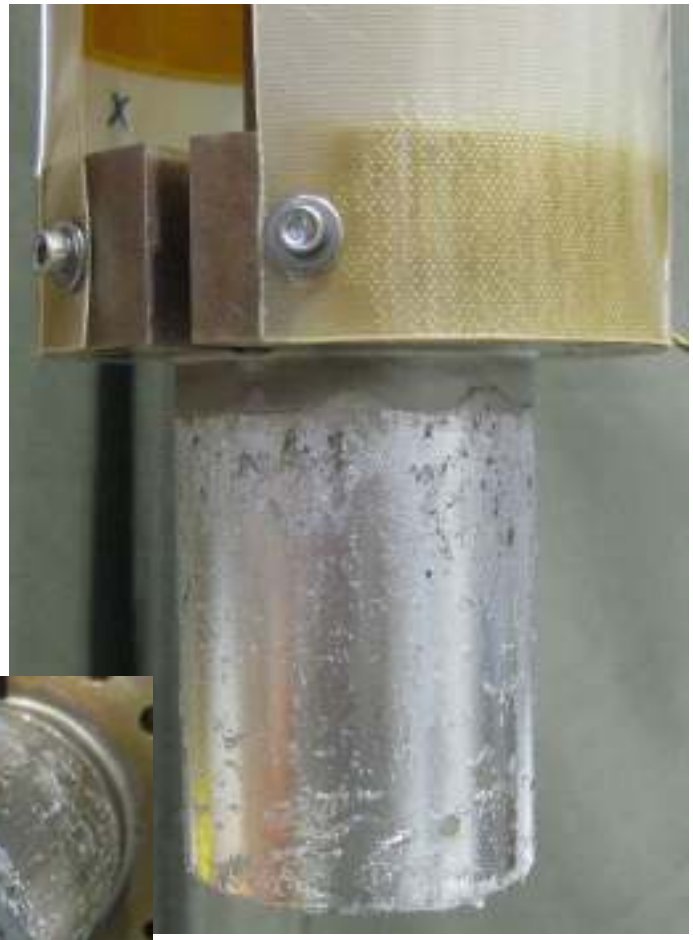
- Uses thermocouple in heater as the control
- Safe as possible
  - Controller programmed
  - Automatic operation
  - Automatic profile end
- Most efficient
  - Attempt to mimic CM#1
- Profile #1, Iteration #3
  - Ramp 0 to 330 °C in 30 seconds
  - Soak 330 °C, 16.0 min.
  - Ramp 330 to 0 °C in 2 minutes
  - End, heater off
- Reached 163 °C
  - Future – Step #2 Soak to 16.5 minutes

Heat Cycle #19 / 10th Separate Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
8:27	19	19	19	18	Profile start
8:30	233	50	46	45	
8:34	280	91	83	84	
8:37	298	117	107	109	Liquidus
8:40	315	139	128	131	
8:44	258	163	152	157	Max. temp.
8:45:30	158	157	148	153	Profile end
8:47	136	156	143	146	Separate
9:01	46	118	117	101	Solidus

Controller Profile #1, It. #3 Control Method #4 15-Feb-10

Tenth Separation



Not gritty, no change in G-10 discoloration, little change in solder coverage but solder viscosity seems thicker, joint did reach target temperature

Tenth Separation – System Data

System: 4,609.5 + 8,718.4 = 13,327.9 - 13,328.6 = 0.7 g loss

4609.5 - 4605.4 = 4.1 g Solder

8718.4 - 8679.2 = 39.2 g Solder

Diameter: 53.50 avg. - 53.44 plated = 0.030 mm (.0012”) / side

Control Method #4, Iteration #4

Refine Soak Duration

- Uses thermocouple in heater as the control
- Safe as possible
  - Controller programmed
  - Automatic operation
  - Automatic profile end
- Most efficient
  - Attempt to mimic CM#1
- Profile #1, Iteration #4
  - Ramp 0 to 330 °C in 30 seconds
  - Soak 330 °C, 17.0 min.
  - Ramp 330 to 0 °C in 2 minutes
  - End, heater off
- Reached 167 °C
  - Future – Step #2 Soak to 16.5 minutes

Heat Cycle #20 / 10th Join Cycle

Time	Control	Mid Tc	Bott Tc	Top Tc	Comment
2:15	21	21	21	20	Profile start
2:18	298	47	51	40	
2:22	321	89	88	76	
2:25:30	322	118	112	110	Liquidus
2:29	329	145	135	138	
2:33	204	167	156	160	Max. temp.
2:34:30	170	160	152	157	Profile end
2:45	69	133	130	131	
2:55	38	118	117	116	Solidus

Controller Profile #1, It. #4 Control Method #4 15-Feb-10

Heat Cycle Summary

- Control Method #1 – completed 4 full cycles
- Control Method #2 – completed 3 full cycles
- Control Method #3 – only 1 heat cycle, unusable
  - +150 minutes, did not reach 160 °C target
- Control Method #, Profile #1, Iteration #1
  - Controller programmed – only 1 heat cycle
- Control Method #4, Profile #1, Iteration #2
  - Controller programmed – completed 1 full cycle
- Control Method #4, Profile #1, Iteration #3 & #4
  - Controller programmed – completed 1 full cycle

Reminders

- Use 78g Indalloy #1E solder (52In/48Sn)
  - Allows 3.0 mm bottom gap, maximum 40% overflow
- Use Scotch-Brite and alcohol to clean nickel
  - Remove oxides, eliminate non-wetted areas in tinning
  - Use Indium Corporation 4OA liquid flux liberally
- Use Boron-Nitride spray to coat heater
- Use CM#4, Iteration #5 for 13 kA leads
  - Soak at 330 °C for 16.5 minutes
  - Lock controller program to prevent changes
- Control speed of lead lowering into solder pool

Conclusions

- Remote solder joint can be made fluxless
  - No solder or flux added after initial tinning
- Remote solder joint is repeatable
  - 10 full cycles were performed
- Remote solder joint is reliable
  - Solder film consistent throughout tests
- 13 kA Controller programming complete
  - Iterated to replicate Control Method #1
  - Safe and consistent operation