**COMPARATIVE GROUNDING CONNECTOR TEST**

**PERFORMED FOR**

**ERICO®, INC.**

**SOLON, OHIO**

**PROJECT NUMBER C94901**

Southern Development
a subsidiary of The Southern Company

**COMPARATIVE GROUNDING CONNECTOR TEST**

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**ERICO®, INC.**

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REQUESTED BY: MR. CURT STIDHAM
ERICO, INC.

PROJECT MANAGER: T. L. McKoon
T. L. McKoon

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## INTRODUCTION

Mr. Curt Stidham, of ERICO®, Inc., contracted with Southern Electric International (SEI)/Georgia Power Research Center to evaluate three different designs of direct burial, electrical grounding connectors. The three designs chosen were exothermically welded (Cadweld®), bolted wedge, and die compression type connections. Mr. Stidham was interested in the heat rise performance characteristics of the various connections when installed on 250 kcmil, 37 strand, soft drawn copper conductor. The conductors were artificially aged in an oven for 24 hours at 500°F to simulate oxidized conductors in an existing ground grid system.

Ten connectors were included in the test program; they are as follows.

- Two exothermically welded type connectors, (Cadweld® Part Number TAC2V2V)
- Two bolted wedge type connectors (AMP, Inc. Part Number 81228-1)
- Two die compression, cross connectors (Burndy Part Number YGL29C29)
- Two die compression, tap connectors (Burndy Part Number YGHC29C29)
- Two die compression, cross connectors (T & B Part Number GG40250-40250)

A complete description and photographs of the connectors tested are included in the **SAMPLES TESTED** section of this report.

The test was conducted to the IEEE Std. 837-1989, "IEEE Standard for Qualifying Permanent Connections Used in Substation Grounding", Section 8.2.1 through 8.7.3, "Current Temperature Cycling", with the following exceptions:

- 8.2.2 Test Samples.....Two samples of each connector type were tested, rather than four as directed by the standard.

- 8.5.1 Current Cycling Period.....The IEEE Std. 837-1989 calls for, as part of section 8 (Current-Temperature Cycling), a minimum temperature of 350°C (8.5.1) for copper conductor. This test program conducted current-temperature cycles to a control conductor temperature of 550°C. Referencing ANSI/IEEE Std. 80-1986, the fusing temperature of soft drawn copper wire is 1083°C, thus the minimum temperature required in IEEE Std. 837-1989 for Current-Temperature Cycling represents only 32% of the fusing temperature. Increasing the testing temperature to 550°C represents a temperature that is 51% of the fusing temperature, thereby providing a harsher test condition on the ability of grounding connectors to surpass the performance requirements of IEEE Std. 837-1989.

- 8.5.2 Number of Cycles.....The IEEE Std. 837-1989 calls for, as part of Section 8 (Current-Temperature Cycling), a minimum of 25 current temperature cycles (8.5.2) This test program conducted 100 current-temperature cycles to provide data on the margins with which the grounding connectors could surpass this minimum requirement.

- 8.7 Measurements.....Temperature measurements were made at the end of each of the 100 cycles rather than every five cycles as directed by the standard. Resistance measurements were made every tenth cycle, through cycle 100, rather than every five cycles as directed by the standard.

- NOTE: Aged cable was chosen for the test to simulate a common situation that exists when a new connection must be made to an existing ground grid network. The grid conductors, over years of service, will become oxidized and wire brushing the exterior of the cable, before the installation of a grounding connector, will not remove the oxide between the interior strands. Therefore, the resulting connector resistance will most likely be higher than an equivalent connection made to pristine conductor. Therefore, the use of aged conductor provided results on connector performance of a practical service condition that is not addressed in IEEE Std. 837-1989, Section 8. All test conductors were serviced aged by heating in an oven for 24 hours at a temperature of 500°F prior to installing the grounding connectors.

- Pages 13 and 14 of IEEE Std.837-1989 are included in **<u>APPENDIX 2.</u>**

## SUMMARY

A modified IEEE Std. 837-1989, Current-Temperature Cycle Test (Section 8) was performed on a variety of electrical grounding connectors to evaluate their relative performance. The connection styles evaluated were those typically used to join a ground lead to a grid system, or to make a connection within the system itself. The test was modified from the standard to produce harsher testing conditions and provide more meaningful results. Instead of clean new conductor, the test was performed on oxidized conductor to simulate conditions found in making connections to existing grids. Also, the control conductor soak temperature was increased from 350°C to 550°C. Current-Temperature Cycle testing was carried out for 100 cycles to provide a more realistic performance comparison.

Results of the test show that the exothermically welded (Cadweld®) connectors, Part Number TAC2V2V out performed the bolted wedge, AMP Part Number 81228-1, and die compression, Burndy Part Numbers YCL29C29 and YGHC29C29, and Thomas and Betts Part Number GG40250-40250 connectors by a wide margin.

By the conclusion of the first cycle all the connectors tested, except the Cadweld® welded connectors, had exceeded the control conductor temperature of 550°C and failed the maximum temperature requirement of IEEE Std. 837-1989 (Section 5.3.1). At this point, both of the exothermically welded (Cadweld®) connectors were still operating at a temperature well below that of the control conductor. The test was continued until either the connector or the conductor burned through and caused an open circuit in the test loop. When an open circuit occurred, the connector was shunted and the test was allowed to continue.

By the conclusion of the 21st cycle all the connectors tested, except for the Cadweld® welded connectors and the Burndy #2 tap connector (Part Number YGHC29C29), had to be shunted. The remaining Burndy connector lasted through cycle 34. At this point, both of the Cadweld® welded connectors were operating at a temperature well below that of the control conductor.

At the end of cycle 58, the Cadweld® welded connector #2 had exceeded the control conductor temperature. The Cadweld® welded connector had to be shunted before the start of the 65th cycle due to the conductor fusing on the 64th cycle, at a distance of approximately eight inches away from the connector. The Cadweld® welded connector #1 lasted through the entire 100 cycles without its temperature ever exceeding that of the control conductor.

Graphs detailing each connector's performance are included in **APPENDIX 1**. Charts of each connector's temperature, at each operable cycle, up to 100 cycles, are included in the **TEST PROGRAM** section.

## SAMPLES TESTED

ERICO®, Inc., in Solon, Ohio, provided the molds and weld materials to install the horizontal Tee (Part Number TAC2V2V), cable to cable, exothermically welded connections. The bolted wedge and die compression type connectors were chosen by ERICO®, Inc., and the Georgia Power Research Center procured the connectors from various manufacturers, along with the proper dies used for installation. No dies or compression tools were required to install the bolted wedge connectors.

The conductor used for the test program was 250 kcmil, 37 strand, soft drawn copper, of the same type and size commonly used in typical substation ground grids. The conductor was artificially serviced aged, by exposure to 500°F for 24 hours in an oven, prior to installing the connectors. For all connectors, prior to connector installation, the conductor ends, and circumference at the ends, were wire brushed to remove any oxide build up caused by the service aging.

**FIGURES 1** & **2** are photographs of Cadweld® exothermically welded connections #1 and #2 taken during the 100 cycle, current cycle, heat rise test.

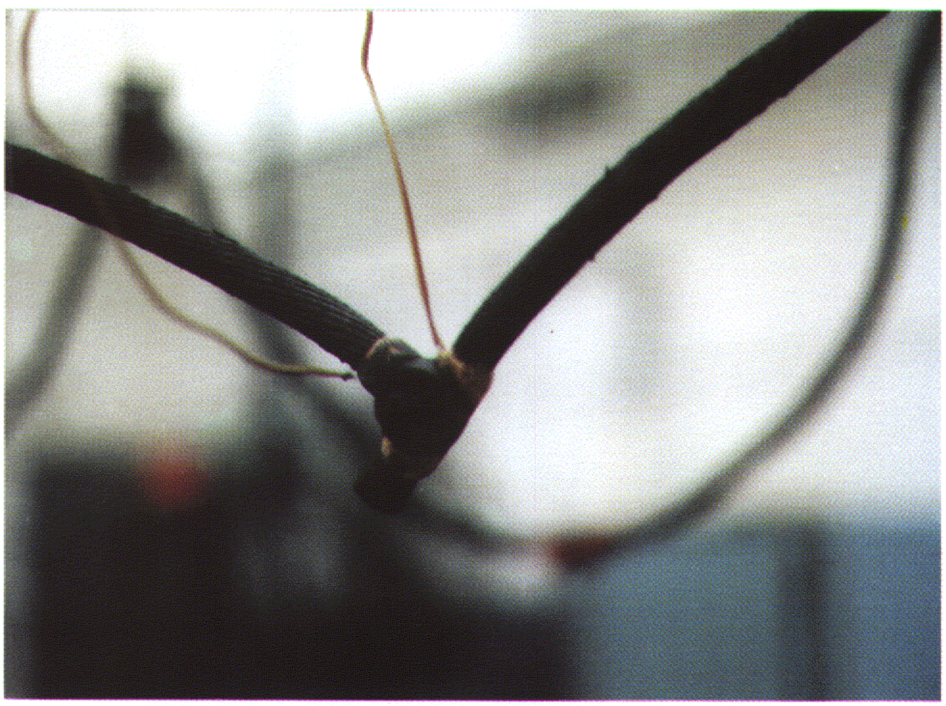


**FIGURE 1**
Cadweld® exothermically welded connection #1

**FIGURE 2**
Cadweld® exothermically welded connection #2
Photograph taken during cycle #57

The bolted wedge design connector (AMP Part Number 81228-1), is a wedge pressure system comprised of a bronze body and wedge, with a copper alloy 'nest' and bronze shear head bolt. After the conductors have been inserted into the body, and the nest inserted between them, a tapered wedge is driven into the body, causing the body to spring open. The conductors are held together by a constant compressive force of the elastic body, trying to recover to its original shape. The connection is accomplished with a standard socket wrench (ratchet). Once the designed torque is reached on the shear head bolt, the bolt breaks away leaving the connection intact. **FIGURES 3 & 4** are photographs of AMP Part Number 81228-1, connectors #1 & #2 taken during the 100 cycle, current cycle test.

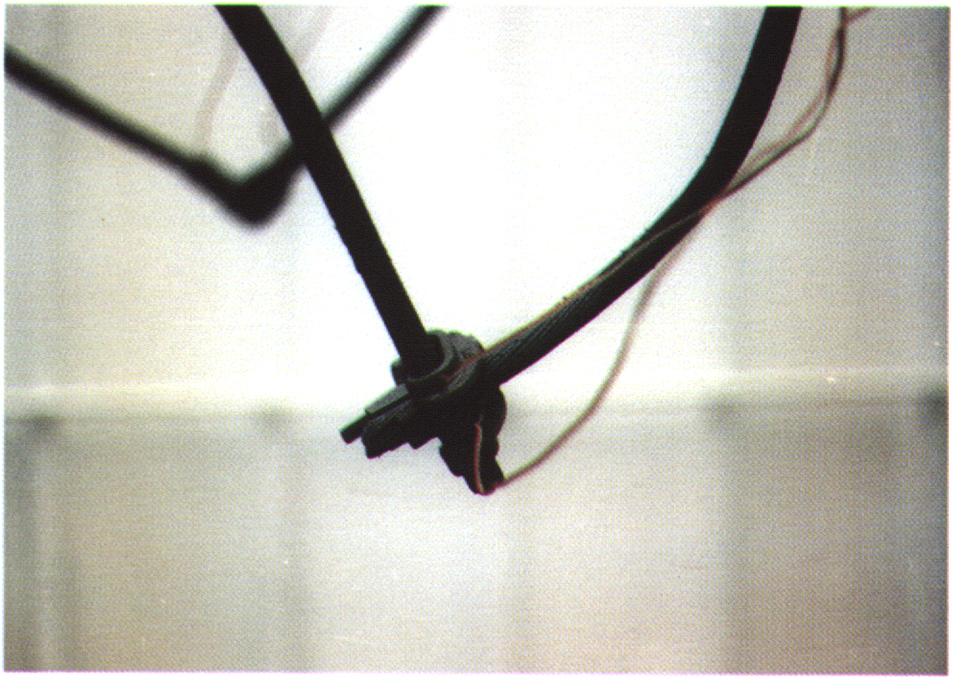


**FIGURE 3**
AMP Bolted wedge connector #1
Photograph taken during cycle #5

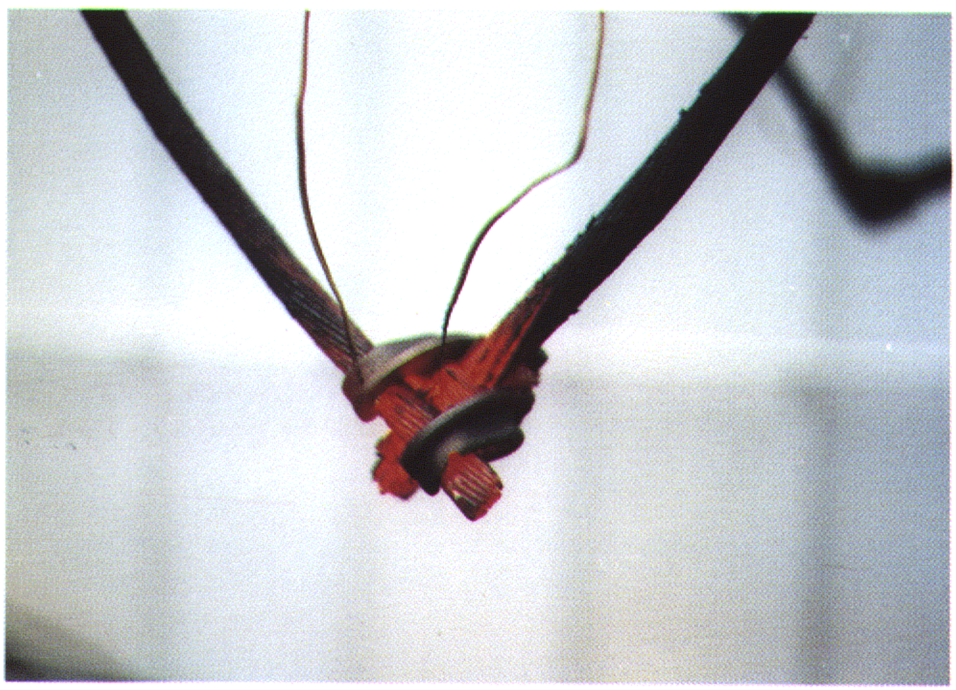


**FIGURE 4**
AMP Bolted wedge connector #2
Photograph taken during cycle #4

The die compression type tap connectors, (Burndy Part Number YGHC29C29) are designed to accommodate two continuous parallel cables in the connector's conductor grooves. The connector is "C" shaped and requires a hydraulic compression tool with a U997 die to install. **FIGURES 5 & 6** are photographs of the die compression type tap connectors #1 & #2 taken during the 100 cycle, current cycle test.

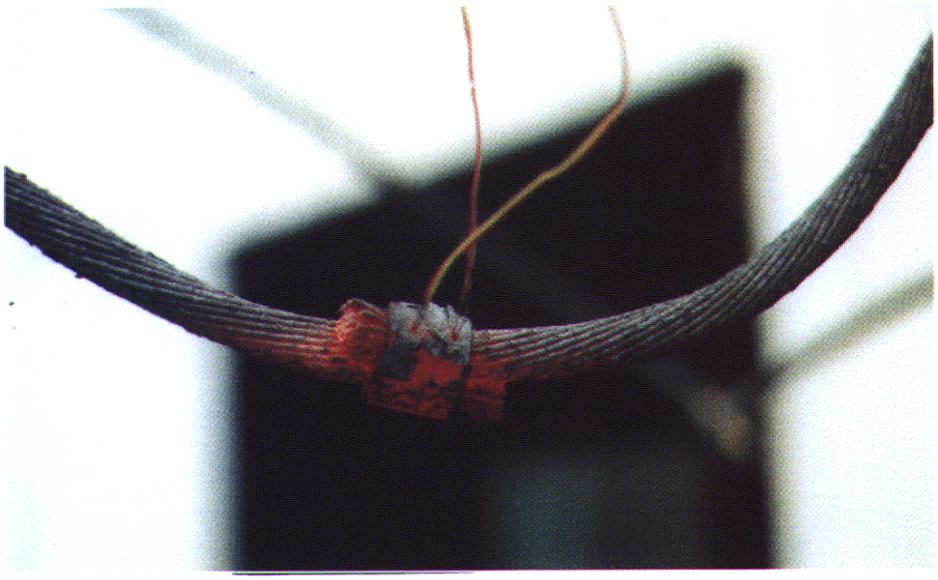


**FIGURE 5**
Burndy YGHC29C29 die compression tap connector #1
Photograph taken during cycle #10

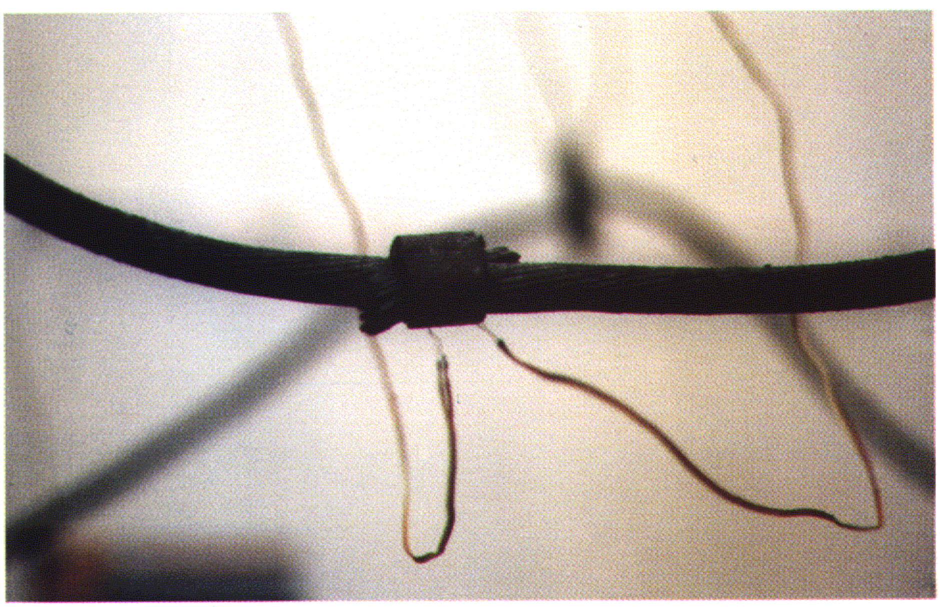


**FIGURE 6**
Burndy YGHC29C29 die compression tap connector #2
Photograph taken during cycle #10

The die compression type, cross connectors, (Burndy Part Number YGL29C29) are designed to make a 90° turn in the ground grid. Similar to the tap connector, the cross connector requires a hydraulic compression tool and a U997 die to install. The connector incorporates two 'C' elements with a 1/2 inch diameter copper rod bent to 90 degrees. When the conductors are inserted and the compression is made, the connector crimps both the conductor and copper rod making a rigid connection. Before crimping, both connector elements can be rotated on the copper rod to any desired position. **FIGURES 7 & 8** are photographs of the die compression type cross connectors #1 & #2 taken during the 100 cycle, current cycle test.

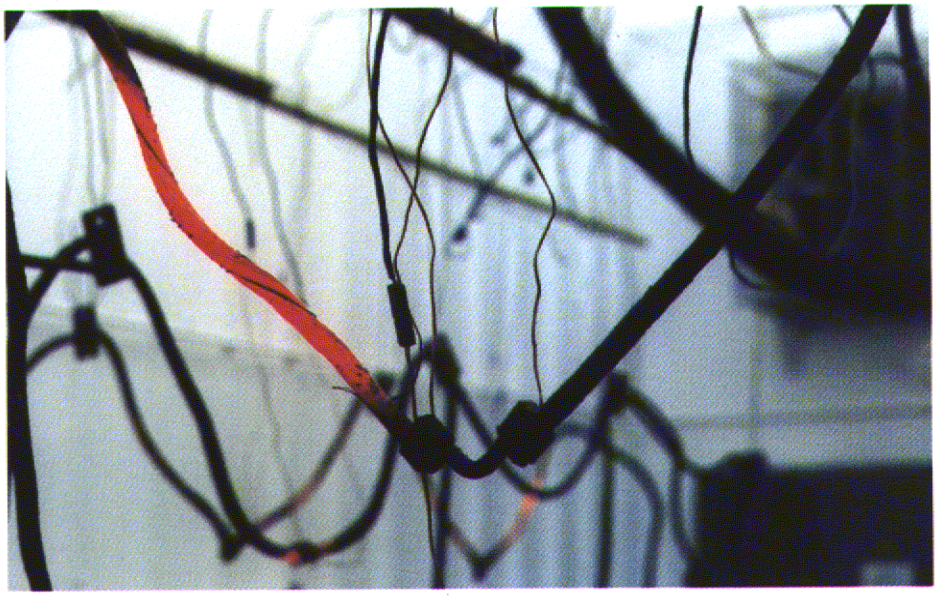


**FIGURE 7**
Burndy YGL29C29 Die compression type cross connector #1
Photograph taken during cycle #8

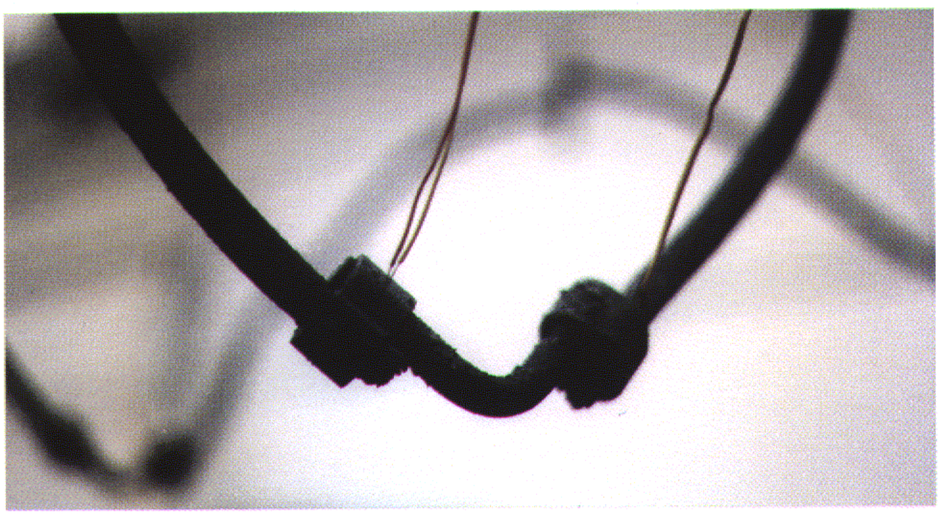


**FIGURE 8**
Burndy YGL29C29 Die compression type cross connector #2
Photograph taken during cycle #29

Another design of the die compression type cross connector tested was (Thomas & Betts Part Number GG40250-40250). This design connector is a one piece construction, also designed for making a 90 degree turn in the ground grid. The connector is designed for cable to cable or cable to rod installation. The connection requires a hydraulic compression tool with a 71H compression die. **FIGURE 9** is a photograph of Thomas & Betts die compression type cross connector #1 taken during the 100 cycle, current cycle test. Photograph of Thomas and Betts connector #2 is not available.

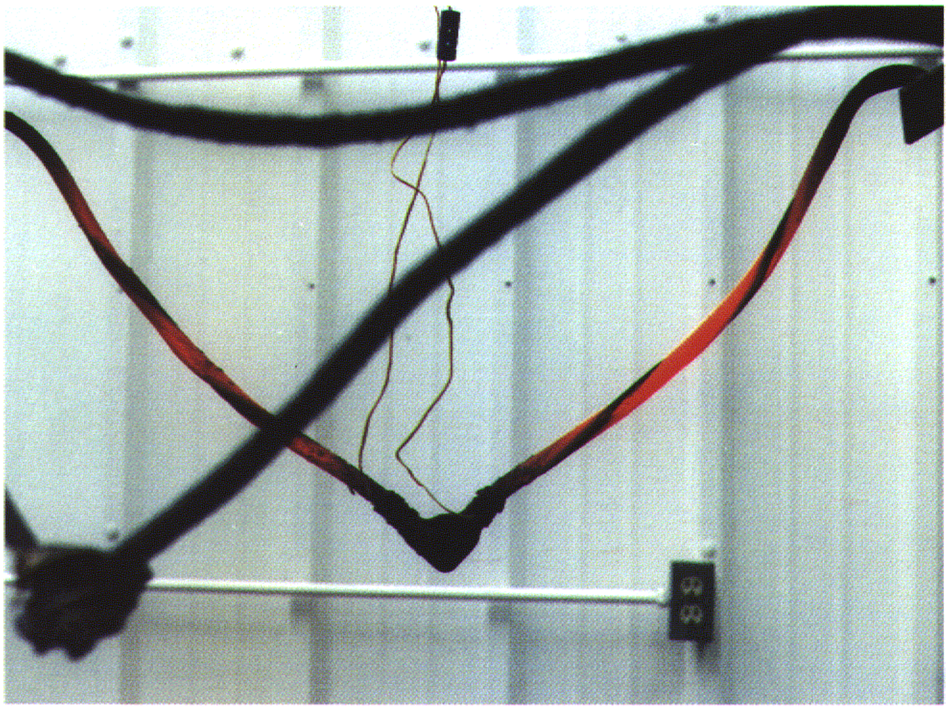


**FIGURE 9**
T & B GG40250-40250 Die compression type cross connector #1
Photograph taken during cycle #15

## TEST PROGRAM

### RESISTANCE

The thermal and electrical evaluation required one current cycle loop. Two connectors of each design, for each manufacturer, were tested. The complete loop contained ten connectors and a control conductor. The loop was prepared in accordance with IEEE Std. 837-1989. **ILLUSTRATION 1** is a sketch of the loop as prepared and tested.

After placing the loop in the current cycle test fixture, type K thermocouples and permanent resistance leads were attached. Prior to energizing the loop with current, an initial voltage drop (resistance) reading was taken on each connector. The initial voltage drop reading is not used in the evaluation of the connector's performance; however, the reading was recorded as a base line for overall change. **TABLE 1** contains the initial connector resistance values taken from voltage drop readings prior to energizing.

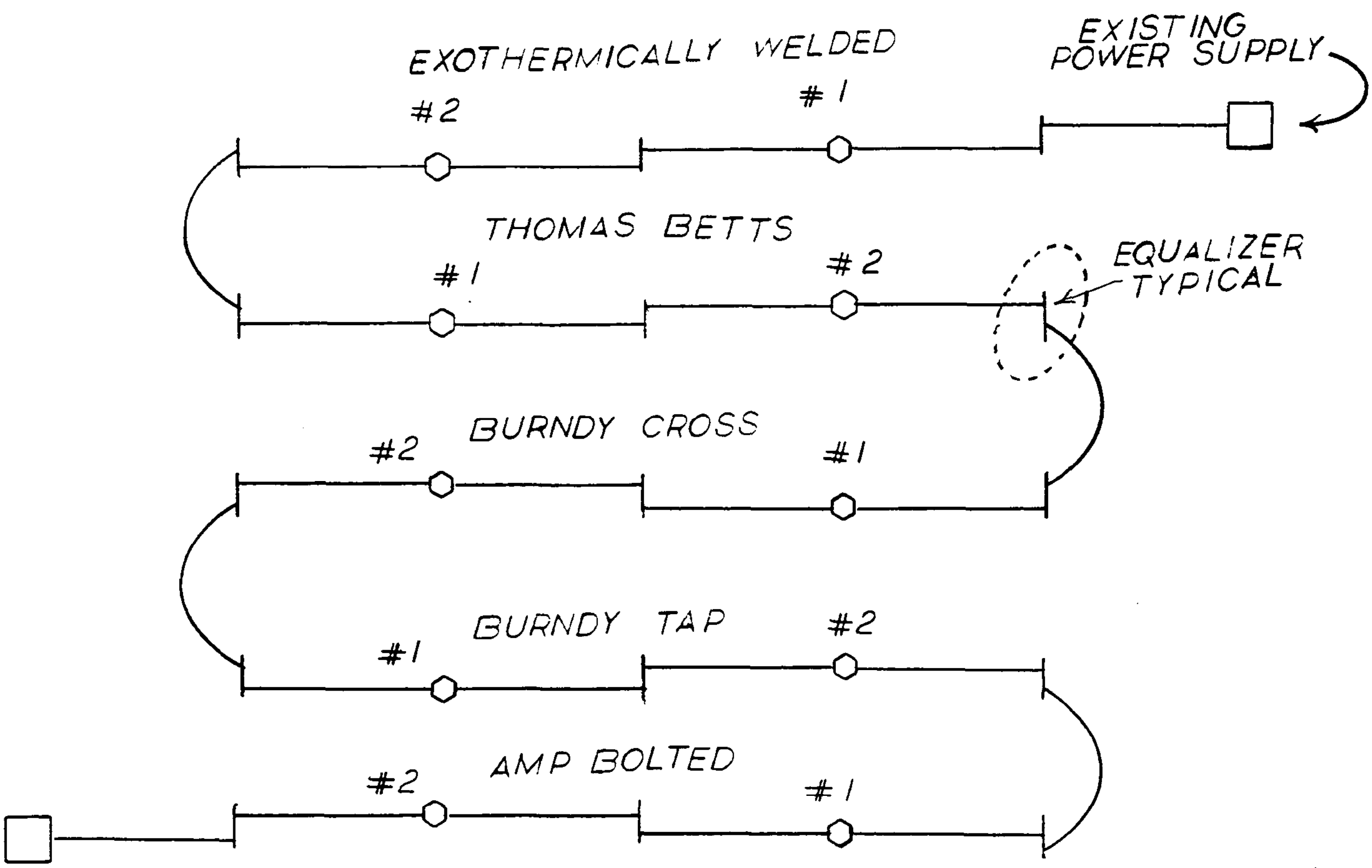



**ILLUSTRATION 1**

## TABLE 1

| CONNECTOR RESISTANCE (IN MICROOHMS)* | |
|---|---|
| Corrected to 20° Celsius | Total Connector Resistance Less Conductor |
| 1) Cadweld® part number TAC2V2V welded connector #1 | 9 |
| 2) Cadweld® part number TAC2V2V welded connector #2 | 27 |
| 3) T & B part number GG40250 - 40250 cross connector #1 | 24 |
| 4) T & B part number GG40250 - 40250 cross connector #2 | 24 |
| 5) Burndy part number YCL29C29 cross connector #1 | 32 |
| 6) Burndy part number YGL29C29 cross connector #2 | 35 |
| 7) Burndy part number YGHC29C29 tap connector #1 | 146 |
| 8) Burndy part number YGHC29C29 tap connector #2 | 178 |
| 9) AMP part number 81228-1 bolted wedge connector #1 | 22 |
| 10) AMP part number 81228-1 bolted wedge connector #2 | 29 |
| 11) 48 inch length of control conductor | 170 |

* Connector resistance is the reading between two equalizers minus the control conductor resistance (IEEE Std. 837-1989)

The test loop was then energized with sufficient current to achieve a temperature of 550° Celsius on the control conductor. During load cycle one, the control conductor attained the 550° Celsius target temperature with 1,600 amperes of current; however, the resistance of some of the connections had increased the overall loop resistance to a magnitude that the existing power supply would not maintain the desired temperature. Consequently, the loop had to be removed from the connector laboratory, and taken to another location in the lab, with a power supply that had the capability of maintaining the desired current. **NOTE:** By the end of cycle one, all of the connectors with the exception of the exothermically welded Cadweld® connectors, had exceeded the temperature of the control conductor and failed the temperature requirement of IEEE Std. 837.

Care was taken to not disturb any of the connections during movement. The loop was moved as an entire assembly and nothing was taken apart. Prior to moving, the test loop was allowed to return to ambient temperature and another voltage drop reading was recorded. When the loop was installed at the new location, another voltage drop reading was recorded to assure that no damage was done to any of the connections during movement. It was observed that some resistance change had occurred during movement. The worst case was for the bolted wedge type connectors. **TABLE 2** contains the 'before and after movement' connector resistance values taken from voltage drop measurements.

**TABLE 2**

| CONNECTOR RESISTANCE (IN MICROOHMS) | | |
|---|---|---|
| Corrected to 20° Celsius | BEFORE | AFTER |
| 1) Cadweld® part number TAC2V2V welded connector #1 | 10 | 1 |
| 2) Cadweld® part number TAC2V2V welded connector #2 | 7 | 23 |
| 3) T & B part number GG40250-40250 cross connector #1 | 172 | 143 |
| 4) T & B part number GG40250-40250 cross connector #2 | 178 | 179 |
| 5) Burndy part number YGL29C29 cross connector #1 | 117 | 97 |
| 6) Burndy part number YGL29C29 cross connector #2 | 64 | 70 |
| 7) Burndy part number YGHC29C29 tap connector #1 | 143 | 170 |
| 8) Burndy part number YGHC29C29 tap connector #2 | 75 | 65 |
| 9) AMP part number 81228-1 bolted wedge connector #1 | 26 | 38 |
| 10) AMP part number 81228-1 bolted wedge connector #2 | 57 | 145 |
| 11) 48 inch length of control conductor | 173 | 176 |

At this point, the test loop was connected to a larger power supply, and the test was continued for the remaining 99 cycles. **TABLE 3** contains the resistance values recorded every tenth cycle for the duration of the test.

## TABLE 3

**CONNECTOR RESISTANCE VALUES EVERY TENTH CYCLE (IN MICROOHMS) LESS 48 INCH LENGTH OF CONTROL CONDUCTOR (IEEE STD. 837-1989)**
**Corrected to 20° Celsius**

| | CYCLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| EXOTHERMICALLY WELDED CADWELD® #1 | -6 | 55 | 0 | 9 | 14 | 25 | 27 | 26 | 25 | 29 |
| EXOTHERMICALLY WELDED CADWELD #2 | 22 | 28 | 24 | 39 | 50 | 112 | *** | *** | *** | *** |
| THOMAS & BETTS PN GG40250-40250 CROSS CONNECTOR #1 | 145 | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| THOMAS & BETTS PN GG40250-40250 CROSS CONNECTOR #2 | 180 | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| BURNDY PN YGL29C29 CROSS CONNECTOR #1 | 212 | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| BURNDY PN YGL29C29 CROSS CONNECTOR #2 | 65 | 68 | 131 | *** | *** | *** | *** | *** | *** | *** |
| BURNDY PN YGHC29C29 TAP CONNECTOR #1 | 182 | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| BURNDY PN YGHC29C29 TAP CONNECTOR #2 | 112 | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| AMP PN 81221-1 BOLTED WEDGE #1 | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| AMP PN 81221-1 BOLTED WEDGE #2 | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| CONTROL CONDUCTOR RESISTANCE | 204 | 207 | 198 | 221 | 233 | 226 | 230 | 234 | 245 | 249 |

*** Denotes shunted connector

**TEMPERATURE**

ERICO® EXOTHERMICALLY WELDED CADWELD® CONNECTION
PART NUMBER TAC2V2V

The ERICO® exothermically welded Cadweld® connection #1 completed the 100 cycle, current cycle test without failure. The maximum temperature recorded during the 100 cycle test was 498° Celsius. At the time of the reading, the control conductor temperature was 551° Celsius.

The ERICO® exothermically welded Cadweld® connection #2 exceeded the temperature of the control conductor at cycle 58. The temperature of the connection was 553° and 533° Celsius at thermocouple locations one and two respectively. The control conductor temperature at the time of the reading was 549° Celsius. As stated in the summary, a 'hot spot' developed on the conductor approximately eight inches away from the connection due to a loss of cross sectional area of the conductor. The connection was allowed to continue to run until the conductor fusing occurred and burned in half at the 'hot spot' during cycle 64. The connector was shunted, and the test was allowed to continue. The shunts used in this test were 48 inch lengths of like conductor used in the test loop. The 48 inch length of shunt conductor was gas welded (brazed) into existing holes that were pre-drilled into the equalizers prior to starting the test.

AMP BOLTED WEDGE CONNECTORS
PART NUMBER 81228-1

During the first six cycles, the bolted wedge connectors began to increase significantly in temperature. The connectors began to glow bright orange within ten minutes into cycle three and arc periodically. By the conclusion of cycle four, bolted wedge connector #2, had reached a temperature of 894° Celsius and began to melt. At this point the connector ceased to perform, and current could no longer be passed through the connection. The connector was shunted with a 48 inch length of the same conductor used to assemble the loop, and the test was continued.

At cycle six, the remaining bolted wedge connector #1, reached a temperature of 960° Celsius. At this point the conductor melted inside the connector and separated. Again, the connection was shunted with a 48 inch length of conductor and the test was continued.

BURNDY DIE COMPRESSION CROSS CONNECTOR
PART NUMBER YGL29C29

At cycle 14, the conductor used in the assembly of Burndy's Part Number YGL29C29, cross connector #1, burned in half approximately five inches from the connector. The connector temperature had exceeded the temperature of the control conductor at both thermocouple locations (642 and 619 degrees Celsius). The conductor developed a hot spot, due to the loss of cross sectional area during the thermal cycling, and eventually burned and separated.

At cycle 18, the same failure mode occurred for cross connector #2. The conductor burned and separated approximately nine inches from the crimped connection. The connector temperature at the time of the conductor failure was 622 and 601 degrees Celsius.

BURNDY DIE COMPRESSION TAP CONNECTOR
PART NUMBER YGHC29C29

At cycle 17, the conductor used to join Burndy's tap connector #1, burned in half at the connection. At the time of conductor failure, the connector temperature, at both thermocouple locations was 646 and 658 degrees Celsius; however, during previous cycles earlier in the test, the connector temperature reached a temperature of 719 and 734 degrees Celsius.

At cycle 34, the conductor used to join Burndy's tap connector #2, burned in half at the connection. The same failure mode is suspected in connection #2 as in connection #1 due to similarities. At the time of the failure, the connection had reached a temperature of 625 and 608 degrees Celsius. During previous cycles, the connection had reached temperatures of 716 and 709 degrees Celsius.

THOMAS & BETTS DIE COMPRESSION CROSS CONNECTOR
PART NUMBER GG40250-40250

At cycle 20, the conductor used to join Thomas & Betts cross connector #2, burned in half approximately four inches from the connector. At the time of conductor failure the connector temperature at both thermocouple locations was 644 and 596 degrees Celsius. The maximum temperature attained on the connector was 674 degrees Celsius during cycle 17.

At cycle 21, the conductor used to join Thomas & Betts cross connector #1, burned in half at the connector. At the time of the failure, the connector temperature was 705 and 708 degrees Celsius.

TABLE 4 shows the maximum temperatures, recorded at the end of each listed cycle, for all connectors tested. **BOLD TYPE** indicates that the connection temperature is operating at a higher temperature than the control conductor temperature.

## TEST EQUIPMENT

To conduct the 100 cycle, current cycle test, the following equipment was used.

- Current cycle test power supply
- Fluke data acquisition unit, Model #2280B
- Biddle low resistance ohm meter, Model DLRO, Catalog #PN 15572-1

<u>TABLE 4</u>

| TEMPERATURE DEGREES CELSIUS FOR LAST READING OF EACH RECORDED CYCLE | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CYCLE NUMBER | CONTROL TEMP. | EXOTHERMIC CADWELD #1 | | EXOTHERMIC CADWELD #2 | | THOMAS & BETTS CROSS CONNECTOR #1 | | THOMAS & BETTS CROSS CONNECTOR #2 | |
| | | TC #1 | TC #2 | TC #1 | TC #2 | TC #1 | TC #2 | TC #1 | TC #2 |
| 1 | 544 | 472 | 477 | 465 | 462 | 577 | 581 | 581 | 575 |
| 2 | 550 | 485 | 496 | 469 | 463 | 608 | 602 | 607 | 597 |
| 3 | 551 | 479 | 498 | 466 | 460 | 598 | 592 | 594 | 584 |
| 4 | 552 | 475 | 483 | 464 | 451 | 592 | 589 | 595 | 589 |
| 5 | 552 | 471 | 479 | 463 | 448 | 589 | 588 | 596 | 587 |
| 6 | 553 | 469 | 475 | 459 | 452 | 592 | 596 | 607 | 593 |
| 7 | 551 | 465 | 471 | 451 | 443 | 607 | 604 | 608 | 591 |
| 8 | 551 | 464 | 470 | 454 | 453 | 601 | 603 | 618 | 596 |
| 9 | 551 | 465 | 469 | 458 | 473 | 606 | 560 | 628 | 583 |
| 10 | 549 | 463 | 469 | 466 | 477 | 611 | 581 | 601 | 595 |
| 11 | 550 | 466 | 471 | 462 | 455 | 614 | 589 | 597 | 591 |
| 12 | 552 | 465 | 469 | 470 | 458 | 599 | 586 | 603 | 598 |
| 13 | 550 | 465 | 470 | 470 | 477 | 615 | 598 | 615 | 598 |
| 14 | 550 | 465 | 470 | 473 | 477 | 602 | 569 | 630 | 599 |
| 15 | 549 | 464 | 469 | 471 | 473 | 617 | 600 | 625 | 598 |
| 16 | 548 | 464 | 469 | 472 | 472 | 620 | 622 | 634 | 597 |
| 17 | 554 | 467 | 472 | 476 | 477 | 612 | 626 | 674 | 612 |
| 18 | 550 | 468 | 474 | 487 | 481 | 578 | 606 | 660 | 616 |
| 19 | 549 | 470 | 474 | 488 | 482 | 620 | 630 | 644 | 596 |
| 20 | 547 | 469 | 472 | 488 | 482 | 705 | 708 | SHUNT | |
| 21 | 550 | 469 | 473 | 487 | 482 | SHUNT | | | |
| 22 | 550 | 467 | 471 | 486 | 481 | | | | |
| 23 | 551 | 466 | 469 | 487 | 481 | | | | |
| 24 | 550 | 466 | 469 | 485 | 479 | | | | |
| 25 | 551 | 467 | 471 | 487 | 481 | | | | |

<u>TABLE 4</u>

| TEMPERATURE DEGREES CELSIUS FOR LAST READING OF EACH RECORDED CYCLE | | | | | |
|---|---|---|---|---|---|
| CYCLE NUMBER | CONTROL TEMP. | EXOTHERMIC CADWELD #1 TC #1 TC #2 | EXOTHERMIC CADWELD #2 TC #1 TC #2 | THOMAS & BETTS CROSS CONNECTOR #1 TC #1 TC #2 | THOMAS & BETTS CROSS CONNECTOR #2 TC #1 TC #2 |
| 26 | 549 | 466 470 | 495 481 | SHUNT | SHUNT |
| 27 | 552 | 465 468 | 487 481 | | |
| 28 | 550 | 468 471 | 490 484 | | |
| 29 | 552 | 467 469 | 489 483 | | |
| 30 | 552 | 467 470 | 489 484 | | |
| 31 | 549 | 468 471 | 488 482 | | |
| 32 | 551 | 468 471 | 489 483 | | |
| 33 | 548 | 470 473 | 485 478 | | |
| 34 | 551 | 472 475 | 494 488 | | |
| 35 | 547 | 469 472 | 492 486 | | |
| 36 | 552 | 473 467 | 500 493 | | |
| 37 | 550 | 471 474 | 499 491 | | |
| 38 | 550 | 470 473 | 498 490 | | |
| 39 | 544 | 466 468 | 494 487 | | |
| 40 | 549 | 472 475 | 497 490 | | |
| 41 | 549 | 472 475 | 498 490 | | |
| 42 | 544 | 474 477 | 504 494 | | |
| 43 | 547 | 474 477 | 501 492 | | |
| 44 | 551 | 477 481 | 510 501 | | |
| 45 | 548 | 476 479 | 507 498 | | |
| 46 | 549 | 469 473 | 505 495 | | |
| 47 | 551 | 470 472 | 504 494 | | |
| 48 | 549 | 475 478 | 507 497 | | |
| 49 | 549 | 478 481 | 513 503 | | |
| 50 | 547 | 478 480 | 505 494 | | |

## TABLE 4

| TEMPERATURE DEGREES CELSIUS FOR LAST READING OF EACH RECORDED CYCLE | | | | | |
|---|---|---|---|---|---|
| CYCLE NUMBER | CONTROL TEMP. | EXOTHERMIC CADWELD #1 TC #1 TC #2 | EXOTHERMIC CADWELD #2 TC #1 TC #2 | THOMAS & BETTS CROSS CONNECTOR #1 TC #1 TC #2 | THOMAS & BETTS CROSS CONNECTOR #2 TC #1 TC #2 |
| 51 | 546 | 476 479 | 510 500 | SHUNT | SHUNT |
| 52 | 551 | 478 481 | 518 505 | | |
| 53 | 552 | 480 483 | 531 517 | | |
| 54 | 551 | 480 483 | 533 517 | | |
| 55 | 552 | 479 482 | 537 520 | | |
| 56 | 553 | 478 481 | 540 523 | | |
| 57 | 540 | 470 473 | 539 521 | | |
| 58 | 549 | 474 477 | 553 533 | | |
| 59 | 551 | 477 481 | 561 541 | | |
| 60 | 549 | 474 477 | 559 538 | | |
| 61 | 549 | 472 475 | 556 535 | | |
| 62 | 550 | 473 476 | 562 541 | | |
| 63 | 551 | 476 478 | 573 551 | | |
| 64 | 550 | 474 477 | 591 565 | | |
| 65 | 549 | 474 477 | SHUNT | | |
| 66 | 546 | 470 473 | | | |
| 67 | 552 | 475 478 | | | |
| 68 | 551 | 473 476 | | | |
| 69 | 547 | 472 476 | | | |
| 70 | 554 | 477 481 | | | |
| 71 | 548 | 473 477 | | | |
| 72 | 554 | 478 482 | | | |
| 73 | 547 | 459 463 | | | |
| 74 | 544 | 454 459 | | | |
| 75 | 552 | 458 463 | | | |

## TABLE 4

| TEMPERATURE DEGREES CELSIUS FOR LAST READING OF EACH RECORDED CYCLE | | | | | |
|---|---|---|---|---|---|
| CYCLE NUMBER | CONTROL TEMP. | EXOTHERMIC CADWELD #1 TC #1 TC #2 | EXOTHERMIC CADWELD #2 TC #1 TC #2 | THOMAS & BETTS CROSS CONNECTOR #1 TC #1 TC #2 | THOMAS & BETTS CROSS CONNECTOR #2 TC #1 TC #2 |
| 76 | 552 | 460 464 | SHUNT | SHUNT | SHUNT |
| 77 | 550 | 456 460 | | | |
| 78 | 552 | 459 462 | | | |
| 79 | 554 | 460 464 | | | |
| 80 | 549 | 454 458 | | | |
| 81 | 555 | 462 466 | | | |
| 82 | 550 | 457 461 | | | |
| 83 | 556 | 462 466 | | | |
| 84 | 550 | 460 464 | | | |
| 85 | 550 | 459 463 | | | |
| 86 | 544 | 454 459 | | | |
| 87 | 549 | 456 459 | | | |
| 88 | 554 | 458 460 | | | |
| 89 | 551 | 457 462 | | | |
| 90 | 549 | 455 459 | | | |
| 91 | 547 | 450 455 | | | |
| 92 | 554 | 449 452 | | | |
| 93 | 548 | 452 456 | | | |
| 94 | 552 | 458 463 | | | |
| 95 | 550 | 455 460 | | | |
| 96 | 555 | 462 466 | | | |
| 97 | 545 | 455 459 | | | |
| 98 | 551 | 461 464 | | | |
| 99 | 550 | 459 463 | | | |
| 100 | 550 | 461 465 | | | |

## TABLE 4

| TEMPERATURE DEGREES CELSIUS FOR LAST READING OF EACH RECORDED CYCLE | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CYCLE NUMBER | CONTROL TEMP. | BURNDY CROSS CONNECTOR #1 | | BURNDY CROSS CONNECTOR #2 | | BURNDY TAP CONNECTOR #1 | | BURNDY TAP CONNECTOR #2 | |
| | | TC #1 | TC #2 | TC #1 | TC #2 | TC #1 | TC #2 | TC #1 | TC #2 |
| 1 | 544 | 618 | 606 | 618 | 619 | 613 | 613 | 601 | 590 |
| 2 | 550 | 625 | 620 | 643 | 634 | 678 | 691 | 663 | 636 |
| 3 | 551 | 624 | 619 | 637 | 626 | 691 | 704 | 667 | 644 |
| 4 | 552 | 628 | 633 | 652 | 641 | 697 | 713 | 654 | 676 |
| 5 | 552 | 628 | 633 | 654 | 646 | 712 | 726 | 671 | 667 |
| 6 | 553 | 640 | 630 | 650 | 643 | 714 | 726 | 702 | 692 |
| 7 | 551 | 649 | 628 | 651 | 644 | 719 | 734 | 716 | 709 |
| 8 | 551 | 663 | 625 | 660 | 673 | 697 | 710 | 668 | 660 |
| 9 | 551 | 648 | 623 | 640 | 674 | 698 | 711 | 686 | 680 |
| 10 | 549 | 652 | 619 | 638 | 667 | 698 | 710 | 681 | 675 |
| 11 | 550 | 644 | 610 | 644 | 669 | 691 | 703 | 679 | 699 |
| 12 | 552 | 643 | 618 | 645 | 668 | 609 | 622 | 663 | 653 |
| 13 | 550 | 642 | 619 | 637 | 635 | 628 | 640 | 647 | 623 |
| 14 | 550 | SHUNT | | 638 | 636 | 630 | 642 | 657 | 633 |
| 15 | 549 | | | 618 | 626 | 633 | 645 | 663 | 642 |
| 16 | 548 | | | 620 | 621 | 646 | 658 | 669 | 648 |
| 17 | 554 | | | 622 | 601 | SHUNT | | 702 | 679 |
| 18 | 550 | | | SHUNT | | | | 541 | 527 |
| 19 | 549 | | | | | | | 567 | 548 |
| 20 | 547 | | | | | | | 562 | 543 |
| 21 | 550 | | | | | | | 565 | 535 |
| 22 | 550 | | | | | | | 559 | 528 |
| 23 | 551 | | | | | | | 563 | 535 |
| 24 | 550 | | | | | | | 562 | 534 |
| 25 | 551 | | | | | | | 567 | 539 |

## TABLE 4

| TEMPERATURE DEGREES CELSIUS FOR LAST READING OF EACH RECORDED CYCLE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CYCLE NUMBER | CONTROL TEMP. | BURNDY CROSS CONNECTOR #1 | | BURNDY CROSS CONNECTOR #2 | | BURNDY TAP CONNECTOR #1 | | BURNDY TAP CONNECTOR #2 | |
| | | TC #1 | TC #2 | TC #1 | TC #2 | TC #1 | TC #2 | TC #1 | TC #2 |
| 26 | 549 | SHUNT | | SHUNT | | SHUNT | | 568 | 541 |
| 27 | 552 | | | | | | | 576 | 548 |
| 28 | 550 | | | | | | | 577 | 545 |
| 29 | 552 | | | | | | | 579 | 545 |
| 30 | 552 | | | | | | | 587 | 556 |
| 31 | 549 | | | | | | | 593 | 576 |
| 32 | 551 | | | | | | | 607 | 593 |
| 33 | 548 | | | | | | | 625 | 608 |
| 34 | | | | | | | | SHUNT | |

## TABLE 4

**TEMPERATURE DEGREES CELSIUS FOR LAST READING OF EACH RECORDED CYCLE**

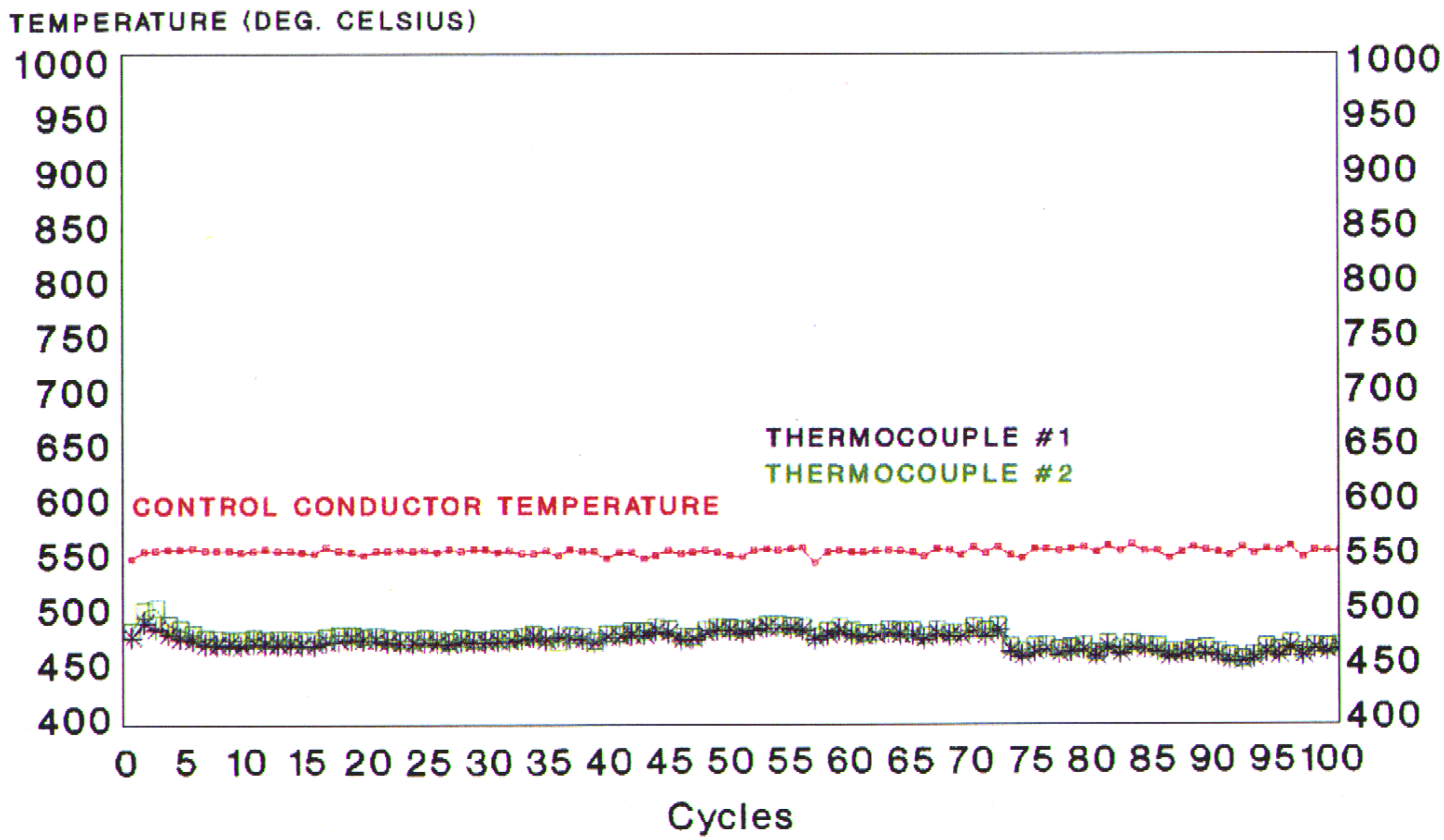
| CYCLE NUMBER | CONTROL TEMP. | AMP BOLT WEDGE CONNECTOR #1 TC #1 | TC #2 | AMP BOLT WEDGE CONNECTOR #2 TC #1 | TC #2 | | |
|---|---|---|---|---|---|---|---|
| 1 | 544 | **612** | **619** | **778** | **658** | | |
| 2 | 550 | **628** | **650** | **850** | **676** | | |
| 3 | 551 | **691** | **809** | **886** | **691** | | |
| 4 | 552 | **620** | **853** | **863** | **894** | | |
| 5 | 552 | **624** | **851** | **SHUNT** | | | |
| 6 | 549 | **656** | **960** | | | | |
| | | **SHUNT** | | | | | |

# APPENDIX 1

# COMPARATIVE GROUNDING CONNECTOR TEST

## CADWELD PART NUMBER TAC2V2V SAMPLE #1

## EXOTHERMICALLY WELDED



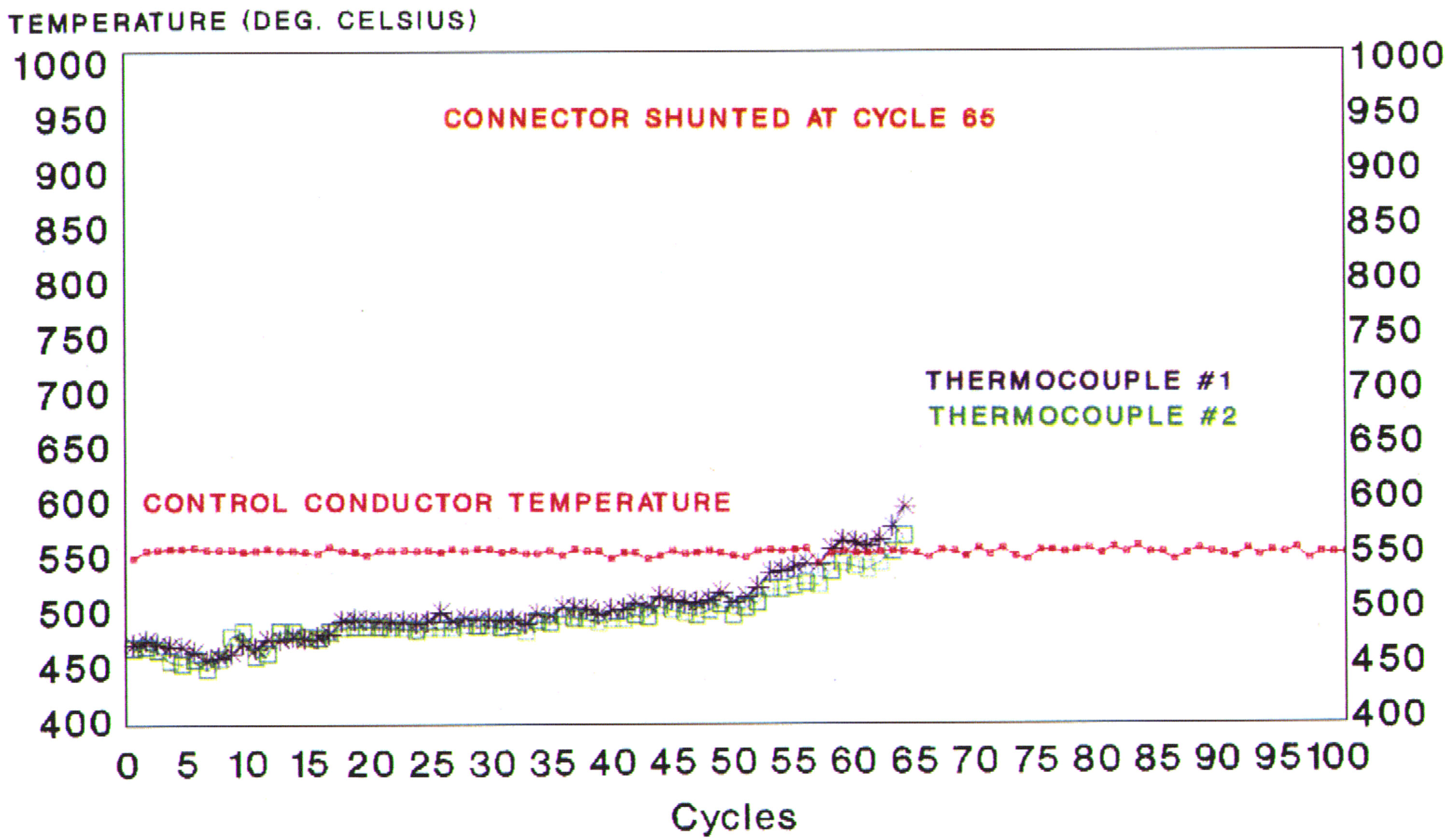

TESTED ON 250 KCMIL, 37 STRAND COPPER

IEEE 837 THERMAL CYCLE TEST (MODIFIED)

TESTED AT GEORGIA POWER RESEARCH CENTER

# COMPARATIVE GROUNDING CONNECTOR TEST

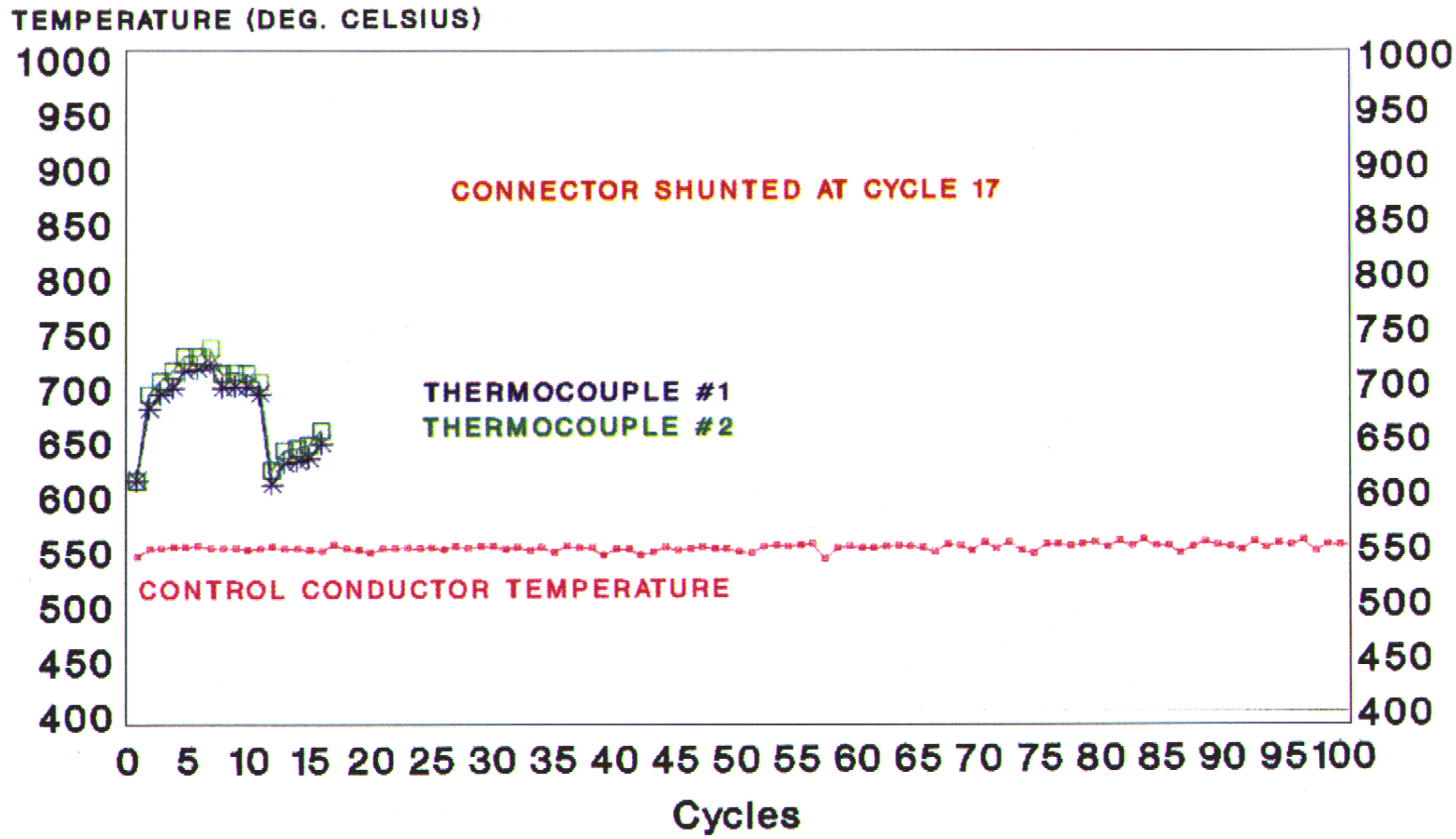
## CADWELD PART NUMBER TAC2V2V SAMPLE #2
## EXOTHERMICALLY WELDED




TESTED ON 250 KCMIL, 37 STRAND COPPER
IEEE 837 THERMAL CYCLE TEST (MODIFIED)

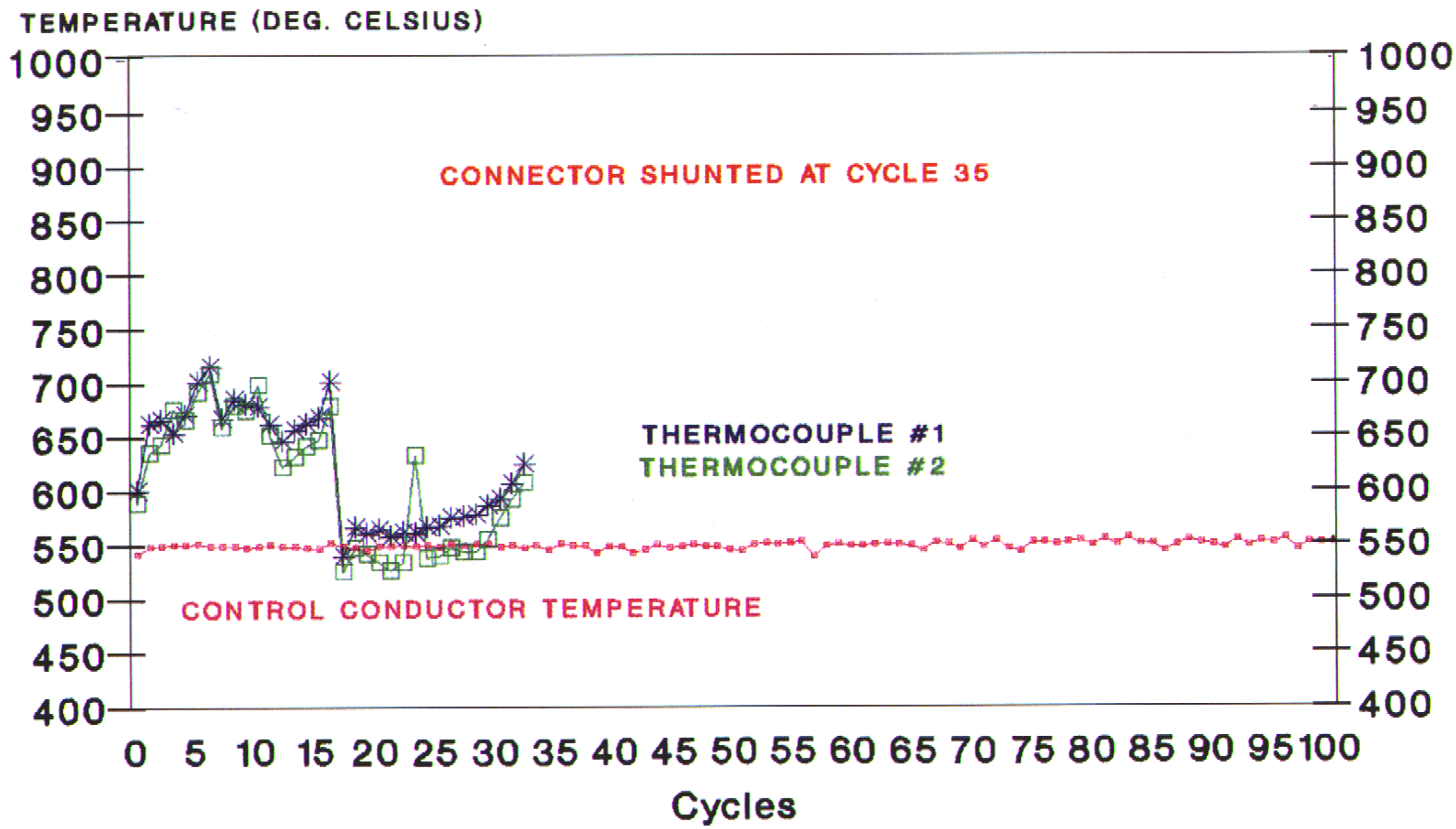
TESTED AT GEORGIA POWER RESEARCH CENTER

# COMPARATIVE GROUNDING CONNECTOR TEST
## BURNDY PART NUMBER YGHC29C29 SAMPLE #1
## TAP CONNECTOR




TESTED ON 250 KCMIL, 37 STRAND COPPER
IEEE 837 THERMAL CYCLE TEST (MODIFIED)
TESTED AT GEORGIA POWER RESEARCH CENTER

# COMPARATIVE GROUNDING CONNECTOR TEST
## BURNDY PART NUMBER YGHC29C29 SAMPLE #2
## TAP CONNECTOR



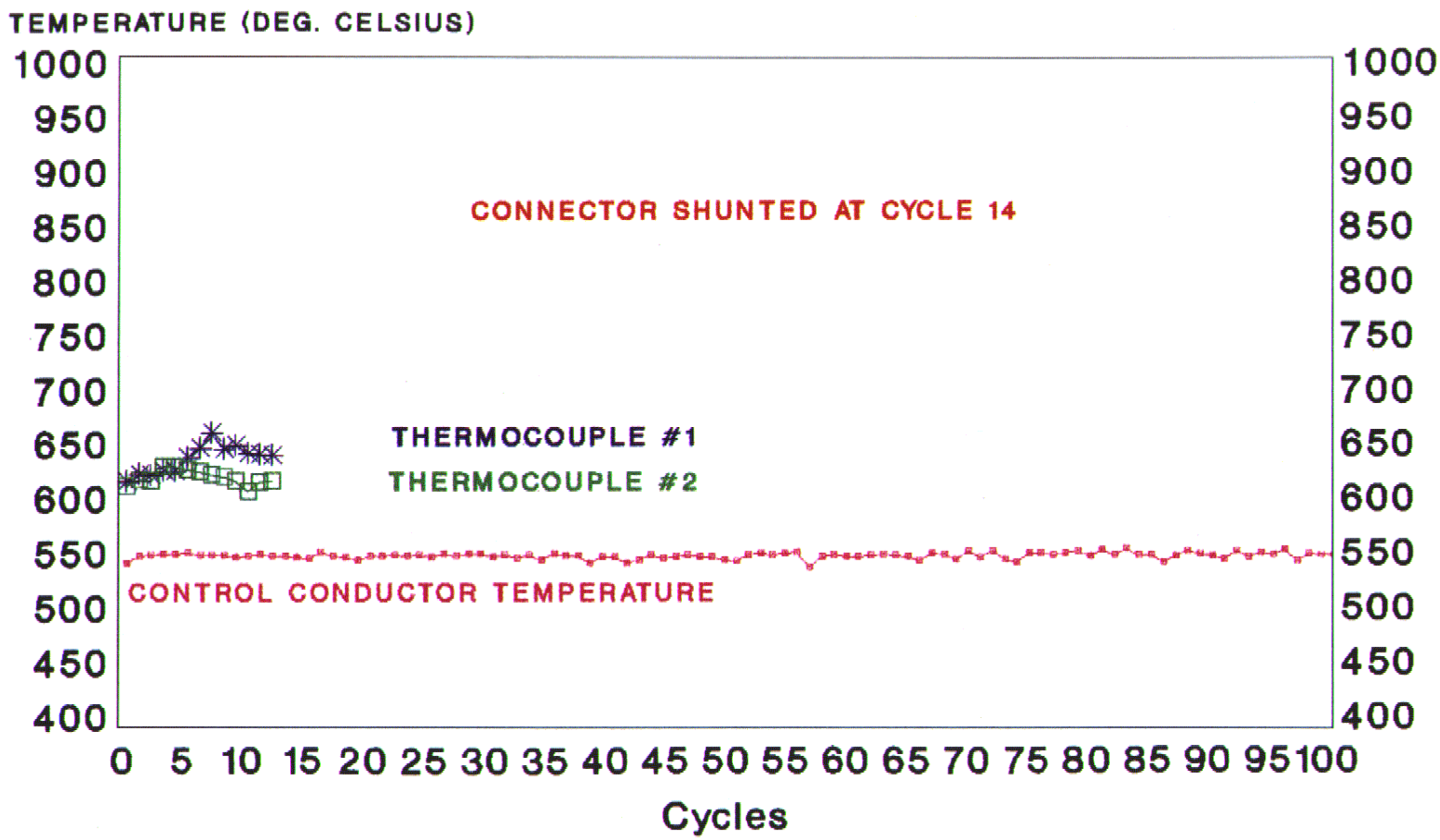

TESTED ON 250 KCMIL, 37 STRAND COPPER
IEEE 837 THERMAL CYCLE TEST (MODIFIED)

TESTED AT GEORGIA POWER RESEARCH CENTER

# COMPARATIVE GROUNDING CONNECTOR TEST

## BURNDY PART NUMBER YGL29C29 SAMPLE #1

## CROSS CONNECTOR

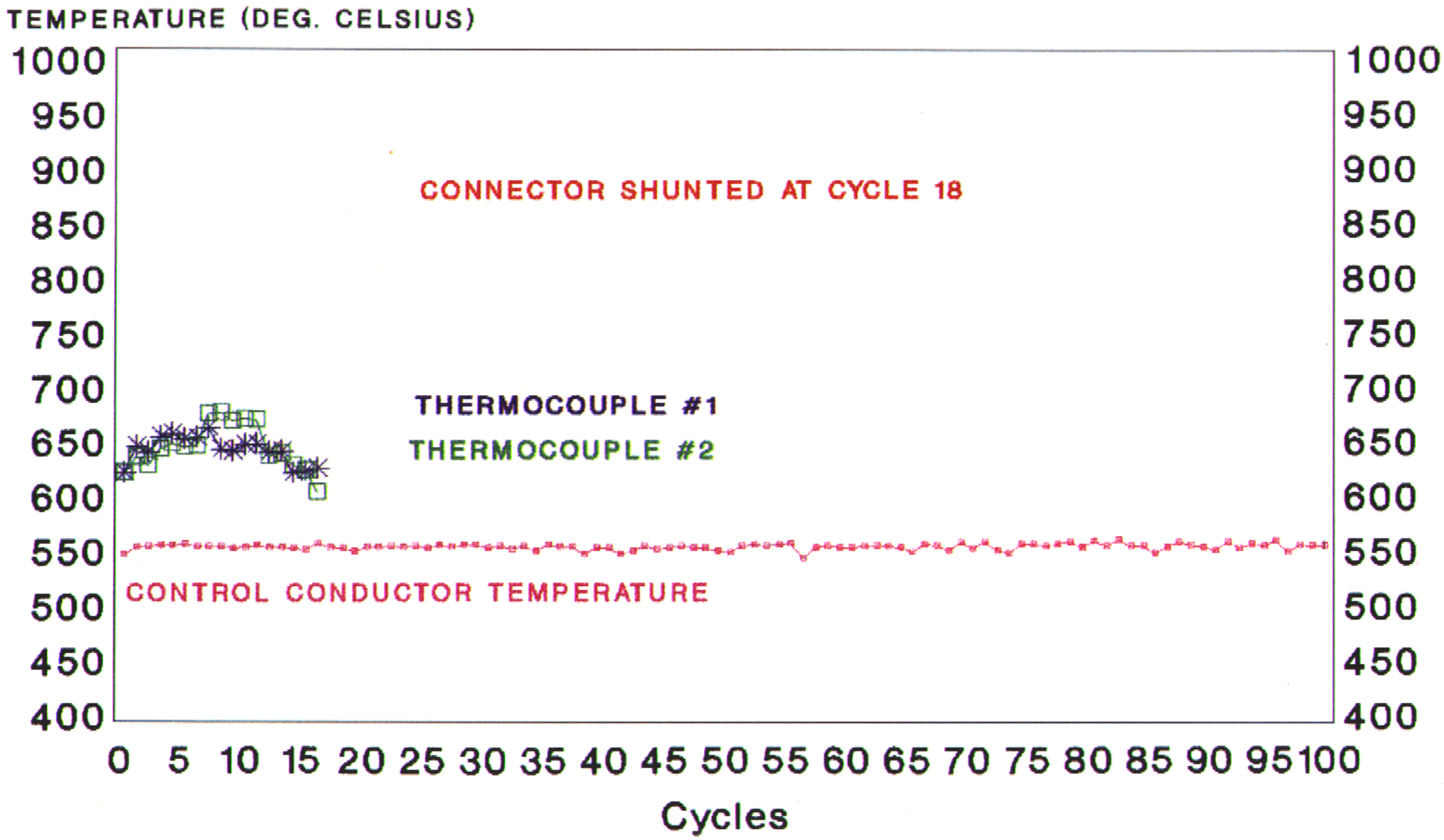



TESTED ON 250 KCMIL, 37 STRAND COPPER

IEEE 837 THERMAL CYCLE TEST (MODIFIED)

TESTED AT GEORGIA POWER RESEARCH CENTER

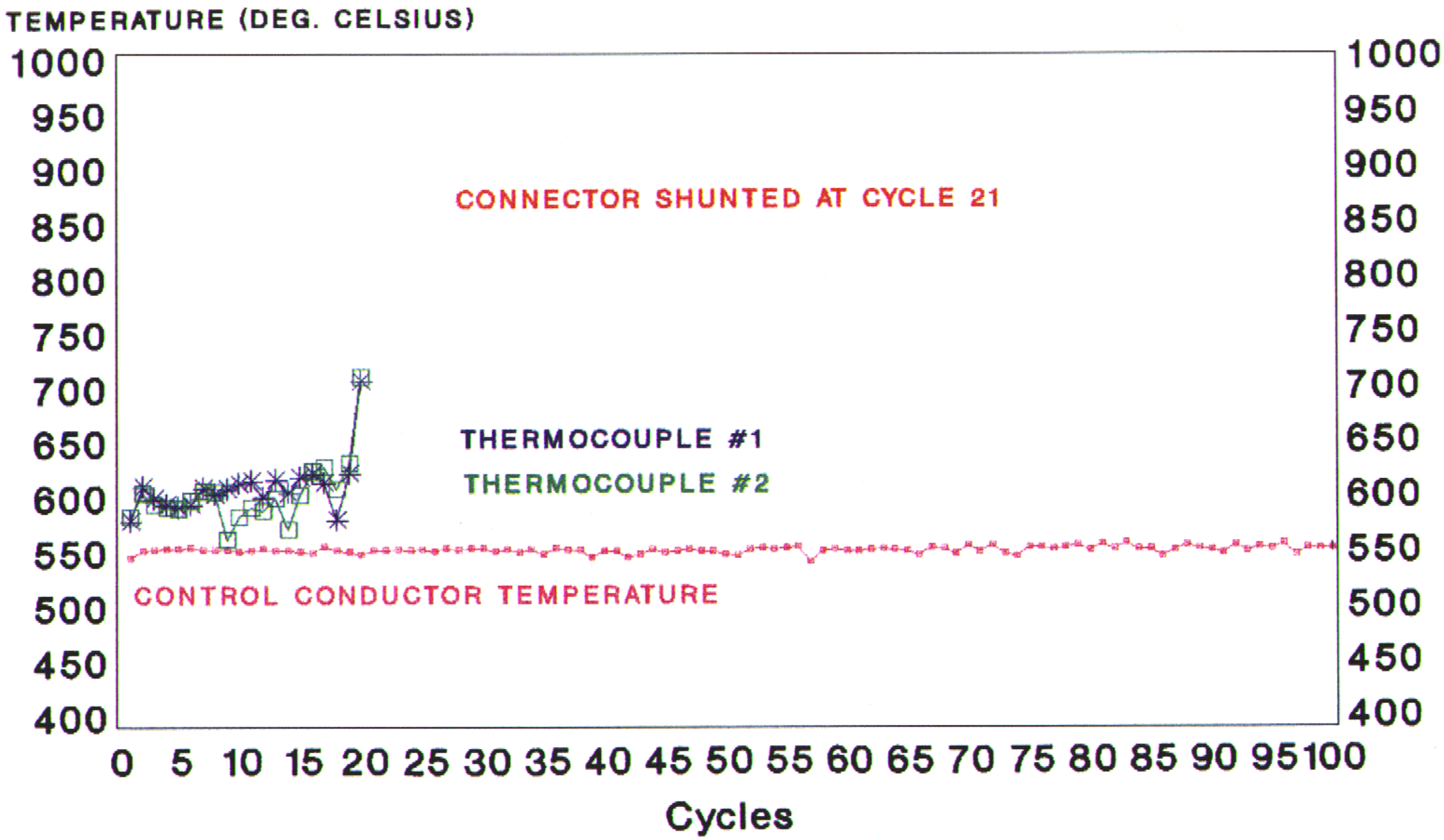
# COMPARATIVE GROUNDING CONNECTOR TEST
## BURNDY PART NUMBER YGL29C29 SAMPLE #2
## CROSS CONNECTOR




TESTED ON 250 KCMIL, 37 STRAND COPPER
IEEE 837 THERMAL CYCLE TEST (MODIFIED)

TESTED AT GEORGIA POWER RESEARCH CENTER

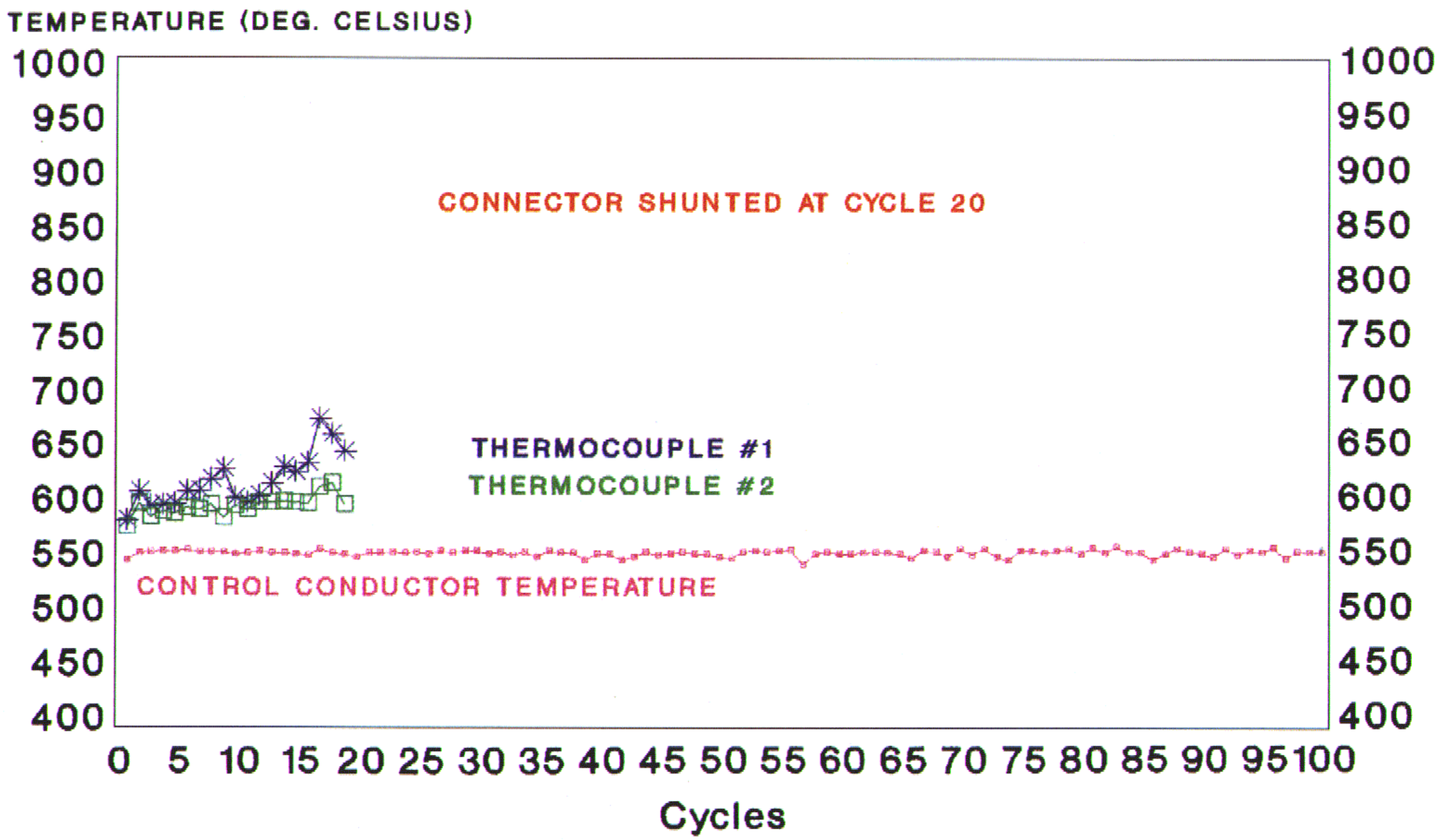
# COMPARATIVE GROUNDING CONNECTOR TEST
## T&B PART NUMBER GG40250-40250 SAMPLE #1
## CROSS CONNECTOR




TESTED ON 250 KCMIL, 37 STRAND COPPER
IEEE 837 THERMAL CYCLE TEST (MODIFIED)

TESTED AT GEORGIA POWER RESEARCH CENTER

# COMPARATIVE GROUNDING CONNECTOR TEST
## T&B PART NUMBER GG40250-40250 SAMPLE #2
## CROSS CONNECTOR



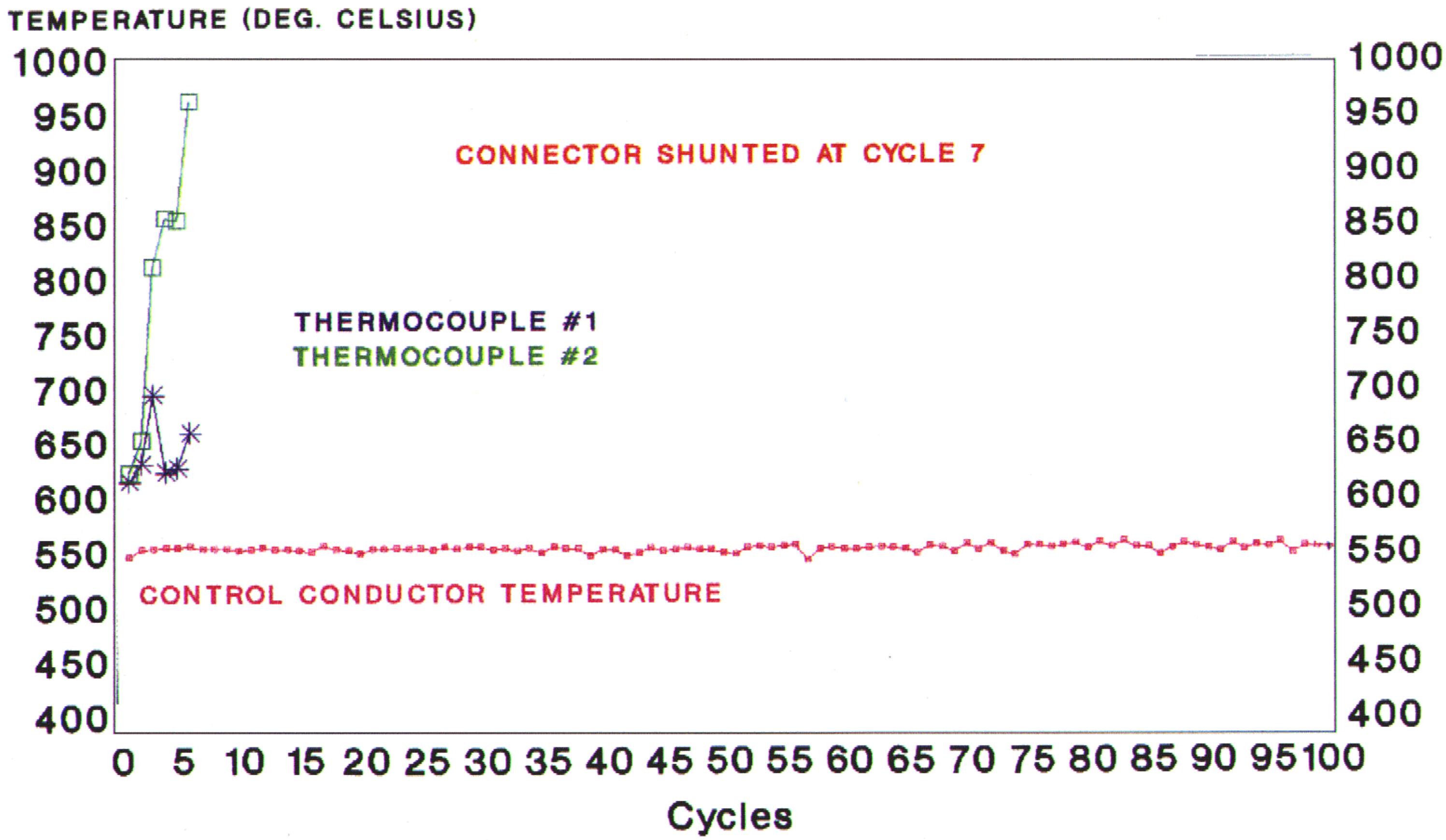

TESTED ON 250 KCMIL, 37 STRAND COPPER
IEEE 837 THERMAL CYCLE TEST (MODIFIED)

TESTED AT GEORGIA POWER RESEARCH CENTER

# COMPARATIVE GROUNDING CONNECTOR TEST

## AMP PART NUMBER 81228-1 SAMPLE #1

## BOLTED WEDGE CONNECTOR

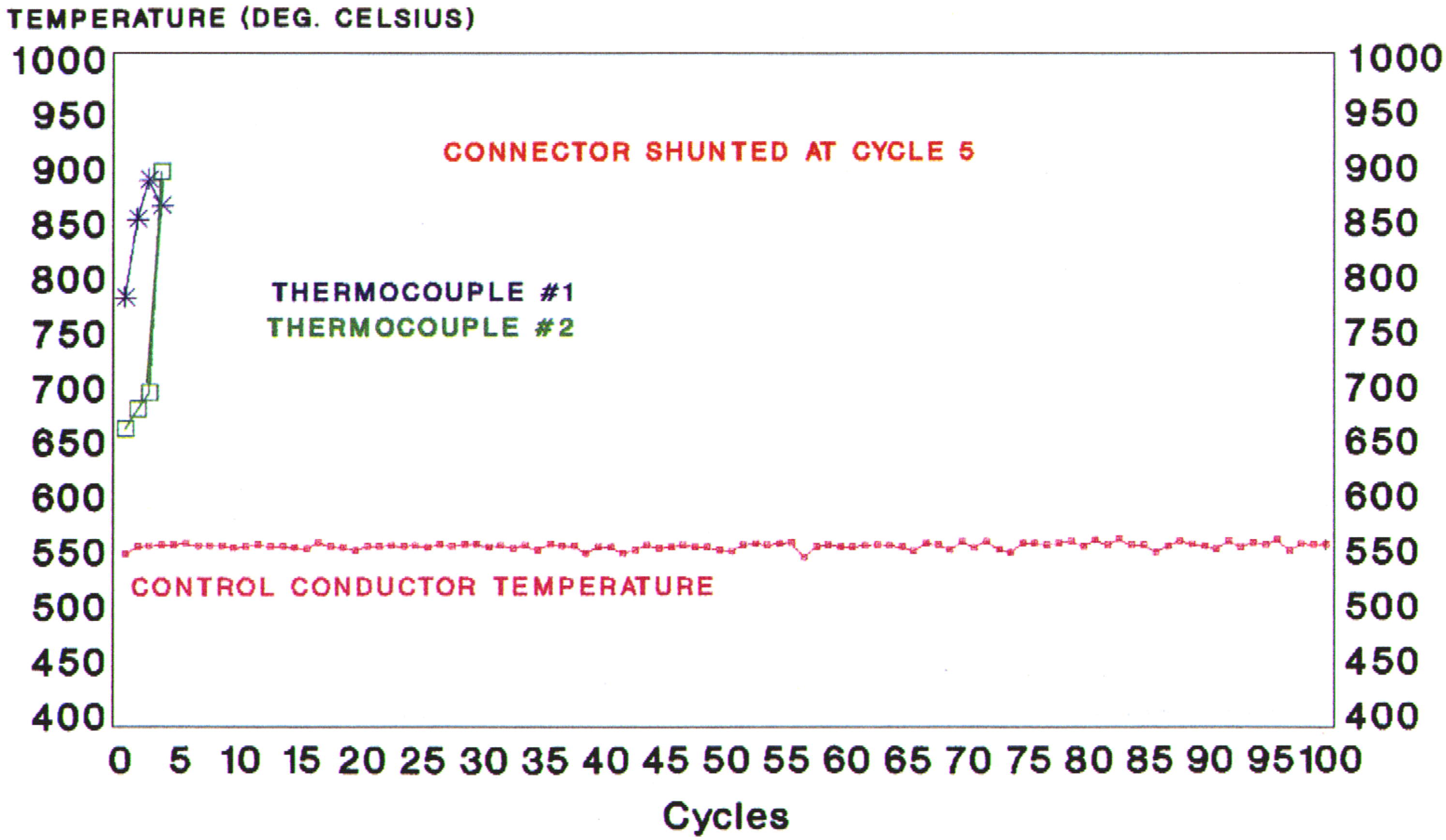



TESTED ON 250 KCMIL, 37 STRAND COPPER

IEEE 837 THERMAL CYCLE TEST (MODIFIED)

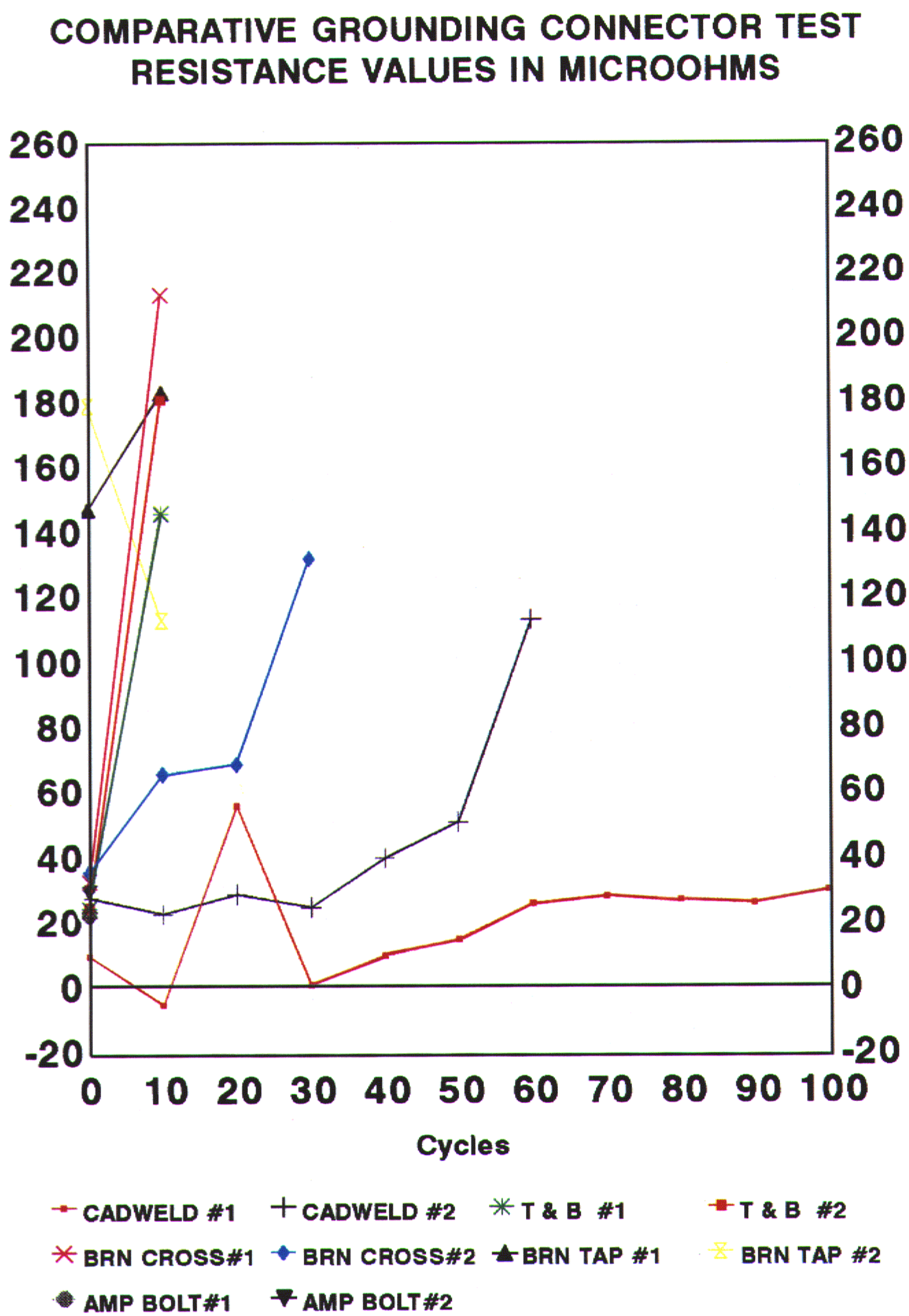
TESTED AT GEORGIA POWER RESEARCH CENTER

# COMPARATIVE GROUNDING CONNECTOR TEST
## AMP PART NUMBER 81228-1 SAMPLE #2
## BOLTED WEDGE CONNECTOR




TESTED ON 250 KCMIL, 37 STRAND COPPER
IEEE 837 THERMAL CYCLE TEST (MODIFIED)

TESTED AT GEORGIA POWER RESEARCH CENTER


COMPARATIVE GROUNDING CONNECTOR TEST
RESISTANCE VALUES IN MICROOHMS
260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20
0
10
20
30
40
50
60
70
80
90
100
Cycles
CADWELD #1
CADWELD #2
T & B #1
T & B #2
BRN CROSS#1
BRN CROSS#2
BRN TAP #1
BRN TAP #2
AMP BOLT#1
AMP BOLT#2

# APPENDIX 2

having an asymmetry and the magnitude as stated above.

NOTE: Using this as a parameter to prove that a connection would survive the most severe forces encountered during a fault, the asymmetrical current value was selected for the test.

The maximum fusing current value of 100 000 A rms symmetrical was chosen because this is the highest value anticipated by utilities.

It is assumed that fault current will divide equally and flow in two directions when entering the ground grid.

**7.3.5 Number of Surges.** The test shall consist of three surges. Repeat each surge after the conductor has been allowed to cool to 100 °C or less.

**7.3.6 Resistance Measurements.** Resistance readings shall be recorded for each sample, in accordance with 8.8 initially, and after the three fault surges when samples have returned to ambient temperature.

## 8. Current-Temperature Cycling Test

**8.1 General.** This test is intended to assure the conformance to resistance criteria of connections subjected to temperature changes caused by fluctuating currents.

**8.2 Current-Temperature Cycling Test.** This test shall be the first test conducted in a series of sequential tests, as listed in Table 1.

**8.2.1 Conductor Combinations.** When joining different types or sizes of conductors, the selection of the conductor combinations and test current shall be that which results in the highest connector temperature while producing the conductor temperatures specified in Table 5.

*Example 1:* Connector for 3/4–1 in galvanized steel rod to #6–#2 copper wire. From Table 6, test currents are 3/4 in rod—274 A, 1 in rod—324 A, #6 wire—230 A, #4 wire—320 A, and #2 wire—440 A. Select a 1 in galvanized steel rod and #4 copper wire and use an initial test current of 320 A, which should achieve a 250 °C temperature on the galvanized steel rod.

*Example 2:* Connector for 1/2–5/8 in stainless-clad steel rod to 350–500 kcmil copper wire. From Table 6, test currents are 1/2 in rod—246 A, 5/8 in rod—285 A, 350 kcmil wire—1441 A, and 500 kcmil wire—1860 A. Select a 5/8 in stainless-clad steel rod and 350 kcmil copper wire and use an initial test current of 285 A, which should achieve a 350 °C temperature on the stainless-clad steel rod.

*Example 3:* Connector for #1/0—#2/0 copper wire to #4/0—250 kcmil copper wire. From Table 6, test currents are #1/0 wire—620 A, #2/0 wire—725 A, #4/0 wire—1010 A, and 250 kcmil wire—1140 A. Select a #2/0 and #4/0 copper wire and use an initial test current of 725 A, which should achieve a 350 °C temperature on the #2/0 copper wire.

**8.2.2 Test Samples.** Four connectors of each size and type shall be required for each series of sequential tests.

**8.2.3 Equalizer.** Equalizers shall be installed on the stranded conductor on each side of each connector. The equalizer provides an equipotential plane for resistance measurements and prevents the influence of one connection on the other in the current-temperature cycling test. Equalizers are not required on solid conductors.

Any form of equalizer that ensures contact of all strands of a conductor for the duration of the current-temperature cycling test may be used.

When the cables to be joined in a current-temperature cycle loop are identical, a continuous piece of cable may be used between the connections. A short compression sleeve centered between the connections will then act as the equalizer.

NOTE: Resistance measurement points on solid conductors shall be the same as those used for conductors requiring equalizers.

**8.2.4 Conductor Length.** The exposed length of the conductor in the current cycle loop between the connectors and the equalizers shall be as given in Table 4.

**8.3 Ambient Conditions.** The current-temperature cycling tests shall be conducted in a space free of drafts at an ambient temperature of 20 °C (68 °F) to 40 °C (104 °F).

**8.4 Control Conductor.** A control conductor, used for the purpose of obtaining conductor temperature, shall be installed in the current cycle loop between two equalizers. It shall be of the same type and size as the conductor, of those joined by the connector under test, that established the highest temperature. Its length between equalizers shall be the same as the test samples.

**Table 4**
**Conductor Length from Connector to Equalizer**

| Copper Wire or Cable Size AWG or kcmil | Aluminum Wire or Cable Size AWG or kcmil | Steel or Clad Steel Wire or Rod Diameter (in) | Current-Temperature Cycling Test Minimum Conductor Length Exposed from Connector to Equalizer (in) | (mm) |
|---|---|---|---|---|
| Up to 2/0 | Up to 4/0 | Up to 7/16 | 12 | 300 |
| Over 2/0 to 500 | Over 4/0 to 795 | Over 7/16 to 3/4 | 24 | 600 |
| Over 500 | Over 795 | Over 3/4 | 36 | 900 |

**8.5 Current Cycling**

**8.5.1 Current Cycling Period.** Each cycle of the current-temperature cycling test shall consist of maintaining the minimum temperature specified in Table 5 on the control conductor for one hour and then cooling to room ambient. For suggested test currents, refer to Table 6.

**8.5.2 Number of Cycles.** The connections shall be subjected to a minimum of 25 current cycles.

**8.5.3 Current Cycling Temperature.** The current shall be adjusted over the first five cycles to result in a steady-state temperature on the control conductor specified in Table 5, and adjusted every five cycles thereafter as required to attain the specified steady-state temperature for a total of 25 cycles.

**8.6 Loop Configuration.** Loop configuration shall provide a minimum space of 2 ft (610 mm) between the connected conductor, 2.5 ft (760 mm) from the floor, 4 ft (1220 mm) from the ceiling, and 2 ft (610 mm) from the walls.

The current cycle loop may be bent back on itself in a U or zigzag shape provided the above spacings are used.

**Table 5**
**Conductor Temperature**

| Conductor | Temperature for Current Cycling Test |
|---|---|
| Aluminum | 250 °C |
| Copper | 350 °C |
| Steel | 350 °C |
| Copper-clad steel | 350 °C |
| Galvanized steel | 250 °C |
| Stainless steel | 350 °C |
| Stainless-clad steel | 350 °C |

**8.7 Measurements.** Resistance and temperature measurements shall be recorded at the beginning of the test and after every five cycles.

**8.7.1 Resistance Measurements.** Resistance measurements shall be made during the current-off period and when the conductor temperature has stabilized at ambient. The measurements shall be made across each connector between potential points located in the center of the equalizers adjacent to the connector or at the equivalent points on a solid conduc tor. For these measurements, a current of a sufficiently low magnitude shall be used to avoid appreciable heating.

**8.7.2 Temperature Correcttion.** Ambient temperature shall be recorded concurrently with each set of resistance measurements, and the resistance shall be corrected to 20 °C. The corrected resistance shall be used in evaluating the performance of the connection.

**8.7.3 Temperature Measurements.** Temperature measurements shall be recorded for the connectors and the control conductor near the end of the current heating period, with current on. The temperature shall be measured by means of thermocouples permanently installed on each connector as close as possible to the point in the current path midway between the two conductors. One thermocouple shall be installed at the midpoint of the control conductor.

## 9. Freeze-Thaw Test

**9.1 General.** This test is intended to assure the conformance to resistance criteria of connections subjected to repeated cycles of freezing and thawing in water.