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WELDING OF HERMETIC CONNECTORS

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DISCLAIMER

WELDING OF HERMETIC CONNECTORS

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Heat distortion generated by welding hermetic glass-to-metal sealed electrical connectors into housings for electronic assemblies frequently causes gross seal failures. Heat sinking, weld process techniques, and weld flange configurations were investigated and processes were successfully developed to minimize failure of hermetically-sealed connectors. Heat sinking and reduction of weld flange thickness along with modified manual fusion welding techniques control connector temperature rise and reduce fatal dimensional strains in the web area of the connector during welding.

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SUMMARY

Certain systems use hermetically-sealed multipin connectors welded into a stainless steel support ring. Failure of these hermetic seals during welding continues to be a problem, and similar problems are anticipated on advanced systems. Since the assembly is expensive, and the detection, prevention, and repair of hermetic seal failures is costly, development of an improved welding process is important. Extended service life also requires a lower system leak rate, thus causing an increased need for maintaining the hermetic seal without supplemental epoxy sealing and repair.

Earlier work, before the start of this project, successfully covered diagnostic leak detection and epoxy presealing of the glass hermetic seals to minimize final assembly failures. The work was limited by production schedule demands and there was little time for process experimentation.

Experience shows that up to 70 percent of the 10-pin SA1810-2 connectors have gross leaks [greater than 0.003 mm^3/s Standard Temperature and Pressure (STP)] after being welded using established welding processes and without using the epoxy pre-seal process. Acceptable leak rates of less than 0.00001 mm^3/s STP were achieved from 20 SA1810-2 10-pin connectors using heat sinks and an intermittent gas-tungsten-arc (GTA) weld technique. The process developed consists of using a massive copper heat sink with silicon thermal joint compound to maintain control of temperature in the hermetic seal area and using a 12-segment GTA weld with compressed argon gas cooling between weld segments.

The process and techniques developed are considered acceptable for welding the SA1810 family of connectors.

The SA1810 design is coaxial glass beads and pins in a stainless steel shell. Differences in coefficient of thermal expansion between the glass and metal results in a compression seal. Failure of the SA1810 hermetic seals during welding was found to be caused by temperature and connector shell distortions from the welding processes. Severe temperature rises during welding cause decreases in compressive loads and shrinkage of the weld zone produces distortions that are fatal to seal integrity.

Investigations of current connector welding processes show that peak welding temperatures of 400 to 500°F (205 to 260°C) are generated in the area of the glass hermetic seal. Thermal studies and experiments on the connector itself indicate that these temperatures cause seal degradation; however, observed connector leak rates after welding cannot be duplicated by exposing individual

connectors to similar temperature profiles. Peak welding temperatures in the seal area can be controlled to 300°F (149°C) maximum using copper heat sinks on the connector back shell and using the modified GTA welding techniques.

Instrumentation to determine the maximum dimensional strain of the stainless steel web around the glass hermetic seals showed that severe strains exceeding the strength of the connector shell material were generated during the continuous electron-beam (EB) weld. Permanent strain offsets were observed indicating that the compressive loading on the glass seals was permanently reduced or removed. Reduction in thickness of the weld flanges, heat sinking, and the use of an intermittent GTA weld technique with forced gas cooling between weld segments successfully reduced critical web strains. Strain observed using this modified technique was predominantly negative (increased glass compression) and the residual strain was typically negative at the completion of welding.

Reduction of weld flange thickness reduces the total weld energy input required for a connector weld, thus reducing the temperature buildup in the connector seal area. The 0.02-inch thickness (0.51 mm) melt down flanges reduce the structural rigidity of the connector which in turn reduces the transient and residual strain offset in the connector web. Weld energies of 30 J/mm were required for the modified GTA weld of 0.02-inch (0.51 mm) weld flanges while 45 J/mm were required for the EB weld of 0.04-inch (1 mm) weld flanges.

Further work on this project will include evaluation of weld zone cooling using electrostatic cooling techniques. Control of connector temperatures using an electrostatic probe from Interprobe, Inc. will be evaluated to determine if the process is an adequate substitute for the copper heat sink and silicone grease compound. Investigations of connector leak rates will continue as an integral part of the topical work being conducted to establish assembly processes that do not require final assembly machining.

DISCUSSION

SCOPE AND PURPOSE

This work was performed as part of an overall effort to develop new and improved assembly processes for future systems. Present techniques need further development to provide better controlled dimensional assembly to avoid final assembly machining, increased reworkability, and improved connector welding techniques. New systems will require lower system leak rates than presently specified. The activity of this report covers the investigation of seal failure causes and the development of processes to prevent these failures. The present assembly welding processes degrade the quality of the glass-to-metal connector seal. As a result excessive leak rates often occur on completed production units. Locating and repairing these failures require considerable labor cost and production flow time. The objective is to attain a system leak rate of less than 0.01 mm^3/s for approximately 50 connector seals and assembly welds without using epoxy pre-sealing for the glass-to-metal seals.

Investigations characterized connector shell temperatures and dimensional strain near the glass seals on the AF&F connectors during gas-tungsten-arc (GTA) and electron-beam (EB) welding. Processes were investigated and developed to control connector shell temperature rise and dimensional strain by using heat sinks, welding techniques, and modified weld flanges.

PRIOR WORK

Previous work was concerned with identifying the cause of hermetic seal failures of production units and the development of diagnostic and repair techniques for glass-to-metal seal failures.* Preliminary investigation was begun in January, 1973. This work established the level of thermal stresses applied to the SA1810 connector from the welding processes, developed heat sinking techniques, and determined the thermal tolerance of the SA1810 connector.

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*Michael Fuller, "Detection of Leaks in Hermetically-Sealed Electronic Assemblies," in *Bendix Technical Quarterly: Electronics Engineering*. UNCLASSIFIED. Bendix Kansas City: BDX-613-431, June 1971.

ACTIVITY

Background

The multipin low voltage connectors used (SA1810 type) have an individual co-axial glass bead insulator and pin configuration fused to an austenitic corrosion-resistant steel (CRES) shell to form a compression seal. The hermetic seal is achieved by maintaining a compressive load on the glass insulator and connector pin over the temperature range of intended use of the connector by selecting materials such that individual coefficients of thermal expansion produce a compressive seal load during the connector manufacturing process.

The manufactured connectors have specified leak rates of less than 0.00001 mm^3/s at standard temperature and pressure (STP). Individual connector leak rates after welding into the assembly must be less than 0.0015 mm^3/s, STP. This assures the cumulative leak rate from all connectors and welds will not exceed 0.01 mm^3/s, STP.

The connectors are GTA and EB welded into a CRES 17-4 PH machined housing. The corners of the rectangular SA1810 connector are GTA welded, before EB welding, to establish accurate location and orientation. Each corner is also pre-welded to compensate for part/beam tracking inaccuracies during EB welding (Figure 1).

The failure of this hermetic seal is believed to be caused by connector shell heating and dimensional strain produced by the welding processes. The welding processes produce severe thermal transients in the glass seal and dimensional distortion during weld zone shrinkage that may cause fracture of the glass insulator and separation of the glass-to-metal interfaces. The welding strain may result in a permanent residual dimensional distortion, or offset, of the connector shell body in such a manner as to cause loss of glass compression, fractures, and separation of glass-to-metal interfaces.

Previous evaluations showed that 14 of 20 connectors leaked in excess of 0.003 mm^3/s after being welded into assemblies using the GTA and EB weld process described above. Sealing techniques were developed using Epon 815, a flexible epoxy compound, around the back shell of the connector after welding was complete. Sealing was accomplished by evacuating to remove entrapped air bubbles and to improve penetration of the epoxy around each pin. The epoxy is cured for 2 hours at 165°F (74°C). This repair technique was successful in reducing reject rates, but it results in additional production costs and the epoxy seal may not be considered adequate for the extended service life of advanced systems.

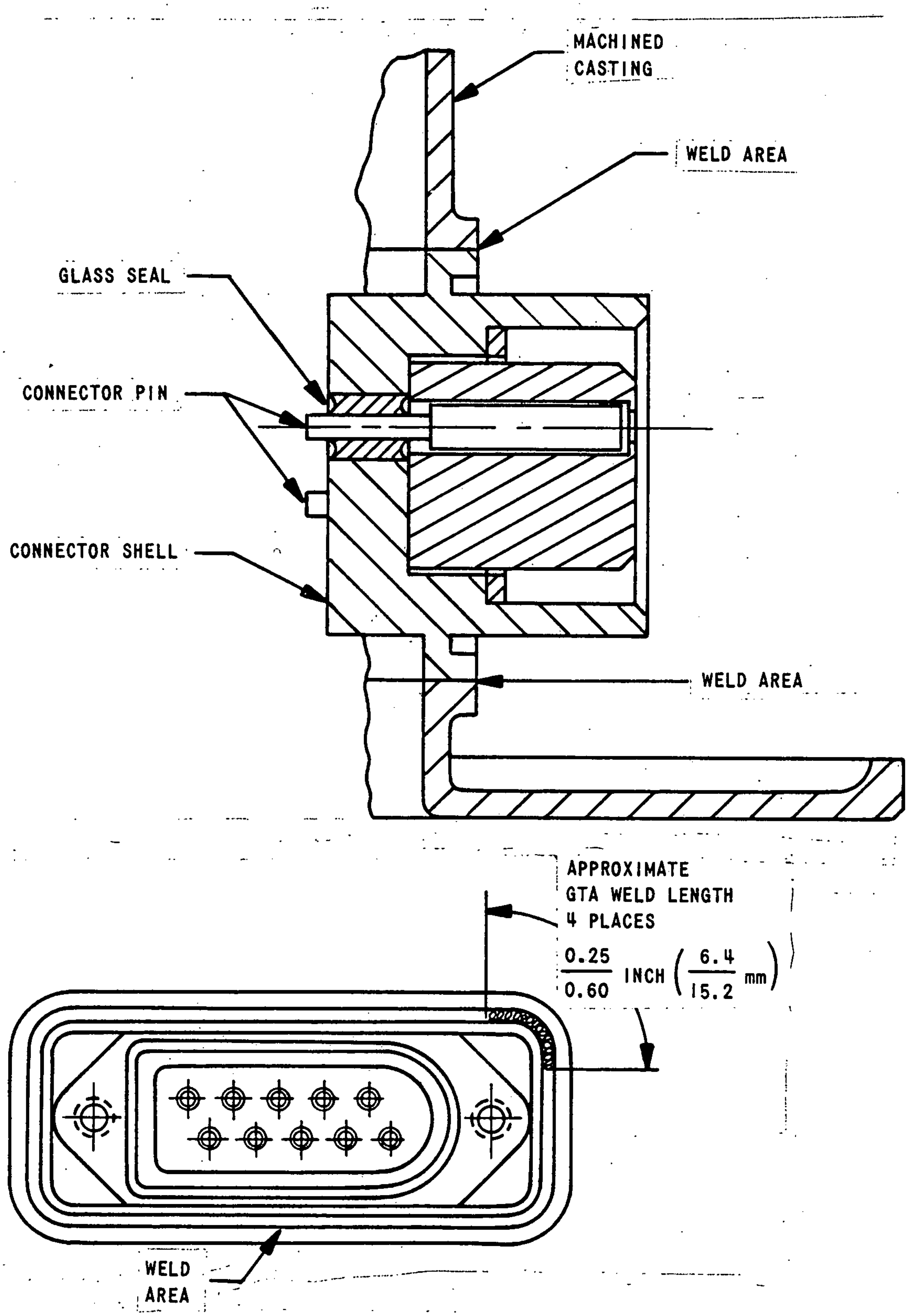

Figure 1. SA1810 Welded in a Machined Casting

Heat Sinking

Control of connector temperatures is critical in preventing seal failure. Factors that affect temperature in the connector seal area during welding are piece part configuration, heat sinking, and the welding process. Previous evaluations show that a massive copper heat sink used with an oxide-filled silicone grease, to reduce thermal impedances between the connector body and the copper sink (Figure 2) is most successful in reducing connector body temperatures (Table 1).

The oxide filled silicone grease (Wakefield Type 120)* provides good thermal contact from the heat sink to the connector, but removal of the residual compound is difficult. Two loaded silicone rubber materials were evaluated for possible use in place of the silicone grease. The rubber compounds provide uniform thermal contact to the connector and do not require cleaning and drying of the assembly after welding to remove the silicone grease. The use of these materials was unsatisfactory. Gaskets were also evaluated for use as heat sinks (Figure 3). The rubber compounds used for gasket fabrication were Abletherm 715-1 and Abletherm 7-2.** Analysis of these materials and Wakefield Type 120 heat sink compound are shown in Table 2. The use of these filled rubber gaskets proved unsatisfactory, because the welding temperatures resulted in material deterioration and outgassing. Two samples were welded, one with each material. The rubber gasket sealed off the back side of the weld joint enough to cause the out-gassing products from material deterioration to vent through the weld zone resulting in serious weld defects. Connector temperatures recorded during these tests were up to 450°F (232°C) indicating that poor thermal conduction was provided by the gasket. The gasket thickness was 0.020 to 0.030 inch (0.51 to 0.76 mm), thus negating their higher thermal conductivity. The Wakefield Type 120 thermal compound thickness, a result of connector-to-heat sink flatness, is less than 0.005 inch (0.13 mm).

Heat sink performance is directly related to the heat sink mass, initial temperature, and the thermal impedance of the sink-to-connector interface. The heat sink shown in Figure 4 has a total weight of approximately 250 grams, and was fabricated from copper. A graph of typical temperature performance for this sink is shown in Figure 5. Wakefield Type 120 thermal compound

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*Wakefield Engineering Company, Wakefield, MA.
**Ablestick Adhesive Company, Gardena, CA.

Text continued on page 15.

Table 1. Comparison of Heat Sink Temperature Reduction on SA1810-2

Heat Sink	Type of Weld	Peak Temperature (°F) (°C)			
		Corner	Diagonal	Pin	Center
None	GTA Tack	395 (201)	212 (100)	114 (46)	129 (54)
Copper*	GTA Tack	382 (194)	212 (100)	107 (42)	108 (43)
Copper With G683*	GTA Tack	216 (102)	224 (107)	148 (64)	153 (167)
Copper With G640*	GTA Tack	216 (102)	162 (72)	111 (144)	123 (51)
Copper With* Wakefield 120*	GTA Tack	220 (104)	162 (72)	126 (52)	148 (64)
Copper Sink on Front Side of SA1810-2	GTA Tack	406 (207)	235 (113)	112 (44)	126 (52)
Copper, Chilled Initially to -70°F (-57°C)*	GTA Tack	303 (151)	187 (86)	134 (57)	154 (68)
None	Complete GTA	454 (234)	-	373 (190)	-
Water Bath	Complete GTA	210 (99)	220 (105)	138 (59)	193 (90)
Water Bath With Copper Sink*	Complete GTA	210 (99)	183 (84)	140 (60)	214 (101)
Water-Filled Sponge on Back Side of SA1810-2	Complete GTA	474 (246)	420 (216)	288 (142)	426 (219)
None	EB	386 (197)	-	331 (166)	373 (190)
Copper*	EB	299 (148)	- -	277 (136)	321 (161)
Copper With G640*	EB	133 (56)	207 (97)	- -	238 (115)

*Shown in Figure 2

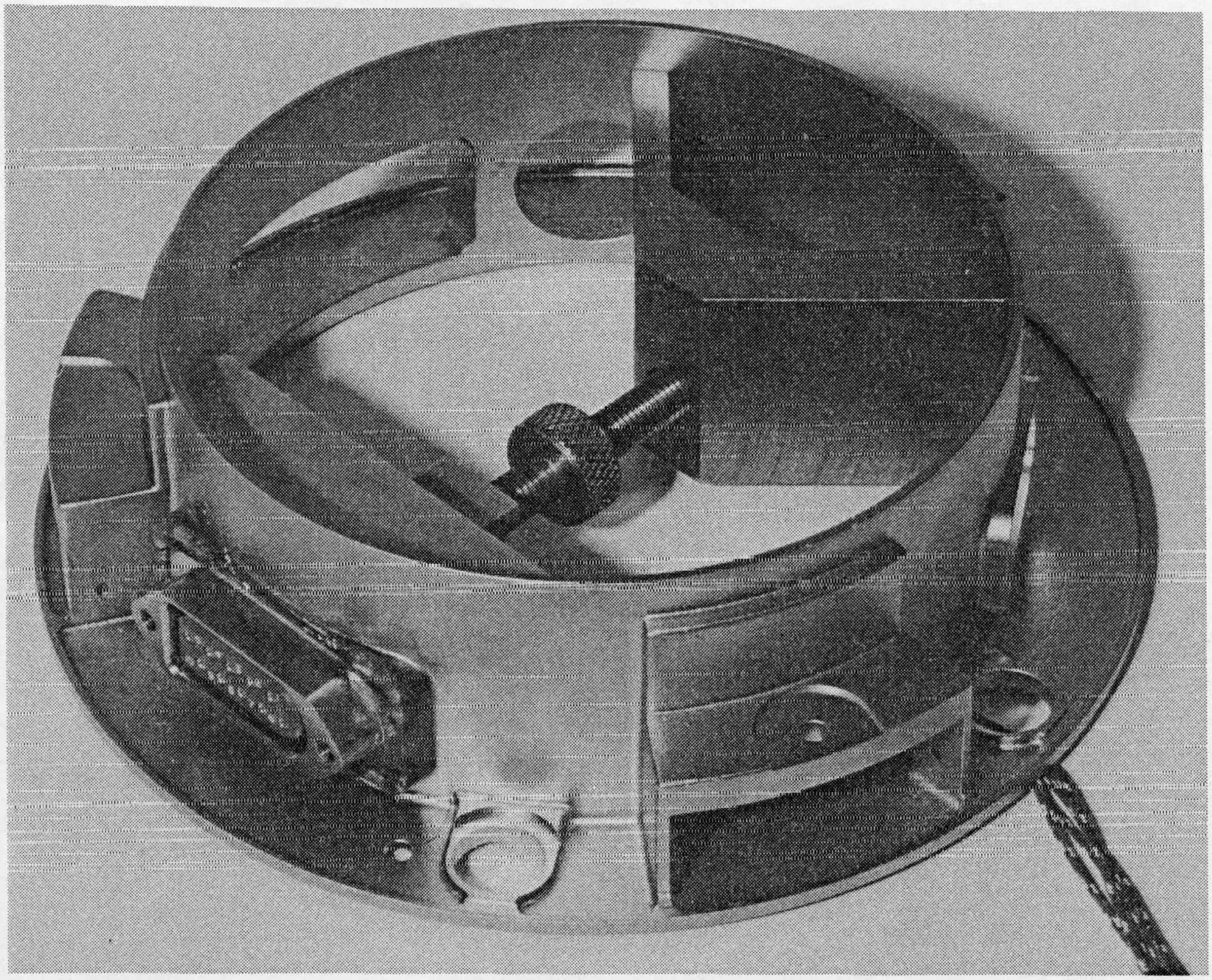

Figure 2. Heat Sink With SA1810-2 and Housing

Table 2. Heat Sink Material Analysis

Proprietary Designation	Filler Content by Percent Weight	Filler Material	Thermal Conductivity (W/m•K)
Abletherm 715-1	80	Cu	2.6 to 3.5
Abletherm 7-2	80	MgO	1.3 to 1.7
Wakefield 120	78	ZnO	0.74

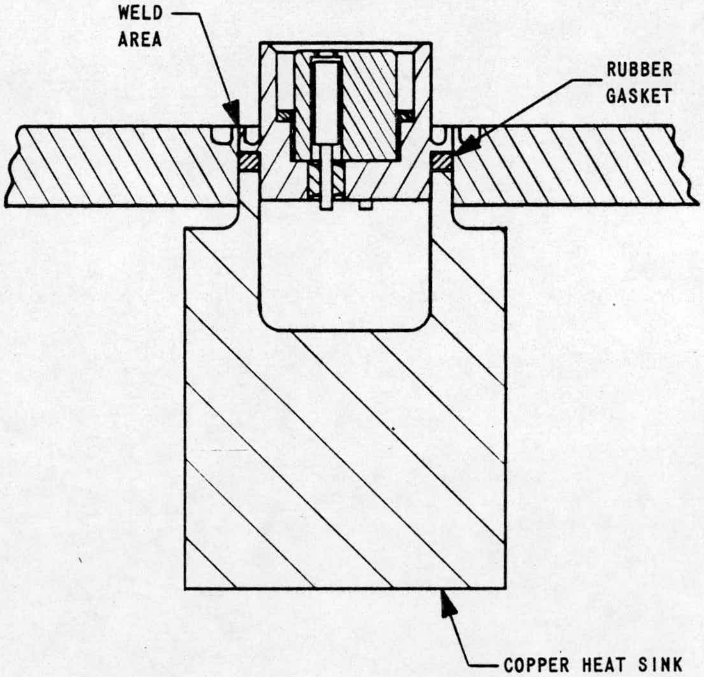

Figure 3. Heat Sink and Rubber Gasket

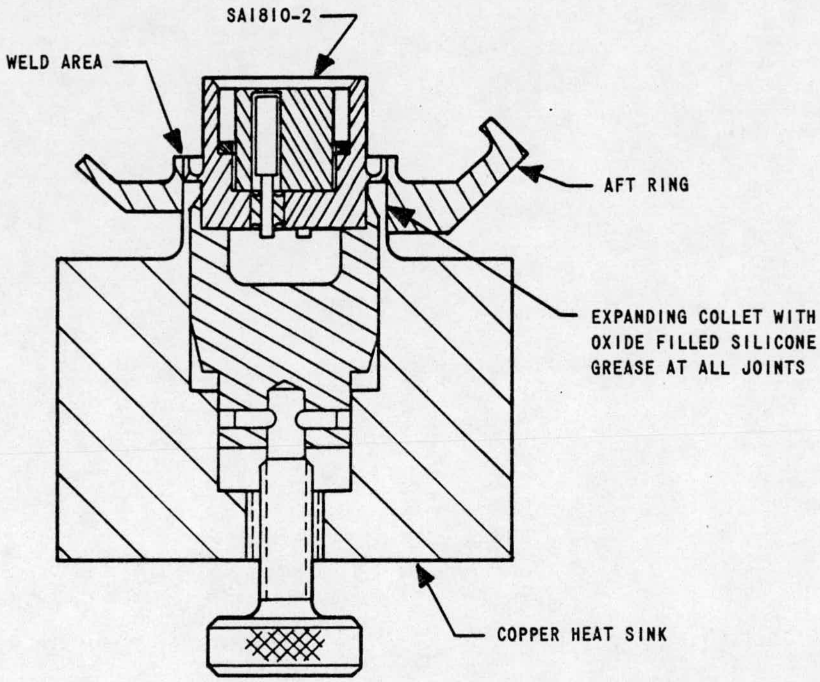

Figure 4. Expanding Collet Heat Sink

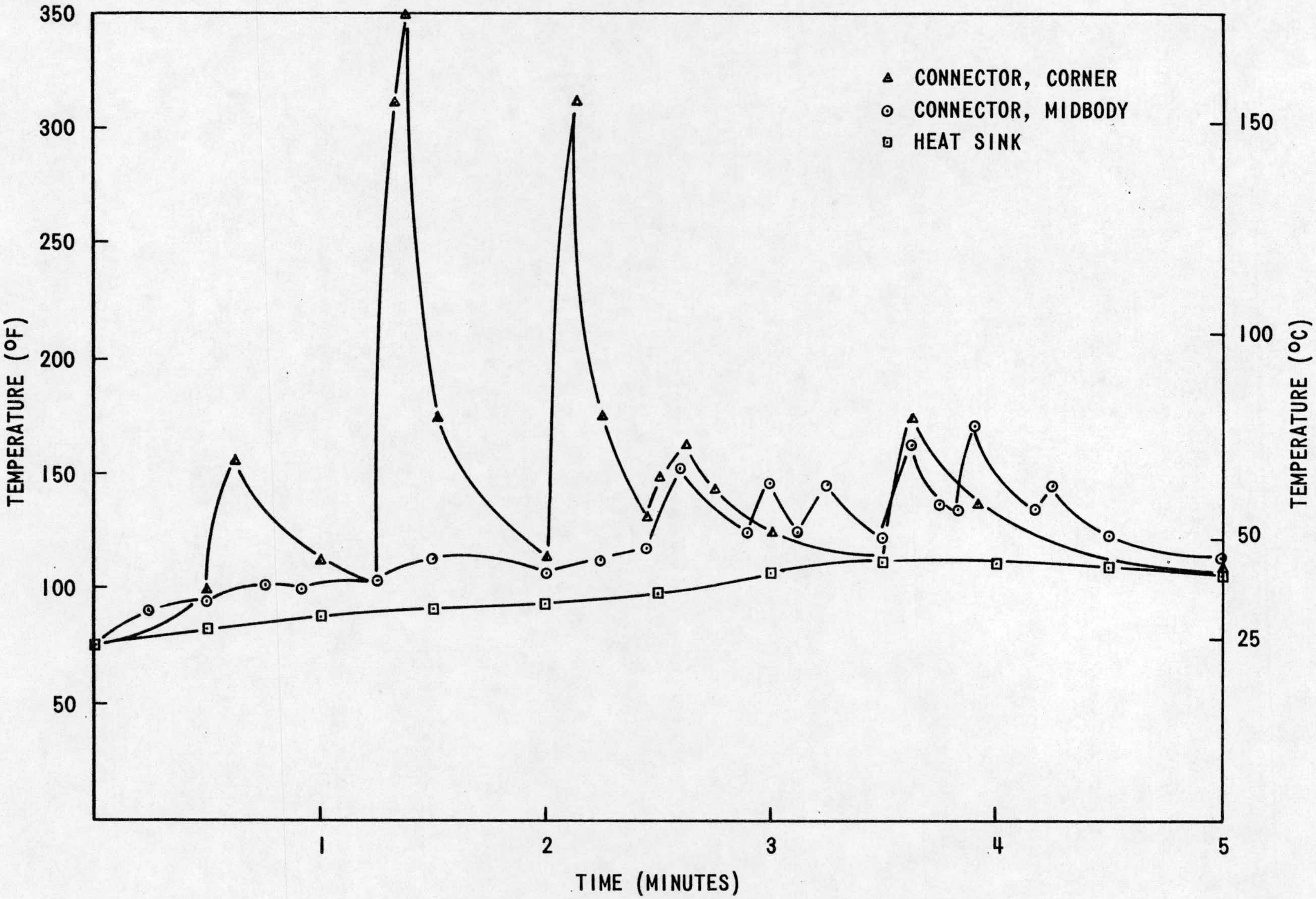

Figure 5. Temperature Versus Time During GTA Weld of SA1810-2

was used in these tests to improve thermal conductivity from the heat sink to the connector. The weld process employed for these tests was GTA using an intermittent weld consisting of 12 segments with forced gas (argon) cooling between each segment.

Connector Web Strain

The dimensional strain in the CRES web around the glass seal provides a significant indication of the weld process severity on the glass bead and the hermetic seal. Fifteen SA1810-2 10-pin connectors were instrumented with miniature foil strain gages to determine the strain levels during the welding processes. The gages were epoxy bonded to the SA1810-2 (Figure 6) with instrumentation wires and thermocouples used for thermal correction of gage output (Figure 7).

The gages used were type EA-09-015DJ-120-LE.* The gage location was selected to provide indications of maximum strain in the narrow web sections of the CRES connector shell. The gages were epoxy bonded to the shell and electrically terminated to a three-wire lead configuration. The gage output was monitored using a balanced, half-active, Wheatstone bridge with the strain gage driven at 0.005 Adc. Apparent strain resulting from differential thermal expansion between the gage and the connector shell was determined experimentally and used to correct gage output for dynamic temperature effects.

The thermal expansion mismatch between the CRES shell and the glass bead produces a residual strain in the connector shell when the connector is manufactured. This residual strain is proportional to the compressive load on the glass bead. Figure 8 shows the decrease in this residual strain as the connector is slowly heated to 130°C. The strain will continue to decrease with increasing temperature until no compressive load exists on the glass insulator. This temperature is approximately 405°C (strain point) for the Corning 1901 glass. Normal assembly processes will repeatedly cycle the compressive stress on the seal interface up to temperatures of 93°C in addition to the transient welding temperature. Significant variations of residual strain levels from connector to connector can be seen from Figure 8.

Residual web strain levels at room temperature were determined by instrumenting a SA1810-2 connector with three strain gages bonded around one glass seal to determine strain. The strain-temperature characteristics resulting from temperature cycles

*Manufactured by Micro-Measurements, Romulus, MI.

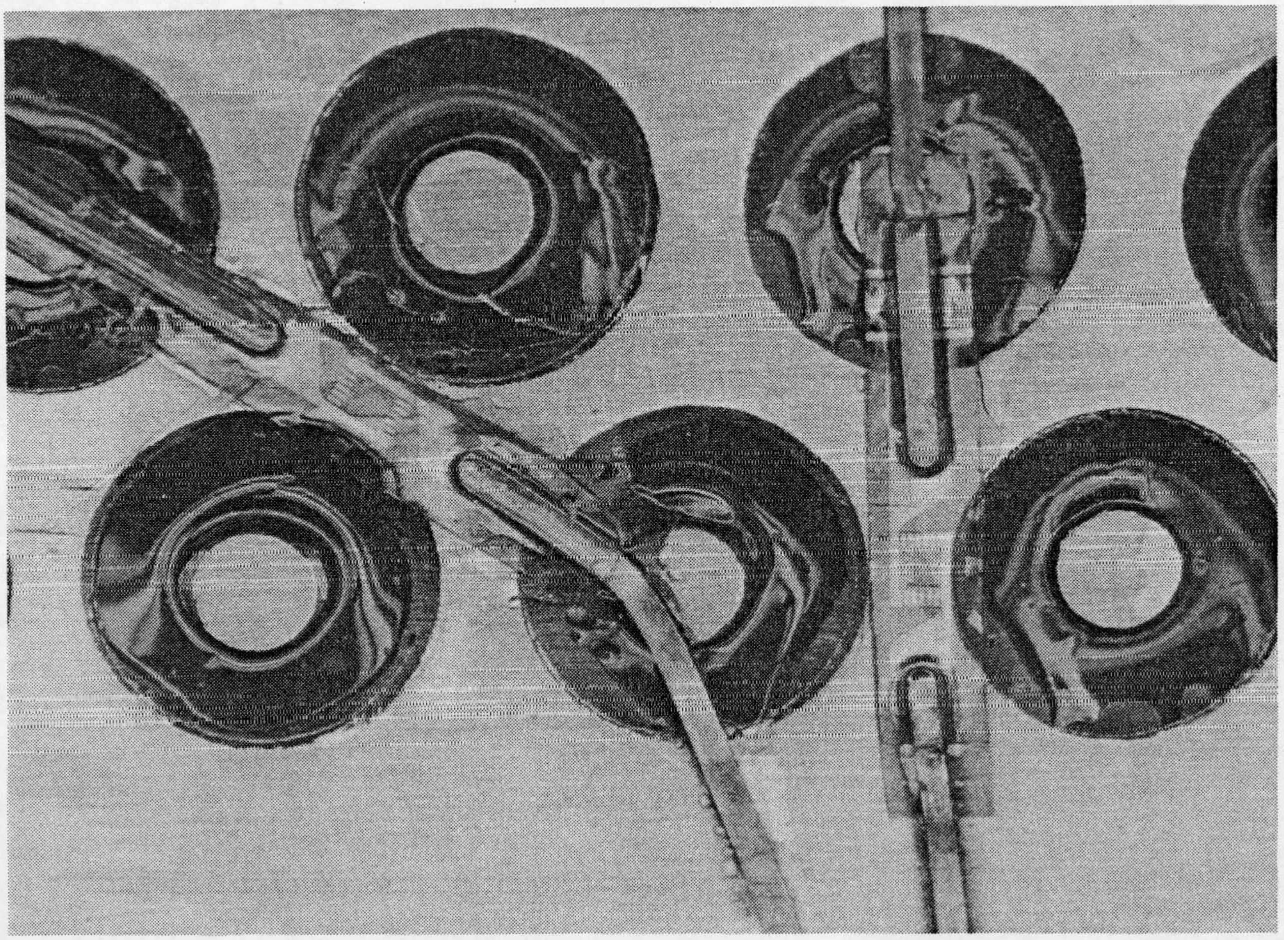

Figure 6. Strain Gages on SA1810-2

for this connector are shown in Figure 9. The pins and glass insulators were then removed from the connector allowing the connector webs to return to a zero stress level. The strain gage readings after glass removal is the magnitude of the residual web strain at room temperature. The rectangular limits depict the 405°C strain point of the glass and the upper strain magnitude that is equivalent to the minimum yield strength of the shell material.

Six instrumented SA1810-2 connectors were welded into machined 304L mounting rings using the normal GTA corner tacking and continuous EB welding to complete the weld. These were welded using the heat sinking procedures developed. Fourteen connectors were welded using a modified GTA hand welding procedure. This procedure is a 12-segment weld with forced argon gas cooling between each weld segment as described below.

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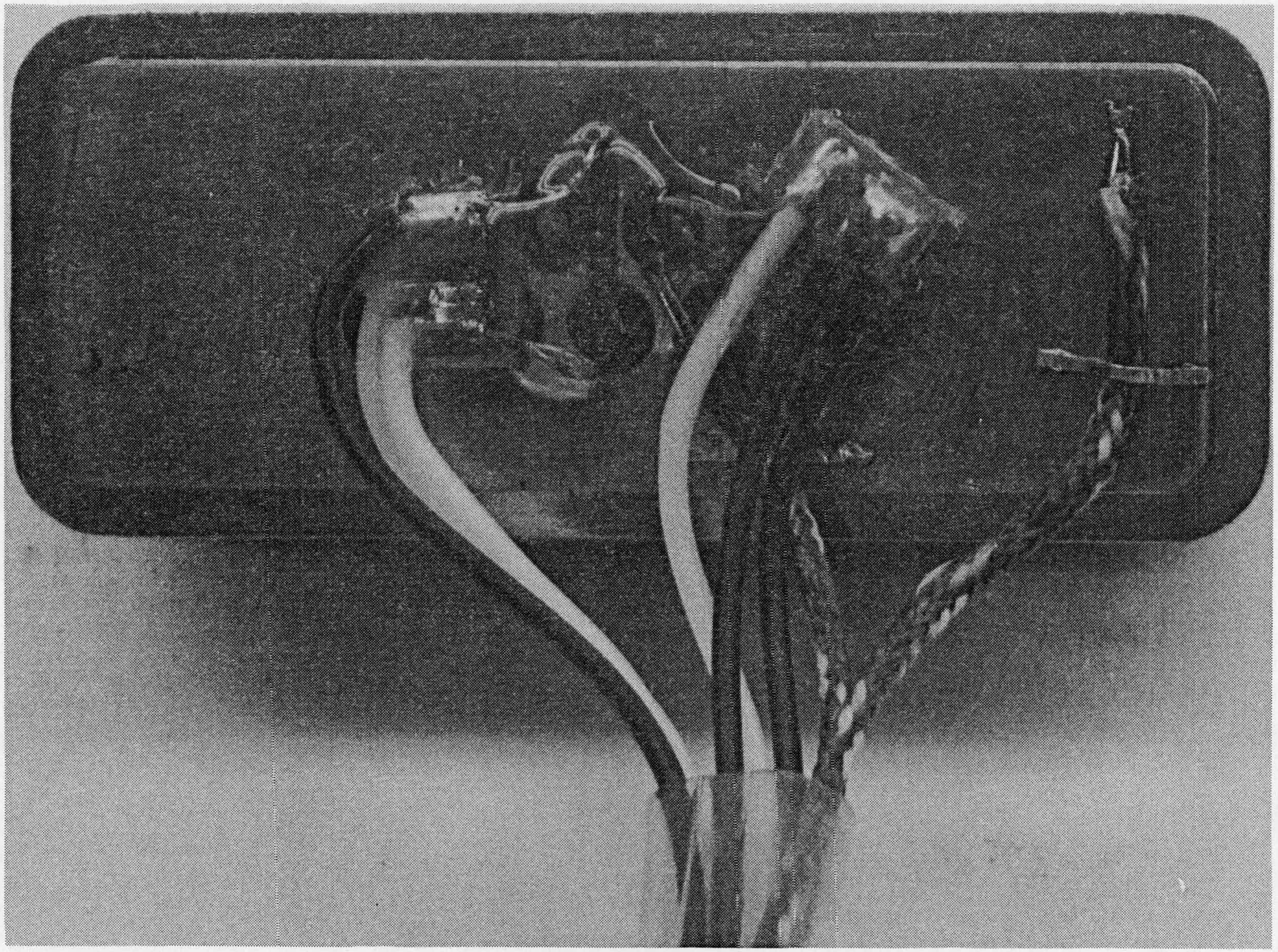

Figure 7. Strain Gages With Instrumentation

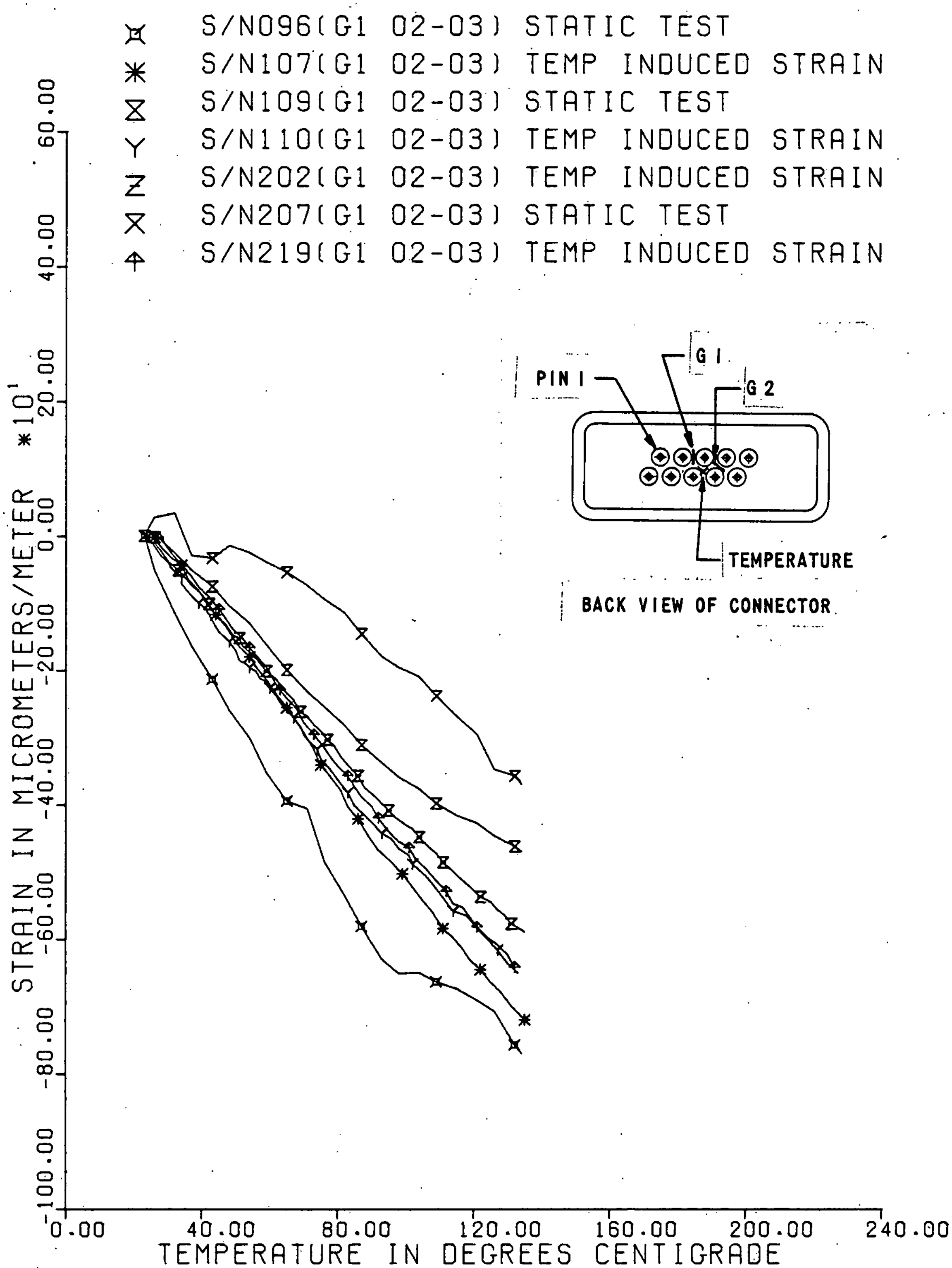

Figure 8. Residual Web Strain

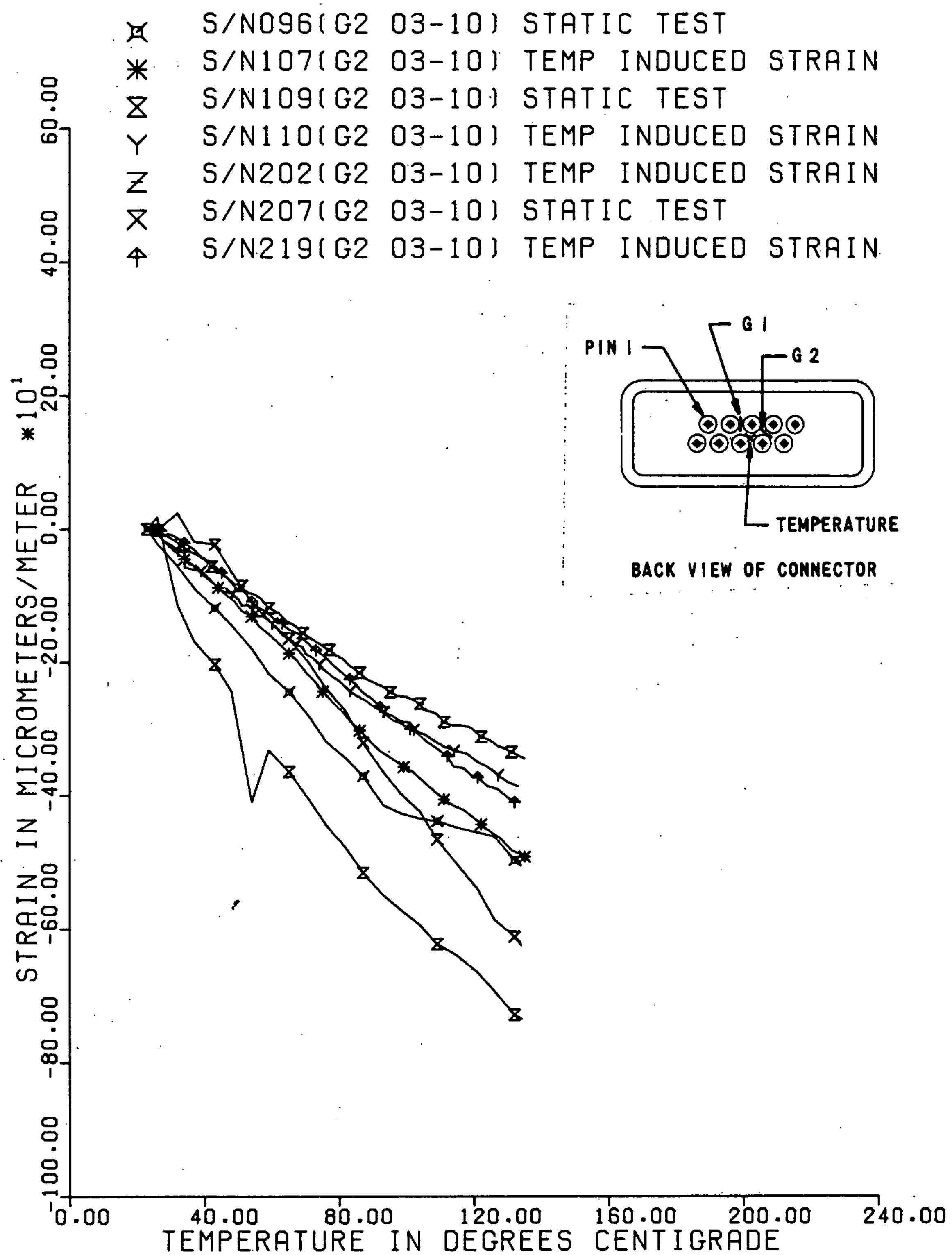

Figure 8 Continued. Residual Web Strain

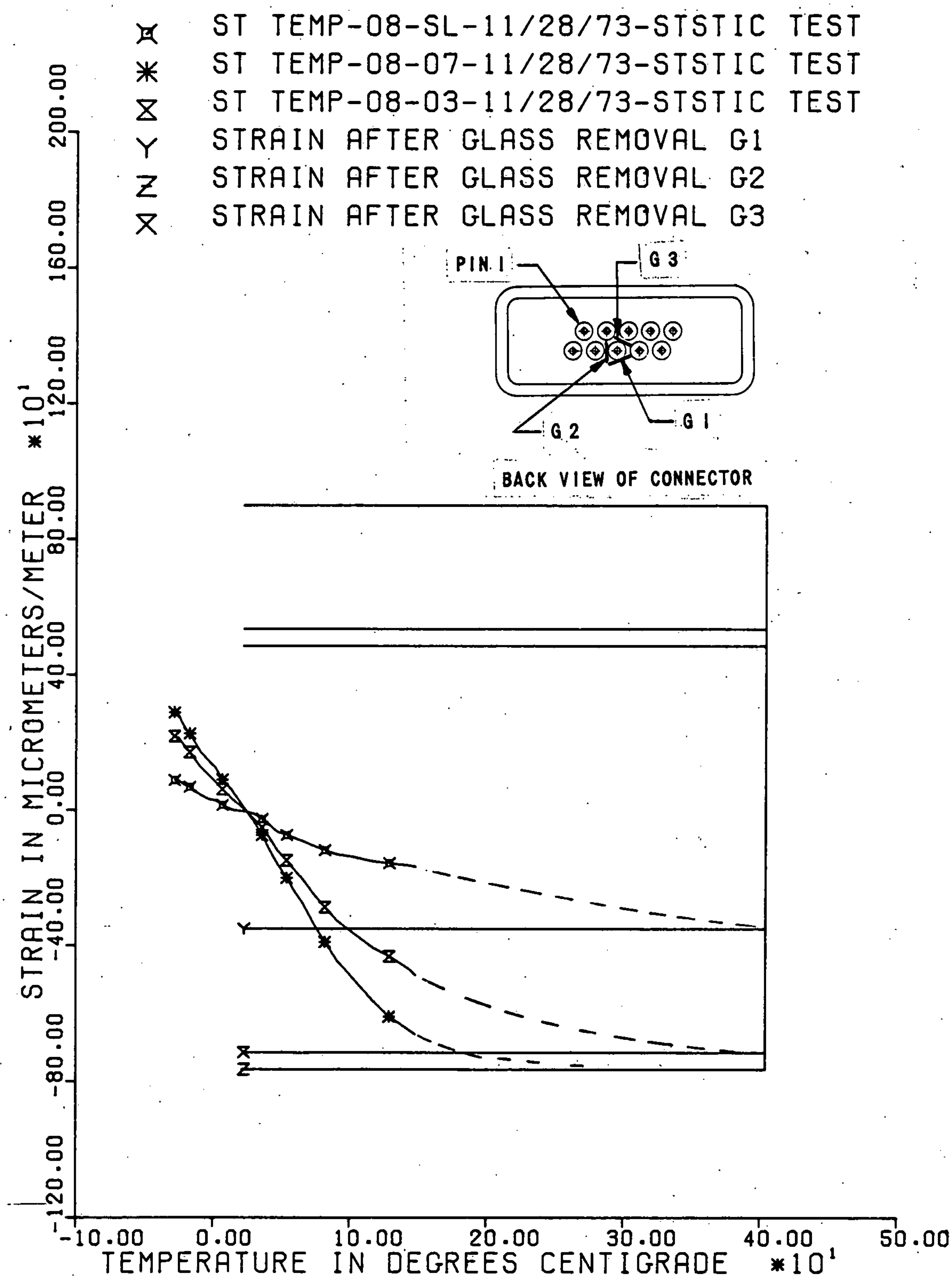

Figure 9. Total Web Strain

Figure 10 shows the configuration for EB welding the connector, and the resulting strain profile is shown in Figure 11. The total strain profile versus temperature for all assembly welding steps is shown in Figure 12. The EB weld produces severe strains, both negative and positive, that indicate stresses are produced that exceed the yield strength of the connector shell.

Weld Flange Configuration

The severity of the web strain during EB welding indicated the need to develop techniques to reduce the strain. Two techniques were investigated. The first was to reduce the thickness of the melt-down weld flanges and the second was to GTA weld in short segments with forced gas (argon) cooling between weld segments. The 12-step GTA welding sequence shown in Figure 13 was effective.

SA1810-2 10-pin connectors were modified by chemical-milling the weld flange from its original thickness of 0.040 inch (1.02 mm) to a thickness of 0.020 inch (0.51 mm). The reduced thickness of the weld flange lowered the weld energy input required because the mass of metal to be melted and the heat transfer from the weld zone to the connector were reduced. The thinner flanges are structurally weaker so that less shrinkage and distortion stresses are transferred to the connector shell.

The reduced temperature and strain resulting from the thinner flanges and the intermittent weld sequence is shown in Figure 14. The resultant weld is illustrated by the connector cross-section shown in Figure 15. Distortion of the weld flanges is apparent in the cross section.

Thermal Compound Clean-Up

The residual filled-silicone compound used in the heat sinking process must be removed from the connector assemblies before further assembly. Clean-up was effectively accomplished by solvent cleaning using toluene followed by spray cleaning using isopropl alcohol. The assemblies were then vacuum dried for 30 minutes at 160°F (71°C). The cleaned surfaces were suitable for subsequent encapsulation and processing.

The silicone compound will interfere with the GTA welding if the compound is in the weld zone. Care must be taken to prevent the presence of the silicone compound on the weld flanges before assembly of the connector to the ring for welding.

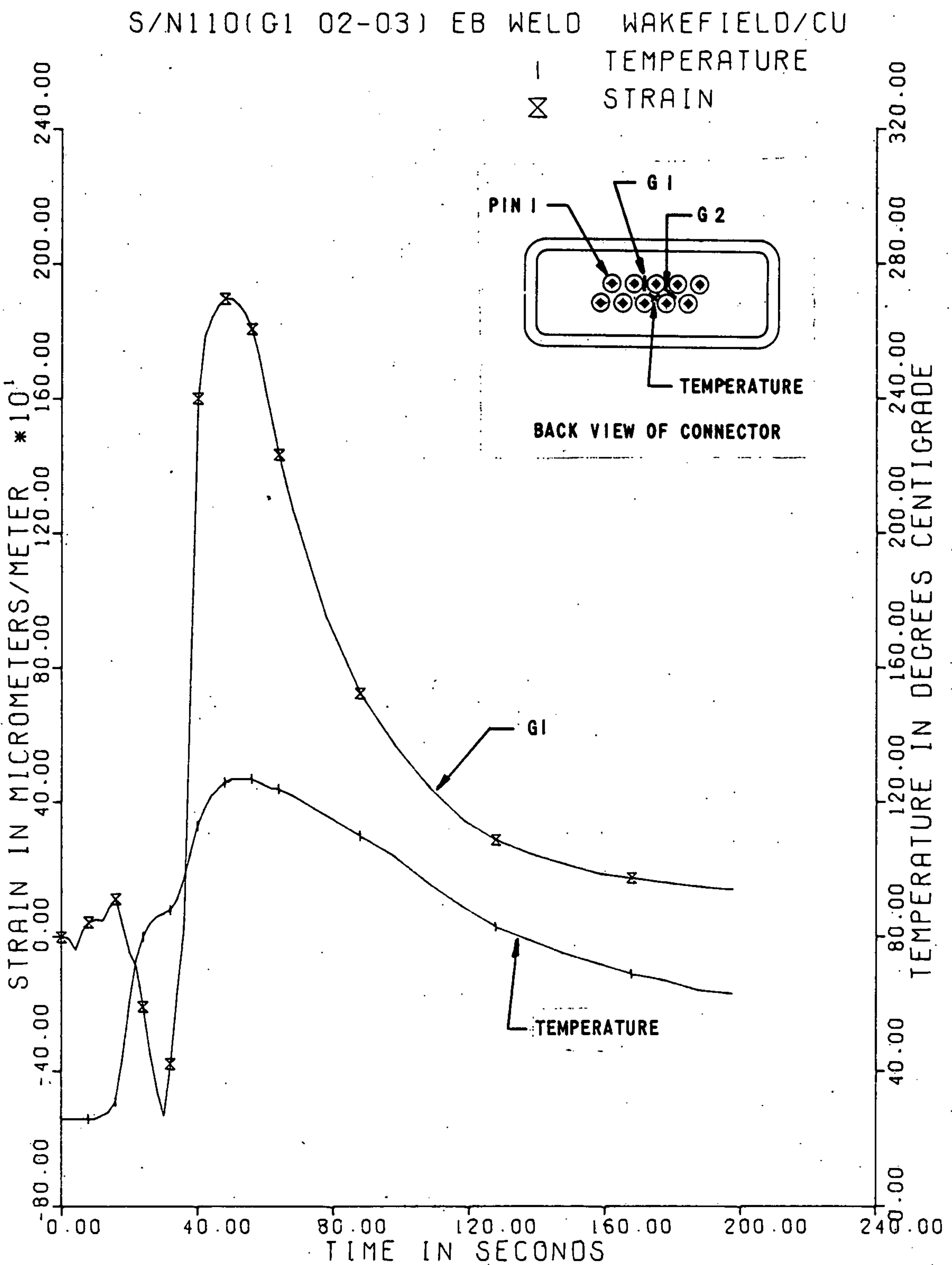

Figure 10. SA1810-2 EB Welded Into Assembly

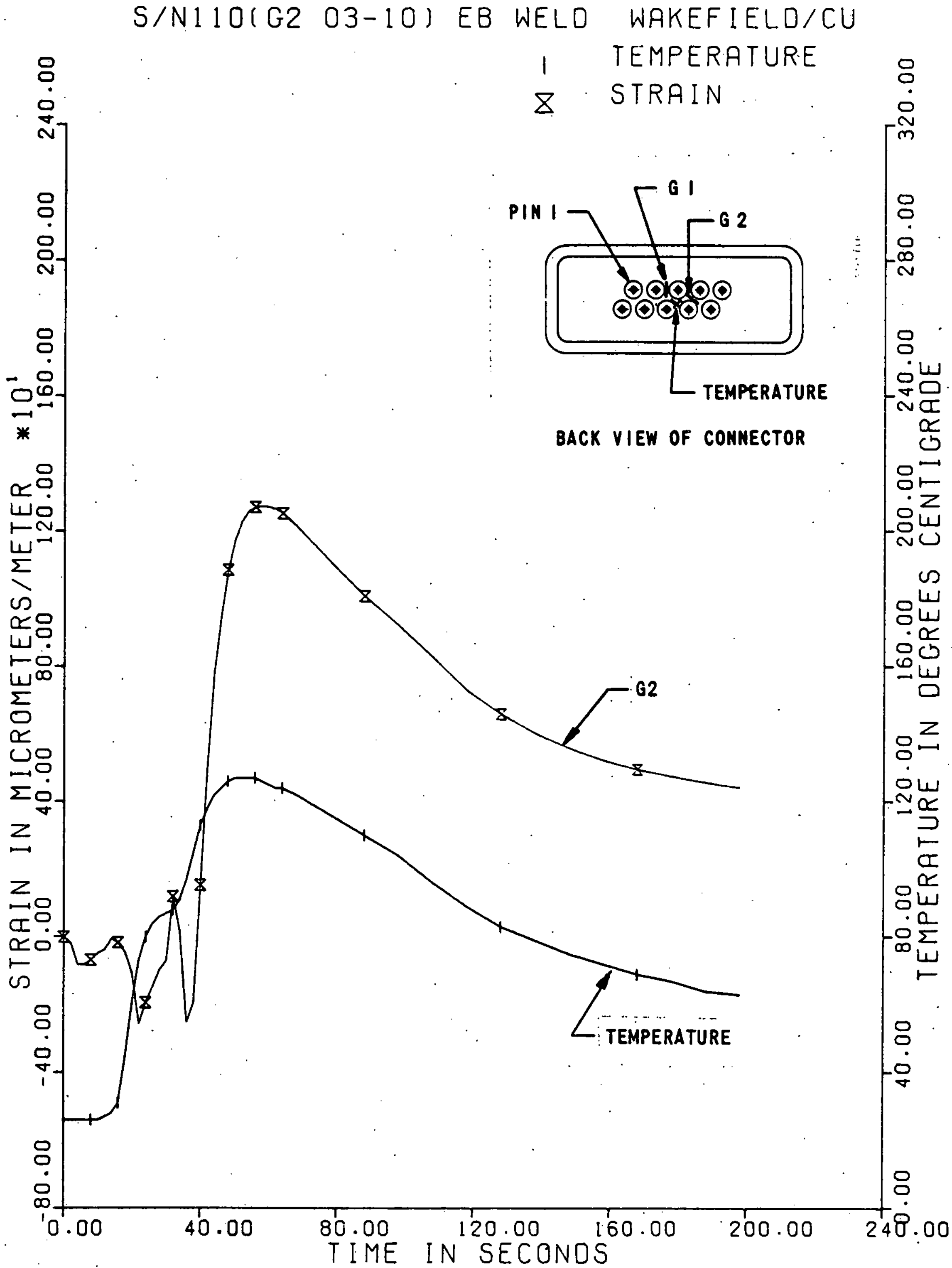

Figure 10 Continued. SA1810-2 EB Welded Into Assembly

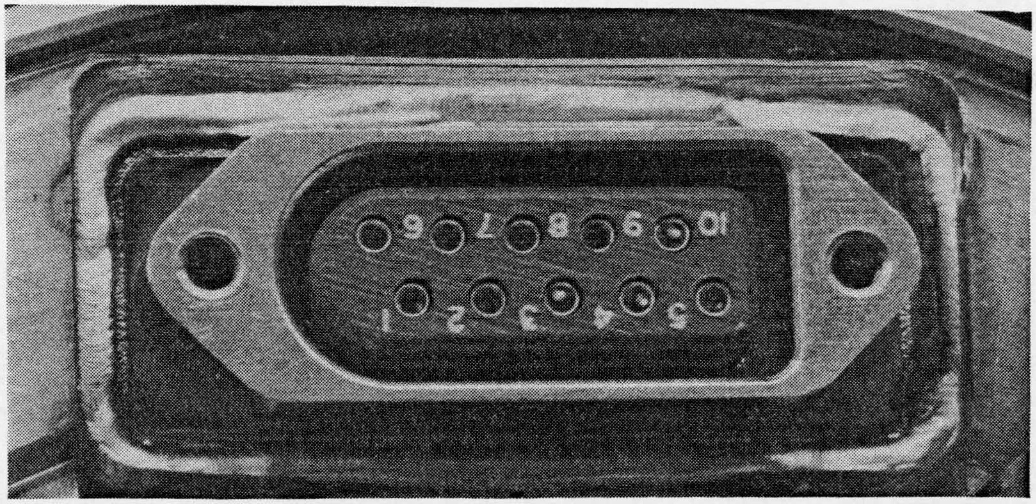

Figure 11. EB Welding Strain

Leak Testing

A total of 10 SA1810-1 (2-pin), 20 SA1810-2 (10-pin), 10 SA1810-3 (27-pin), and 10 rf connectors were welded to the configuration shown in Figure 11. The connectors were individually helium leak tested at the start of the evaluation and after all welding steps. The SA1810-2, 10-pin connectors, were additionally exposed to a simulated soldering temperature before welding. This test consisted of heating each individual pin on the end with a temperature controlled soldering iron [700°F (371°C) 1/8 inch (3.2 mm) chisel tip] for 5 to 8 seconds. All leak rates, before and after welding, were below the leak detection system limits, 0.00001 mm^3/s.

Weld Energy Versus Flange Thickness

The effect of flange thickness on total connector weld energy input was evaluated to determine the effectiveness of thickness reduction on reducing weld energy input. Figure 16 shows the results from three flange combinations. The 0.02 to 0.04 inch (0.51 to 1.02 mm) configuration reduced the input by one third from that required for the 0.04 to 0.04 inch (1.02 to 1.02 mm) configuration. The 0.04 to 0.04 inch configuration requires approximately 4400 J of weld energy input for a complete EB weld of the SA1810-2 compared to approximately 11000 J for a GTA weld. The 0.02 inch (0.51 mm) configuration required approximately 3500 J for a GTA weld (12 segments), indicating a favorable configuration compared to the established EB process. The 0.02 inch configuration was not evaluated using the EB process.

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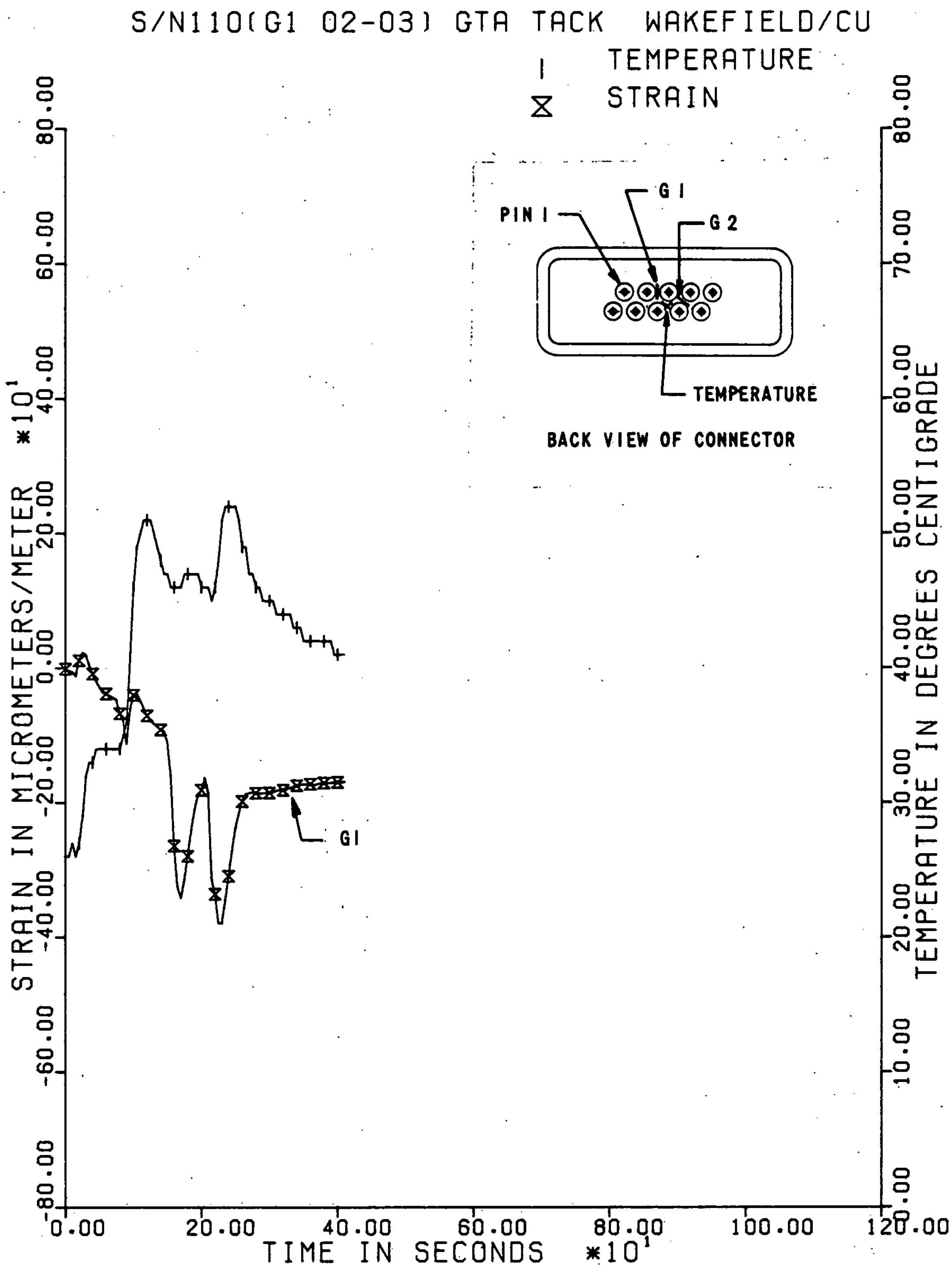

Figure 12. SA1810-2 Strains From Assembly Welding

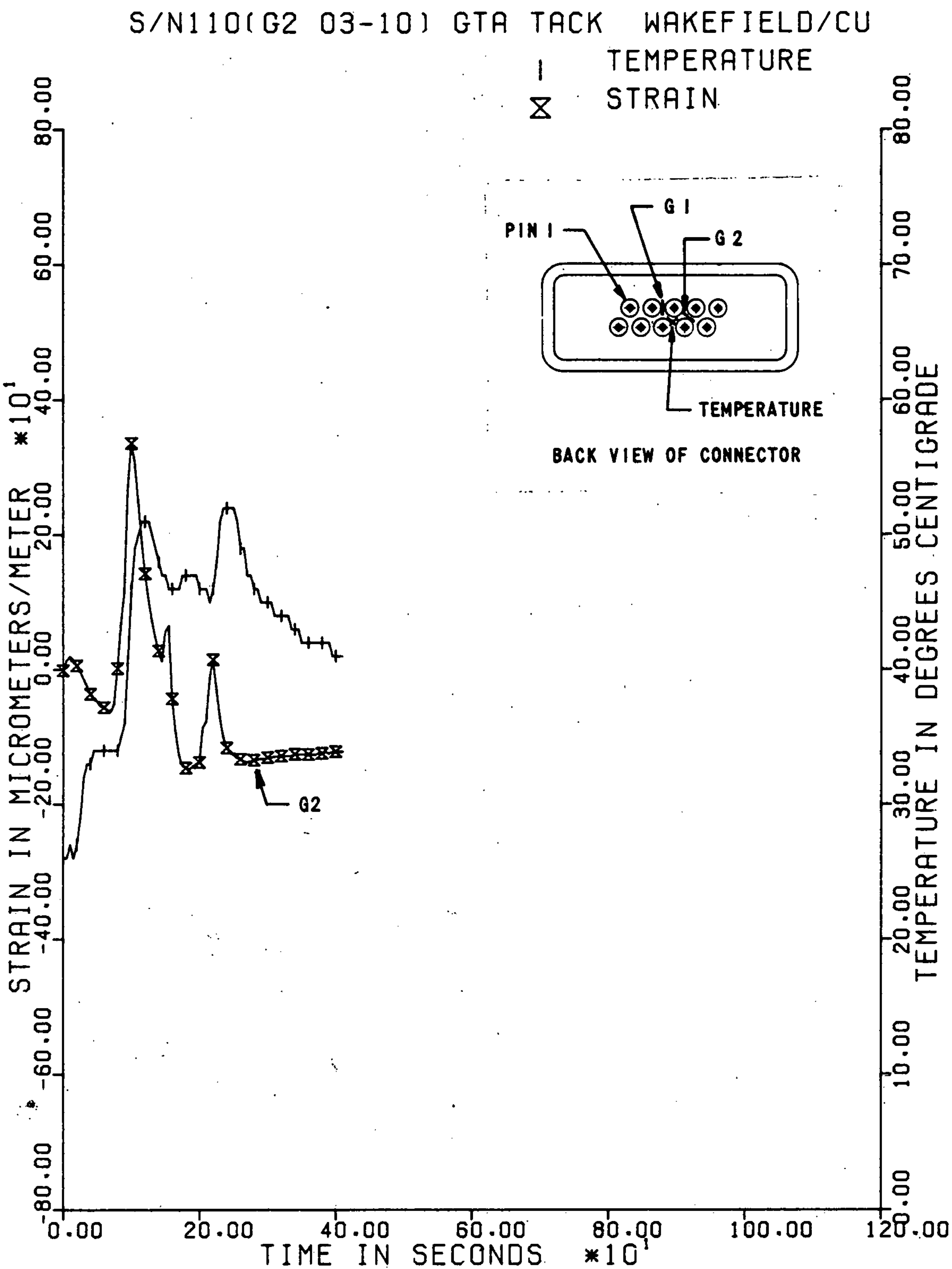

Figure 12 Continued. SA1810-2 Strains From Assembly Welding

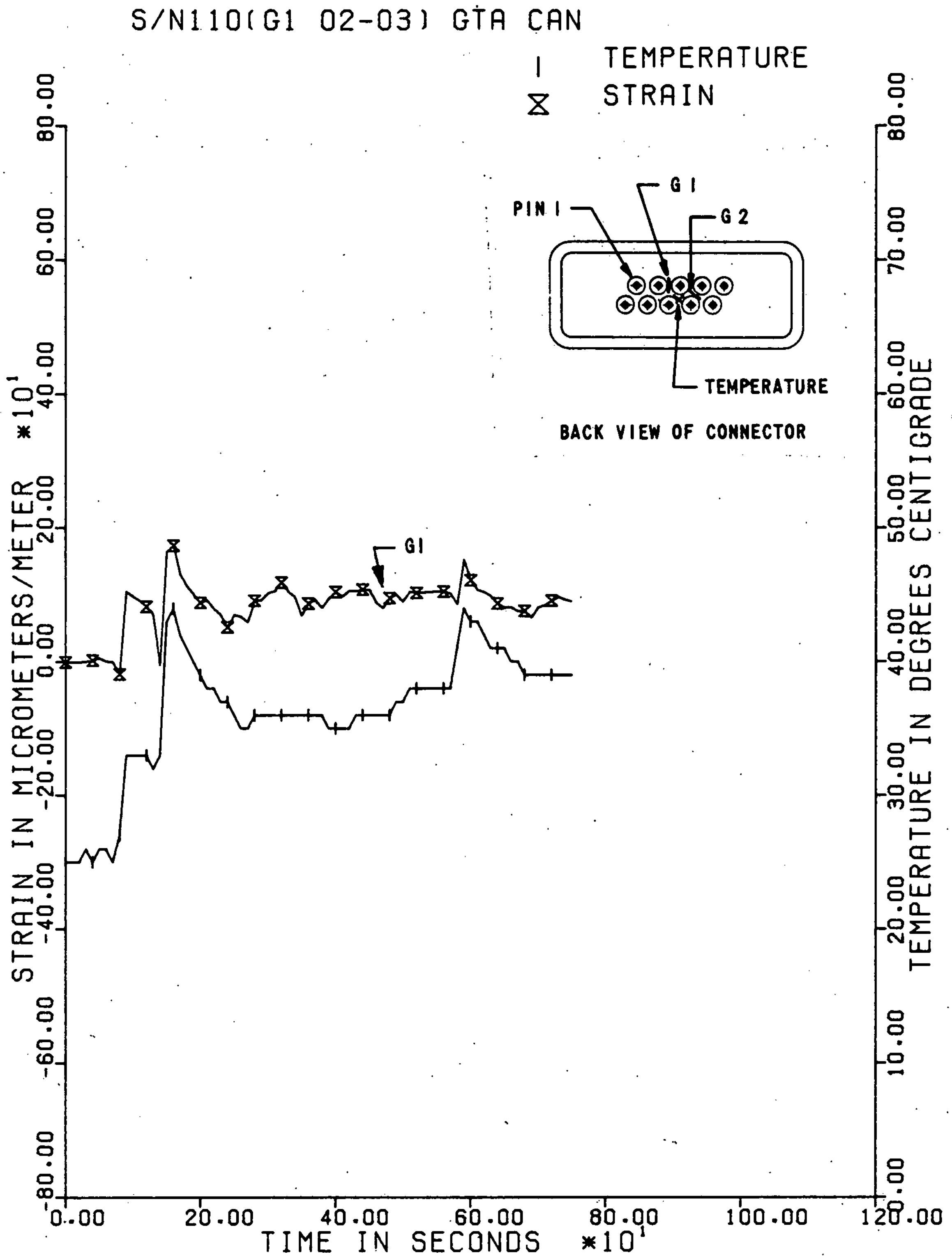

Figure 12 Continued. SA1810-2 Strains From Assembly Welding

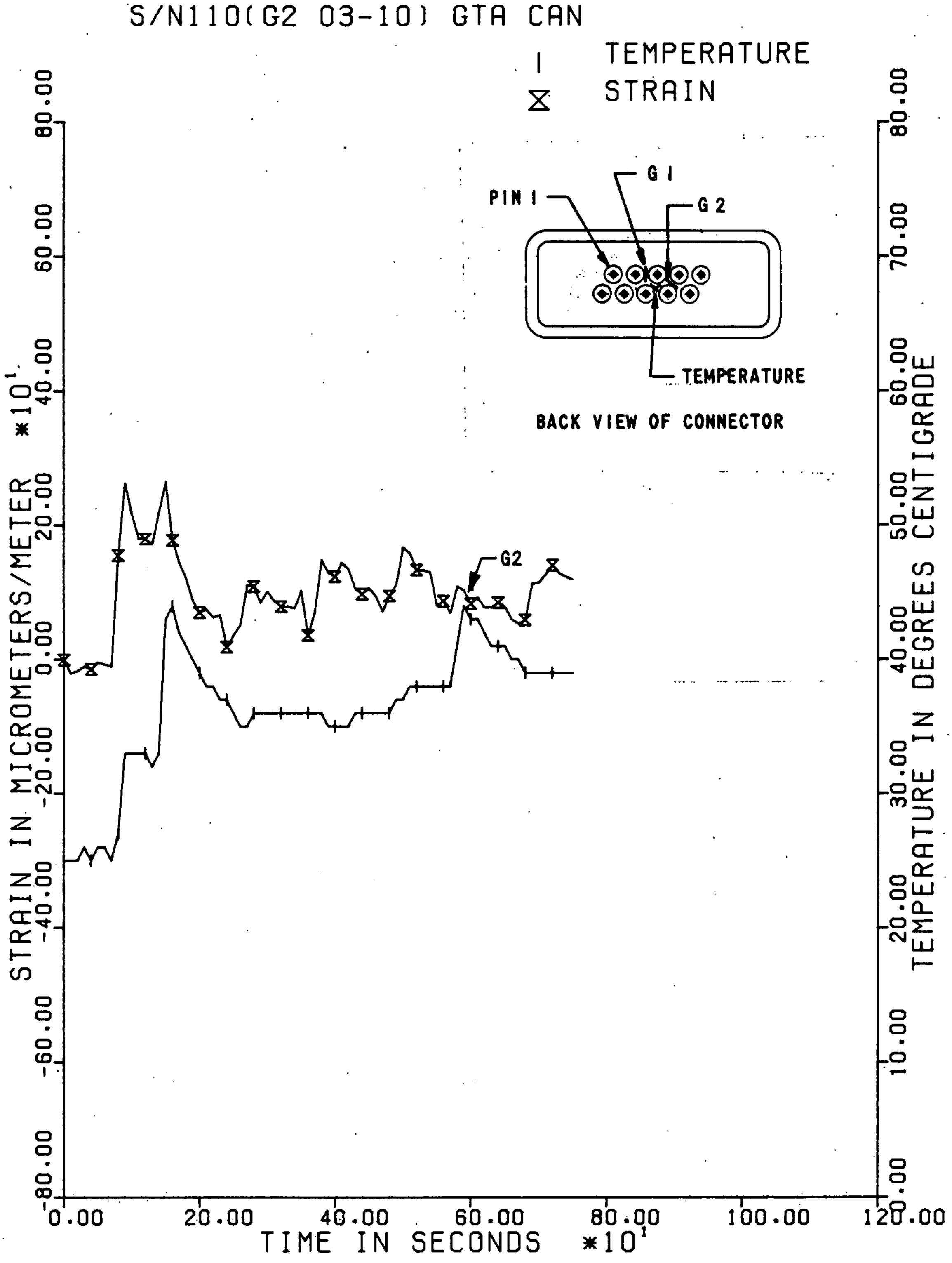

Figure 12 Continued. SA1810-2 Strains From Assembly Welding

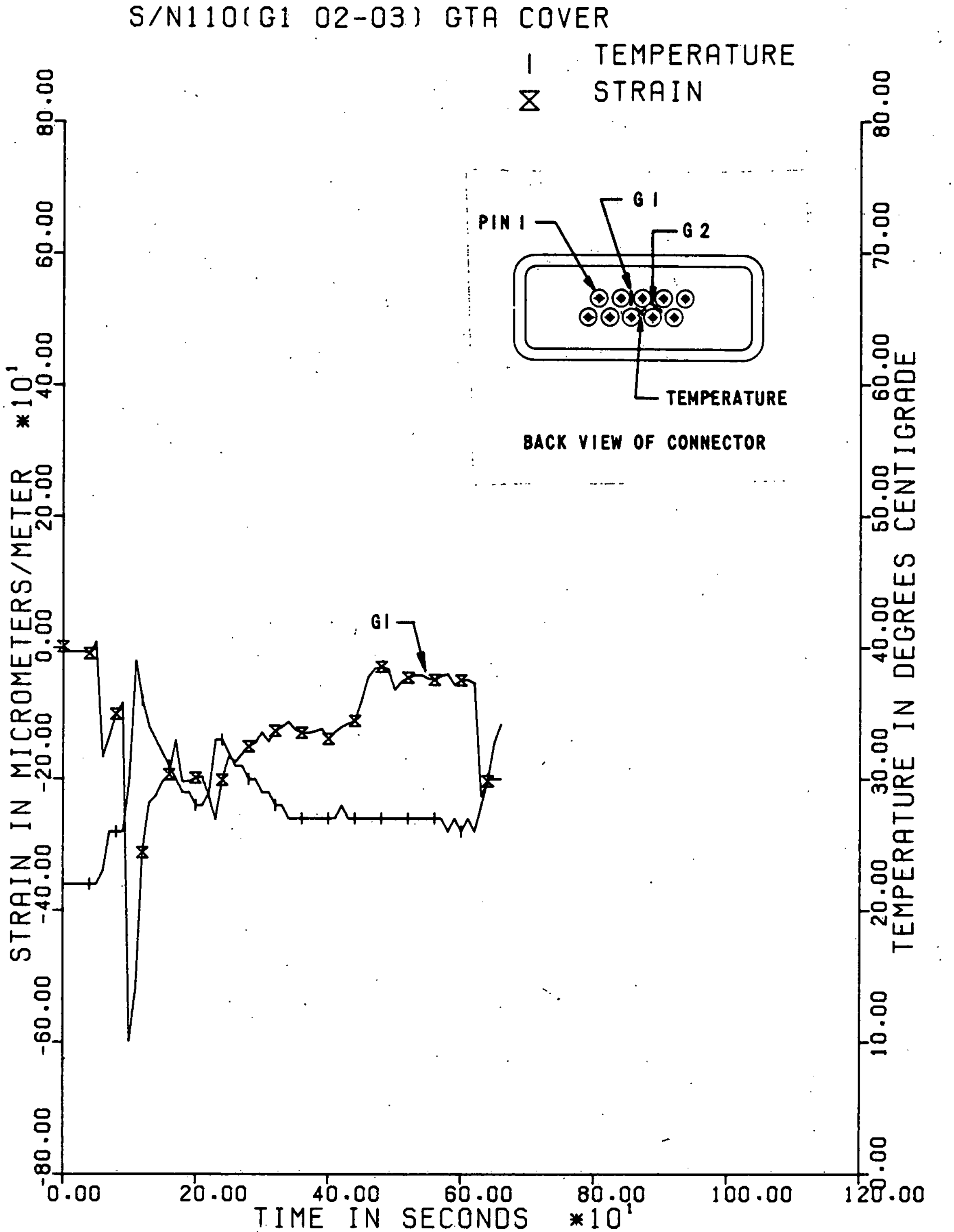

Figure 12 Continued. SA1810-2 Strains From Assembly Welding

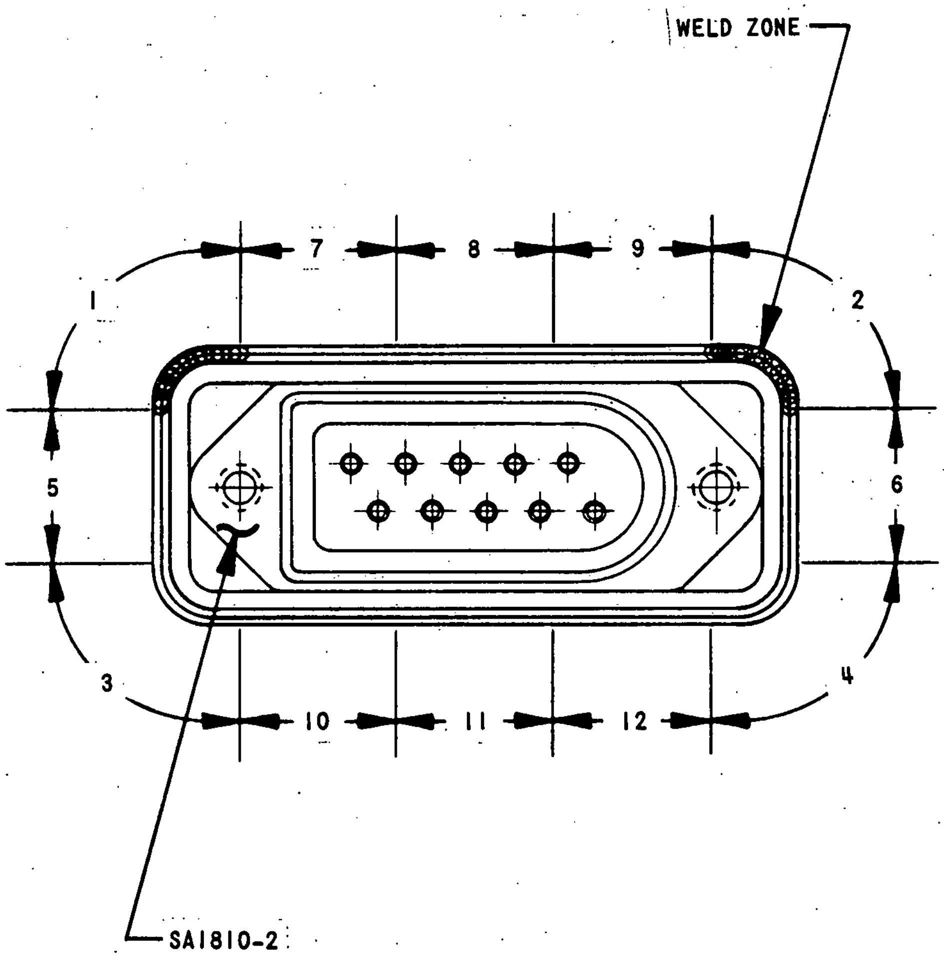

Figure 13. GTA Weld Sequences

Table 3 compares the GTA weld energy input required for edge and butt welding five thicknesses of 304 stainless steel. A significant decrease is apparent between the 0.050 inch (1.27 mm) and the 0.030 inch (0.76 mm) weld energy requirements. This data established the tolerance limits to be applied to the flange thickness of 0.020 to 0.030 inch (0.51 to 0.76 mm).

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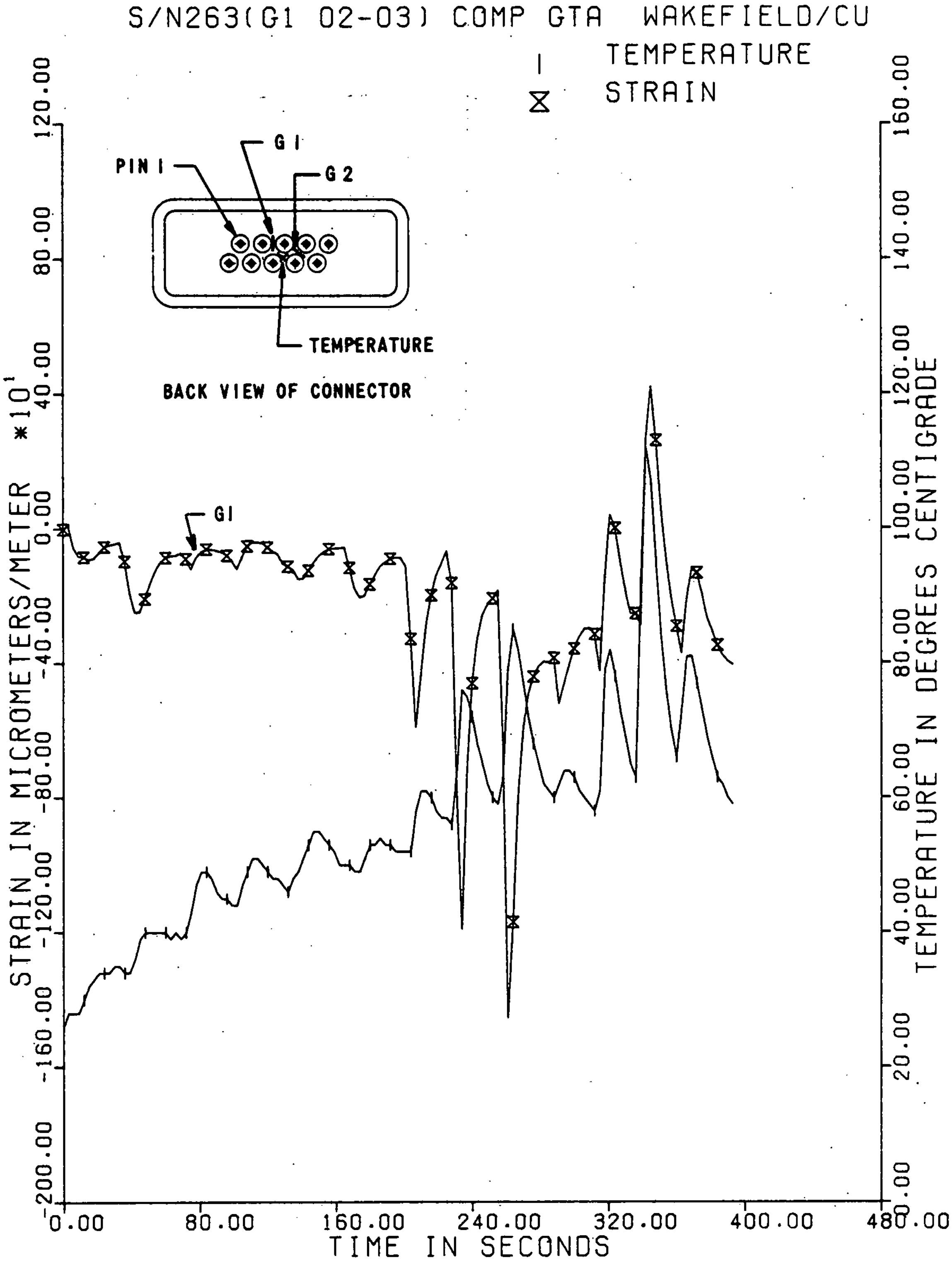

Figure 14. Strain and Temperature for GTA Hand Weld With Heat Sink

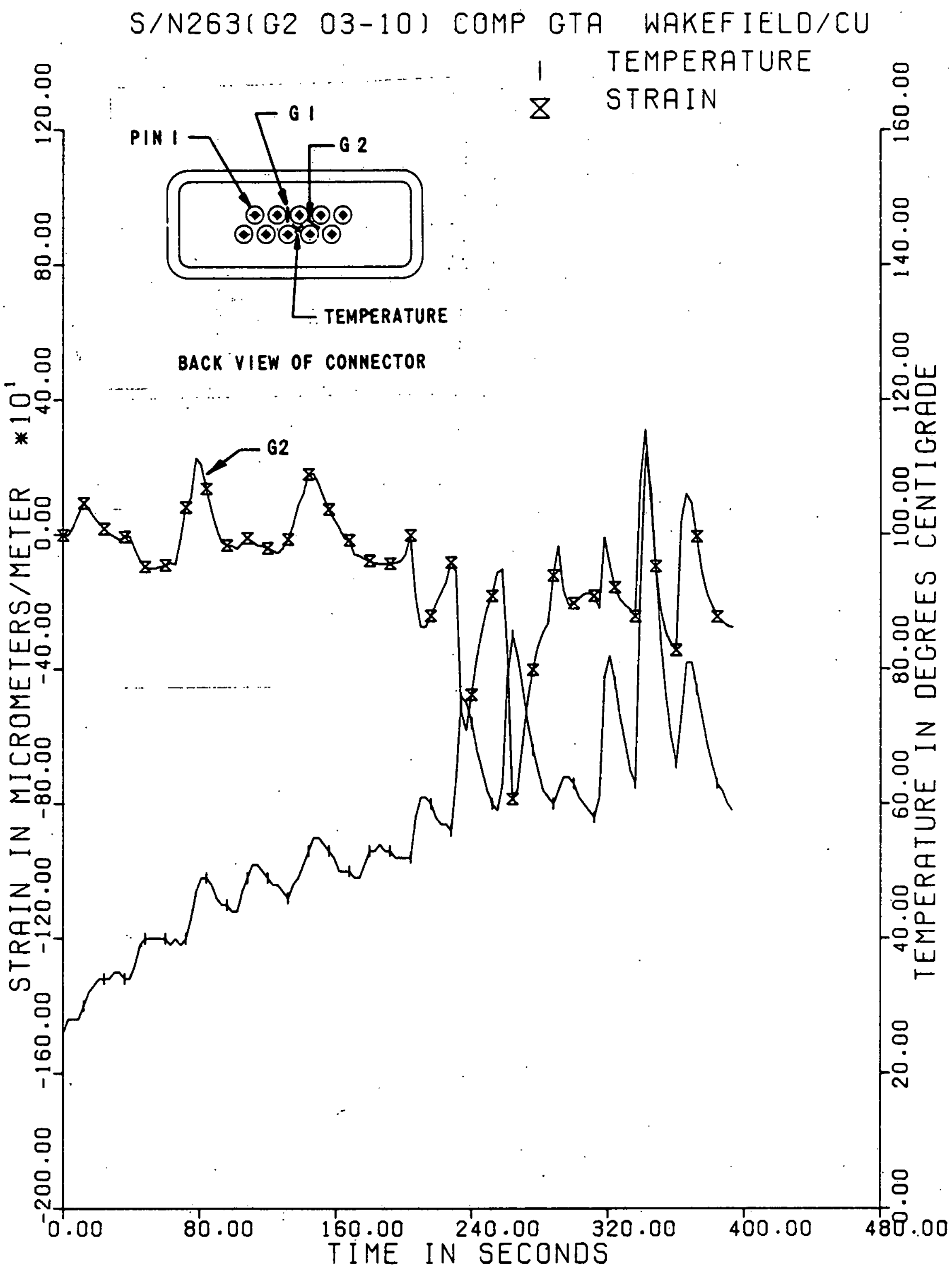

Figure 14 Continued. Strain and Temperature for GTA Hand Weld With Heat Sink

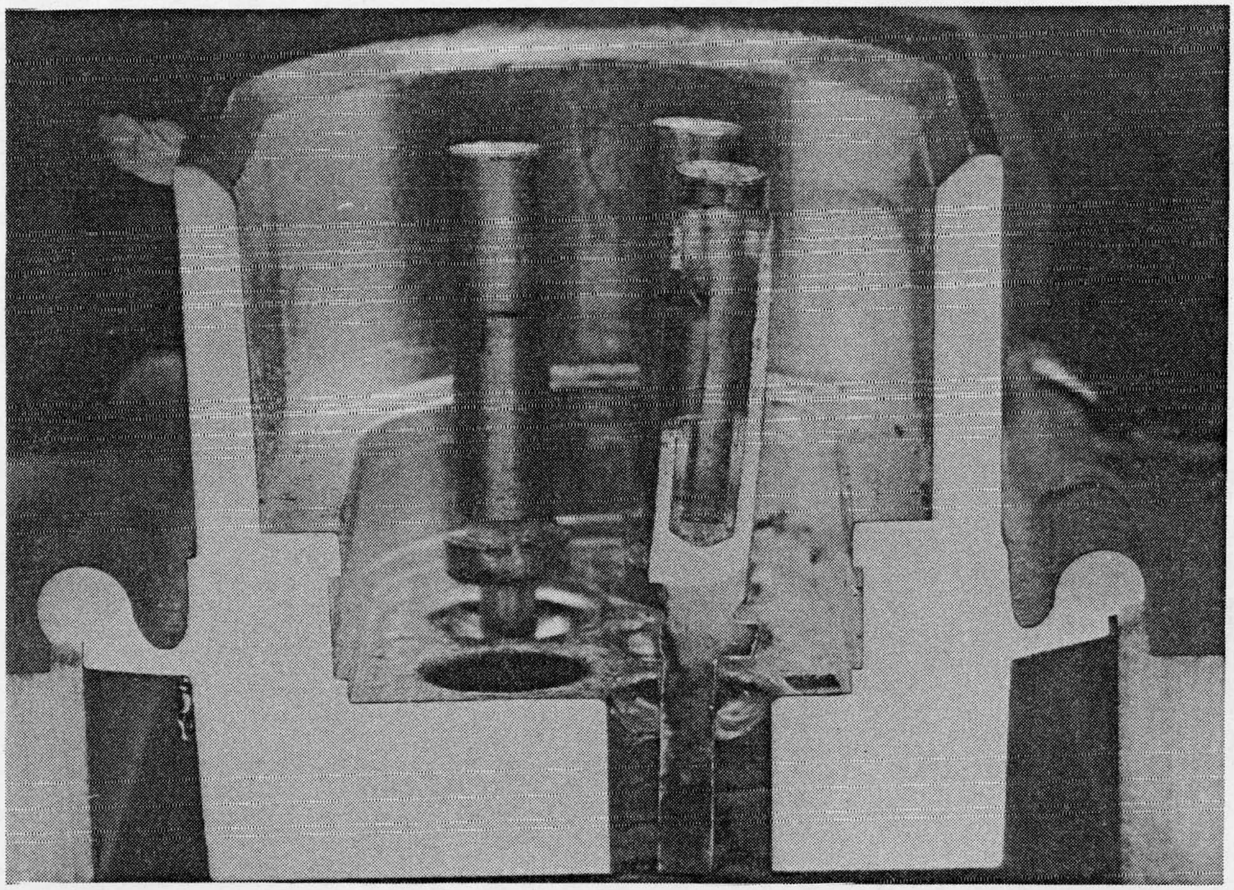

Figure 15. Reduced Weld Flange, SA1810

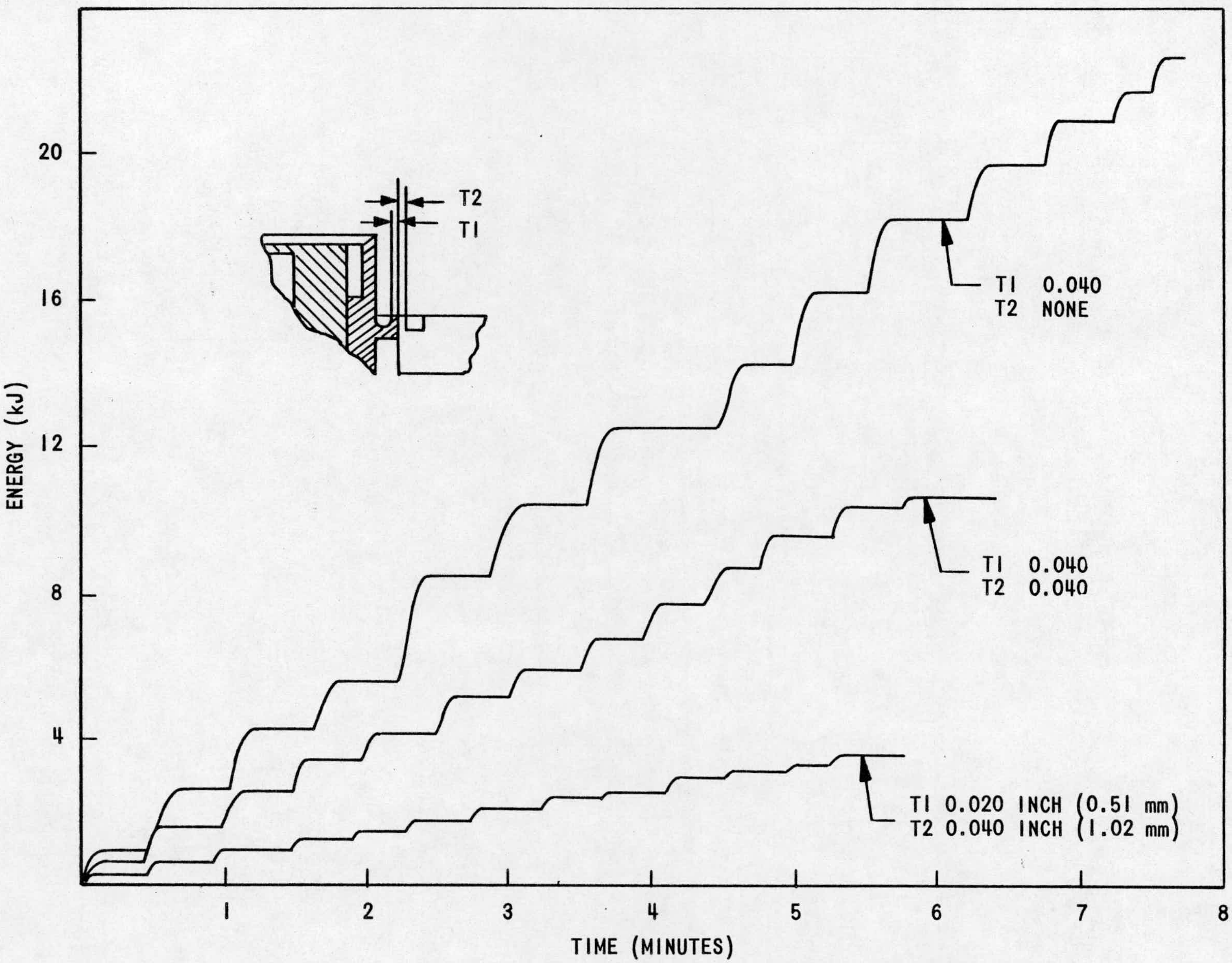

Figure 16. GTA Weld Energy Versus Flange Thickness

Table 3. GTA Weld Energy Versus 304 Stainless Steel Metal Thickness

Type of Weld	Metal Thickness (inch) (mm)	Time (seconds)	Watts	Weld Energy* (Watt-Seconds)
Edge	0.019 (0.48 mm)	21	70	1470
Butt	0.019** (0.48 mm)	--	--	--
Edge	0.030 (0.76 mm)	18	90	1620
Butt	0.030 (0.76 mm)	33	78	2574
Edge	0.050 (1.27 mm)	20	155	3100
Butt	0.050 (1.27 mm)	26	150	3900
Edge	0.078 (1.98 mm)	30	155	4185
Butt	0.078 (1.98 mm)	27	150	4650
Edge	0.090 (2.29 mm)	27	168	4050
Butt	0.090 (2.29 mm)	27	170	4590

*Average of six welds 2 inches (50.8 mm) in length
**Metal was too thin for butt welding with equipment used

ACCOMPLISHMENTS

Welding processes produce thermal and dimensional stresses that cause connector seal failure. Control of peak temperatures on the connector during welding is possible using properly designed heat sinks. Heat sinking does not significantly reduce the dimensional stresses associated with continuous EB welding around the connectors.

Leak rate data from controlled thermal cycling tests of connectors show that peak welding temperatures alone do not cause the magnitude of leaks observed in these experiments and in production units. Degradation of SA1810 seal integrity occurs in the 400 to 600°F (204 to 316°C) exposure region. Heat sinking, using an expanding collet design with oxide-filled silicone grease to improve thermal contact, successfully limits connector web temperature to less than 300°F (149°C) during EB and GTA welding.

EB welding, a continuous circumferential weld, produces severe strains in the connector web area. These strains are predominantly positive (indicating decreased compressive load on the glass) and residual strains offset at weld completion were positive resulting in a permanent reduction of compressive seal load. These transient strains in the positive direction are believed to cause glass seal cracking and separation of the glass-to-metal interfaces.

An intermittent GTA hand weld sequence was developed that did not produce the severe strains of EB welding. The GTA process resulted in strains that are predominantly negative (increased seal compression) and residual strains indicated some permanent increase in compressive seal load. The intermittent segmented GTA hand weld also allows forced gas cooling between welds, further limiting connector temperature rise. Leak testing of 20 SA1810-1 10-pin connectors welded into mounting rings showed no detectable change in leak rate. Leak rates were below the range of the leak detection equipment (0.00001 mm^3/s).

The SA1810 family of connectors can be successfully welded into the assembly using the segmented GTA weld and heat sinking. Disadvantages of this process are clean-up of the silicone heat sink compound and the intermittent weld increases the possibility of weld defects because of multiple starts and stops. Both of these problems can be overcome, but each tends to increase dependence on operator skill.

Reduction of weld flange thickness reduces the total weld energy for GTA hand welding to approximately that required by EB welding. Thinner weld flanges additionally limit heat conduction to the seal area and present a zone of reduced structural rigidity where weld shrinkage and distortions can be relieved without stressing the glass seals. Flange thicknesses of 0.02 to 0.03 inch (0.51 to 0.76 mm) were found best suited for GTA welding.

The developed process using heat sinks and a full GTA weld results in a cost savings when compared to the established GTA tack-EB weld process. These savings result from:

- Deletion of EB set-up and weld time (partially offset by a moderate increase in hand welding over previous tack welds required);
- Reduction in failure analysis and repair costs; and
- Deletion of the epoxy pre-sealing process.

FUTURE WORK

Work is continuing on improved heat sinking methods. Electrostatic cooling techniques will be reviewed and evaluated for application with GTA welding. A high voltage probe from Interprobe Inc., Chicago, IL, will be evaluated to determine if problems of copper heat sinks and silicone compound clean-up can be avoided.

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