

**3M Brand Composite Conductor  
Connector Current Cycle Qualification Test  
for  
1272 Compression Connectors**

**3M Company  
Purchase Order 0001048576**

**NEETRAC Project Number: 03-181**

**February, 2004**



Requested by: Mr. Colin McCullough  
3M

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Reviewed by:   
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**Summary:**

3M contracted with NEETRAC to perform qualification tests on connectors for 3M's 1272 kcmil Composite Conductor. A total of 16 connectors were connected in a series loop, and subjected to an accelerated life test based on the ANSI C119.4 connector current cycle test (CCT). One additional splice connector was subjected to the optional current cycle submersion test (CCST). The CCST test subjects the connector to a rapid quench in chilled water. The 100-cycle CCST is more severe than the standard 500-cycle CCT, and is designed to be an economical alternative to the 500-cycle test. In this case, the CCST test was performed on one connector to address a concern related to chilled rain on hot connectors. For both the CCT and CCST tests, the ANSI C119.4 CCT methods and acceptance criteria were modified to reflect the higher operating temperature limits for the 3M Composite Conductor. The CCST sample passed the acceptance criteria, and was removed from the test loop at the end of cycle 106. All CCT connectors performed well after 500 cycles from room temperature to a 240° C conductor temperature. After meeting the ANSI 500-cycle criteria, the connectors were subjected to an additional 100 additional cycles at 300° C conductor temperature. All connectors passed the ANSI criteria at the end of 100 cycles to 300° C.h

**Samples:**

- 1) 22 meters (72 feet) of 3M 1272-kcmil Composite Conductor
- 2) Four (4) Alcoa Fujikura (AFL) full-tension splice connectors, catalogue number B9095-C, for 1272 3M Composite Conductor
- 3) Four (4) AFL full-tension dead-end terminal connectors, catalogue number B9119-A, for 1272 3M Composite Conductor
- 4) Four (4) AFL jumper terminal connectors (tubular to 4-bolt NEMA pad), catalogue number B9102-C, for 1272 3M Composite Conductor
- 5) Four (4) AFL jumper splice connectors (partial-tension), catalogue number B9112-C, for 1272 3M Composite Conductor

**References:**

- 1) NEETRAC – 3M Proprietary Information Agreement Dated 3/27/01
- 2) 3M Purchase Order 0001048576

- 3) PRJ 03-181, NEETRAC Project Plan
- 4) ANSI C119.4-2003

### **Equipment Used:**

- 1) Connector lab high-current DC power supply
- 2) HP 3421A/National Instruments LabView control and data acquisition interface (controls the test, and records temperatures, Control #'s CQ 0227 and CQ0216)
- 3) AVO/Biddle DLRO digital low-resistance Ohmmeter, Control #'s CQ 1083

### **Procedure:**

Testing was conducted in accordance with a NEETRAC procedure entitled “PRJ03-181, CONFIDENTIAL – 1272 kmil ACCR Connector Current Cycle Test. The procedure controls all technical and quality management details for the project.

Personnel from AFL and 3M visited NEETRAC for connector installation. NEETRAC’s Tommy McKoon assisted Wayne Quesnel (AFL) and Kamal Amin (3M) on the connector installation process. AFL-supplied the crimp head and compression dies for the special connectors, and was responsible for connector installation. Using the connector and conductor samples, NEETRAC constructed a series loop in accordance with the ANSI C119.4 guidelines. Equalizers (aluminum plates) were welded to the conductor mid-way between each connector in the series loop. Equalizers are specified in the C119.4 Standard to provide equipotential locations for resistance measurement, and to ensure isolation of each connector from the thermal influence of other connectors in the test. Figure 1 shows the “as built” configuration of the current loop.

A high-current DC power supply was connected to the loop. Current was adjusted to obtain a steady-state control conductor surface temperature of 240° C. Current measured 1980 Amperes for the required steady-state temperature. Previous testing at extreme temperatures has shown that adjusting loop current to compensate for ambient temperature changes results in problems meeting the temperature stability criterion. This is not a connector problem, but rather a problem with using criteria for a 123° C test on a test run at 240° C. It was agreed that we would live with temperature variation after finding a reasonable current. The ANSI Standard forbids current adjustments after initial settings, so this procedure is in accordance with the test protocol.

Cycle timing was set for 120 minutes on and 120 minutes off in accordance with the ANSI C119.4 Standard. The test ran smoothly, and temperatures ran very close to target even with the steady current. Early in the test there were several instances of thermocouples pulling out of connectors as the loop moved in response to thermal growth. The wiring harnesses were adjusted for more slack, and there were no thermocouple pull-outs after cycle 66. The data file shows low temperature for the connectors for the cycles that occurred while the thermocouple was hanging. Those data points were deleted to keep the data presentable on a graph. Data from the other connectors show that the current cycles were completed where data were not available, and the data record exceeds the ANSI minimum requirement by a considerable margin even with the missing data. There are short gaps in the graphs where data points were deleted.

After 500 complete thermal cycles, the current was adjusted to raise the control conductor surface temperature to 300° C. One hundred thermal cycles were completed at the higher temperature, for a total

of 600 cycles. The modified cycle time was maintained until the test completed 600 cycles. The profile differs from the ANSI C119.4 in the following respects:

- 1) Control conductor temperature was 240° C, instead of 100° C rise above ambient (typical control conductor temperature is 123° C).
- 2) At the end of the standard 500 thermal cycles, 100 additional cycles were completed with the control conductor maximum temperature of 300° C.

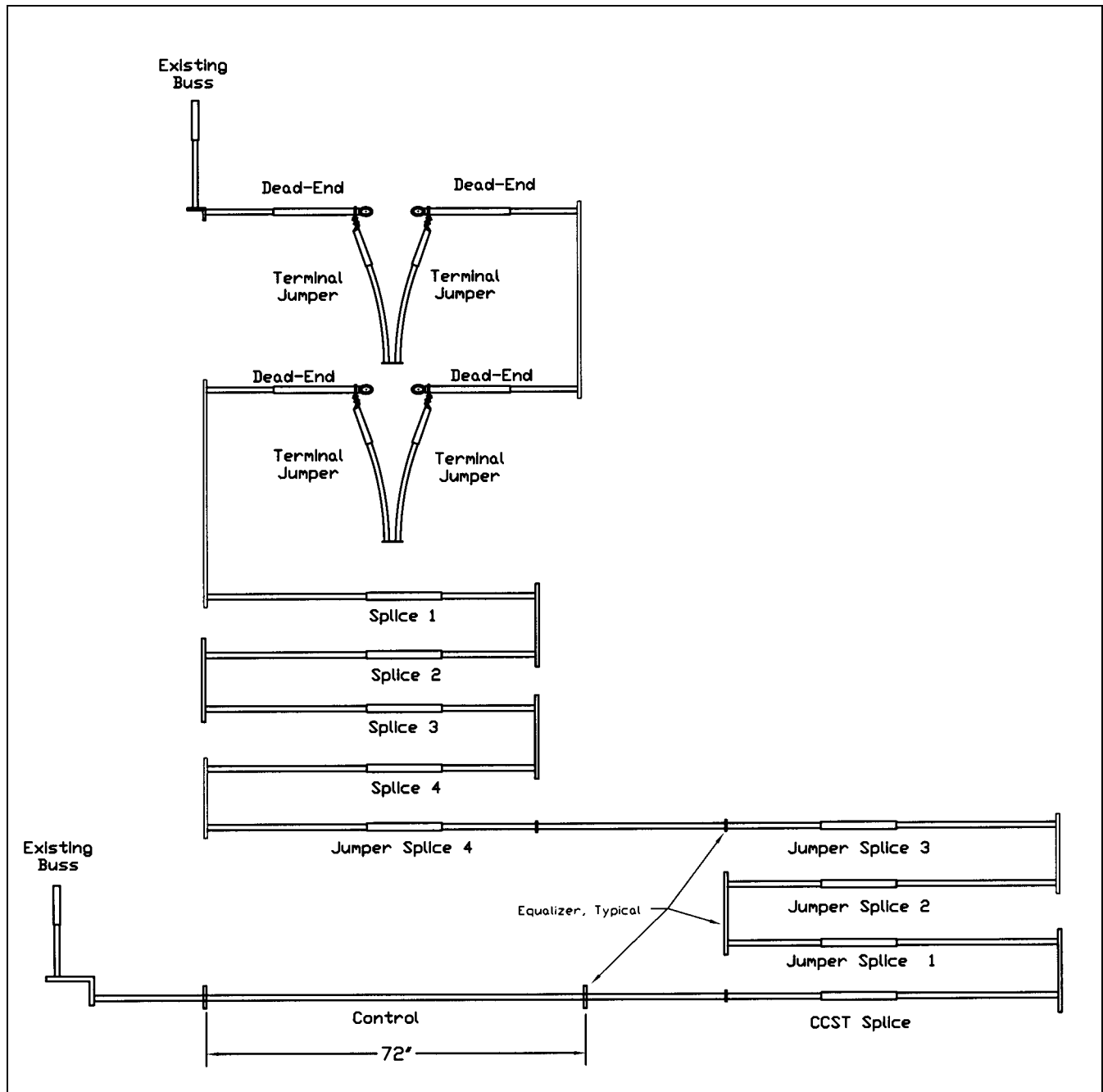
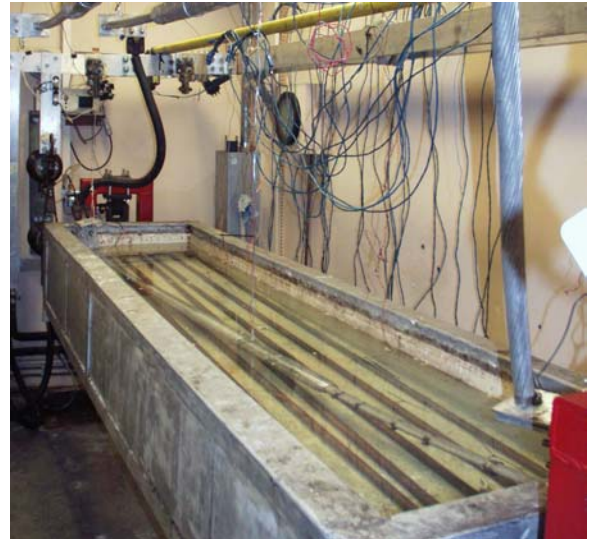


Figure 1 Sketch showing connector test loop arrangement

Connector and conductor temperatures were recorded automatically. The DC power supply was under automatic control during the test. Connector resistances were measured manually on the intervals specified in ANSI C119.4. The resistance measurement is from equalizer to equalizer, and therefore includes a length of conductor in the resistance measurement. This is the design of the standard, and is considered acceptable because resistance stability is the criterion for connector performance in C119.4. Photographs 1 through 4 show the connector test loop during the test.



Photograph 1, CCST sample, "current on"



Photograph 2, CCST sample during cold water quench



Photographs 3 and 4, CCT (air quench) samples in connector lab overhead space

Figure 2 shows a typical cycle for the connectors in the test.

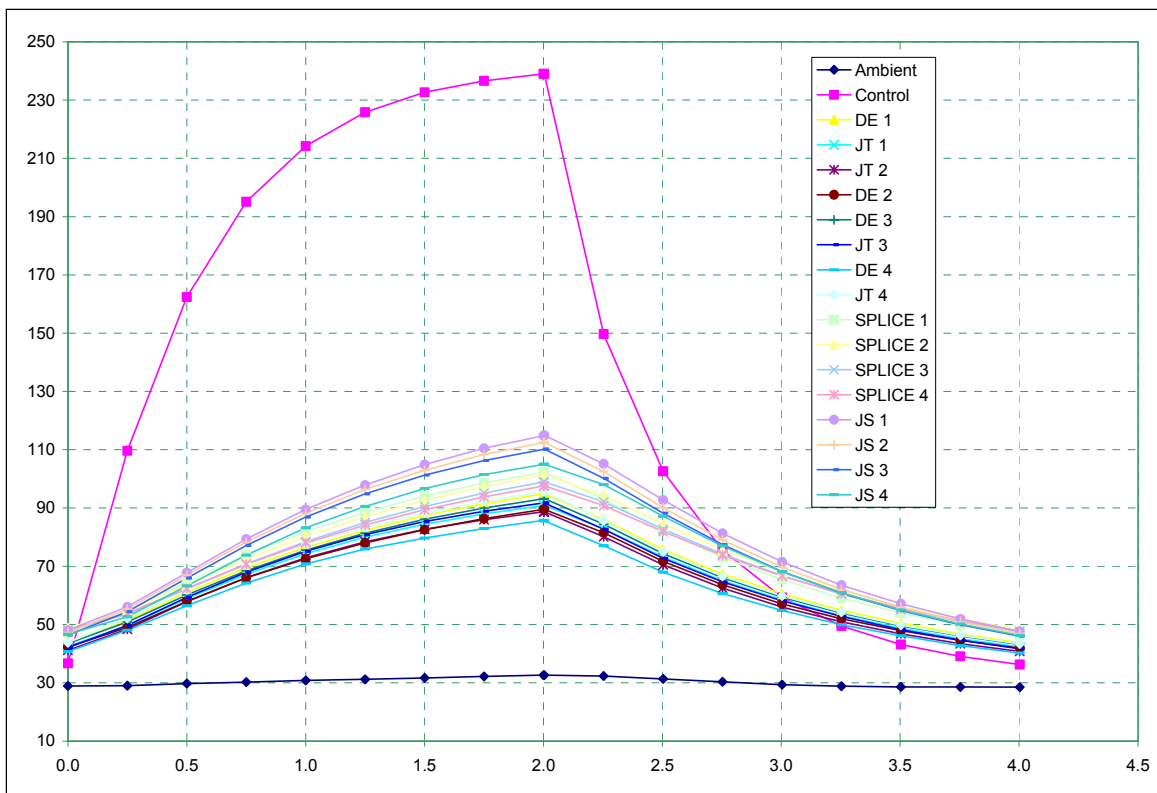


Figure 2, typical temperature cycle for 1272 loop

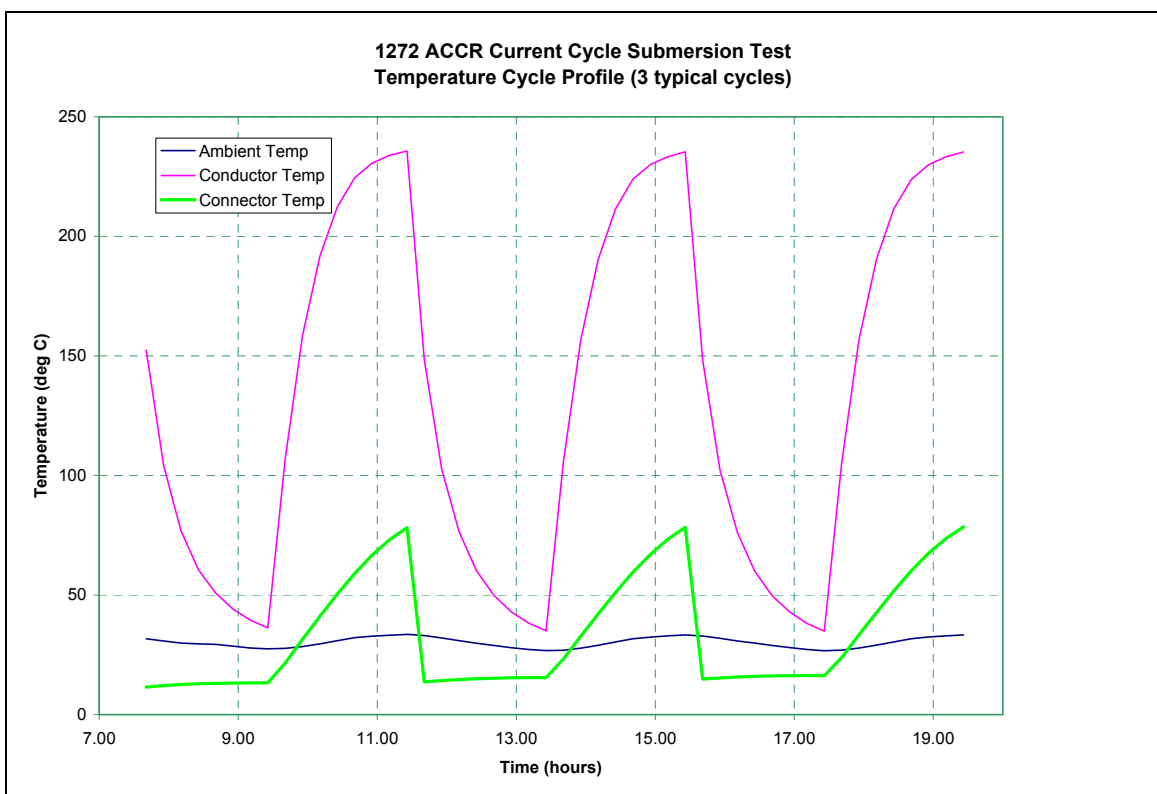


Figure 3, Temperatures for connector and conductor for the CCST sample

## **Results:**

To qualify under the ANSI C119.4 standard, a connector must meet the following three criteria. For the CCT test (air quench), the connector must complete 500 thermal cycles. For the CCST (water quench) test, the connector must complete 100 cycles.

- 1) Connector temperature at the end of the heating cycle must not exceed the temperature of the control conductor.

Results and Discussion: See Figures 4 through 7 for charts illustrating the behavior of each connector. Connectors of each type are on a single graph. It may be difficult to see the one for an individual connector when the temperature of each connector closely matched its cohorts in every case. Cases where the connector temperature does not match the cohorts may be due to thermal influence of adjacent connectors, and not due to connector performance. The CCST sample is cooler because it starts from a lower temperature. See the resistance data for information more sensitive to the connector condition.

- 2) Temperature difference between the connector and control conductor must be stable within 10° C of the average temperature difference exhibited during the 500 cycles.

Results and Discussion: See Figures 8 through 11 for charts illustrating the behavior of each connector. In this case each connector is on a separate graph, because the acceptance criterion is unique for each connector. This criterion is designed for the standard ANSI test where the control conductor temperature is typically 125° C. Passing this requirement with the control temperature at 240° C demonstrates extremely stable behavior.

- 3) Connector resistance must be stable during each measurement within +/-5% of the average resistance exhibited during the test.

Results and Discussion: See Figures 12 through 15 for charts illustrating the behavior of each connector. Again, each connector is on a separate graph, because the acceptance criterion is unique for each connector. The data show stable resistance over all phases of the test.

Criterion 1 ensures that a connector's size (convection cooling area), and resistance (heat generation) are appropriate to ensure that annealing and other thermal effects are not more severe at the connector than in the free span. Criteria 2 and 3 are based on observations and theory that splices approaching failure begin to exhibit unstable temperature and resistance behavior well before resistance increases to the point that connector temperature exceeds the free span temperature.

## **Conclusions:**

All 17 connectors in the test exceeded the performance requirements of ANSI C119.4 acceptance criteria. These results make it reasonable to conclude that all connectors will provide reliable service in transmission line service.

**Acknowledgement:**

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**Disclaimer:**

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of Energy.



## **NEETRAC Project 03-181**

### **Current Cycle Test for 1272 3M Composite Conductor Connectors**

#### **Appendix**

**Detail graphs showing end-of cycle temperature and resistance data for each connector**

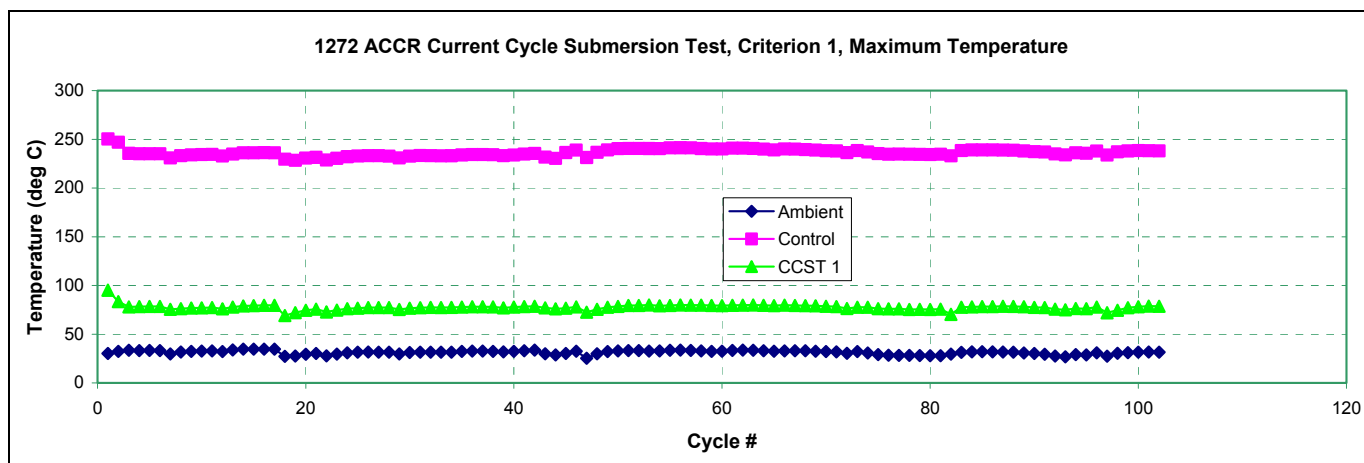


Figure 4, end-of cycle temperature data for CCST (water quench) compression splice sample

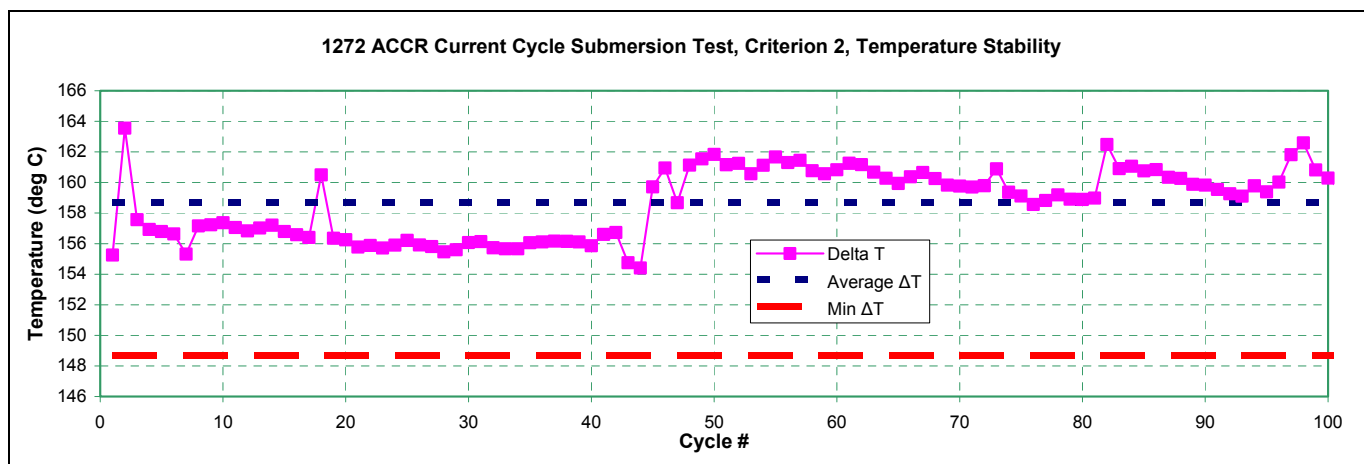


Figure 5, Temperature stability data for the CCST (water quench) compression splice (criterion 2)

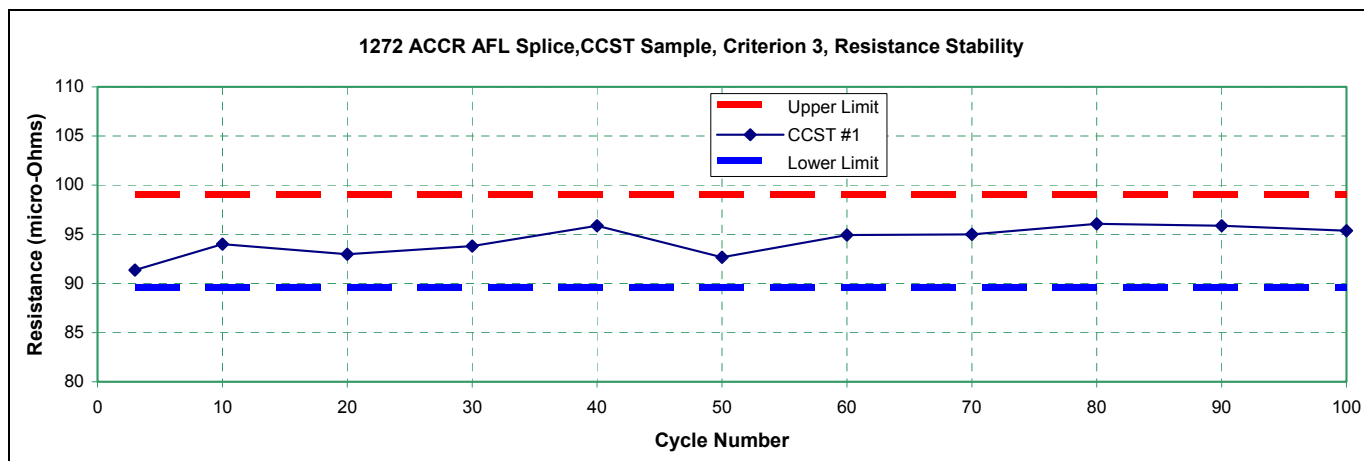


Figure 6, Resistance data for the CCST (water quench) compression splice (criterion 3)

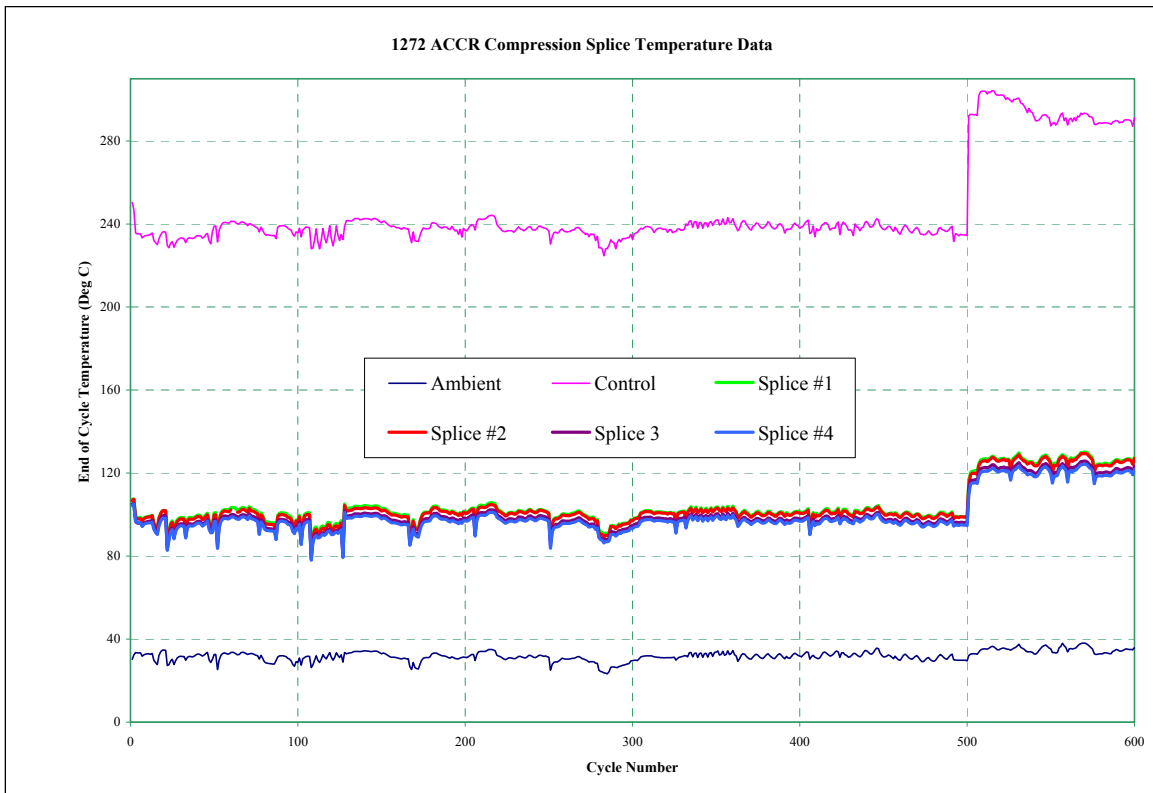


Figure 7, end-of-cycle temperature data for compression splice CCT (air quench) samples

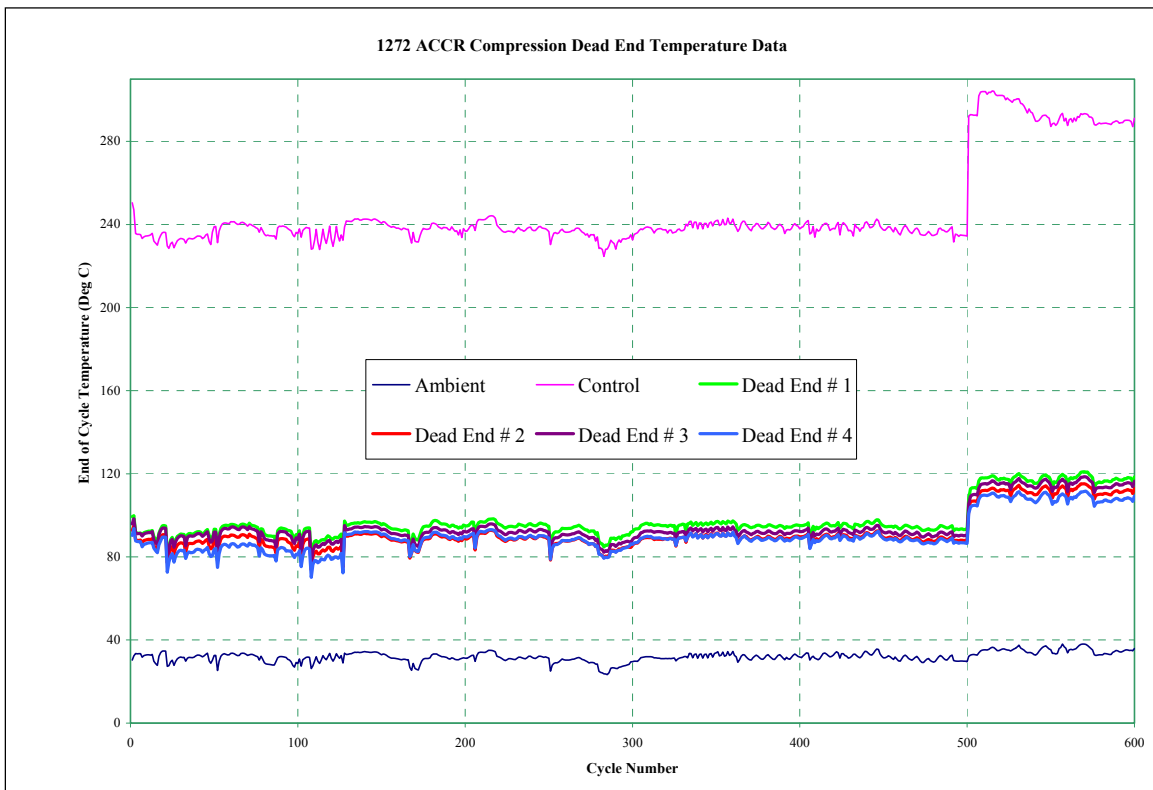


Figure 8, end-of-cycle temperature data for dead end terminal samples

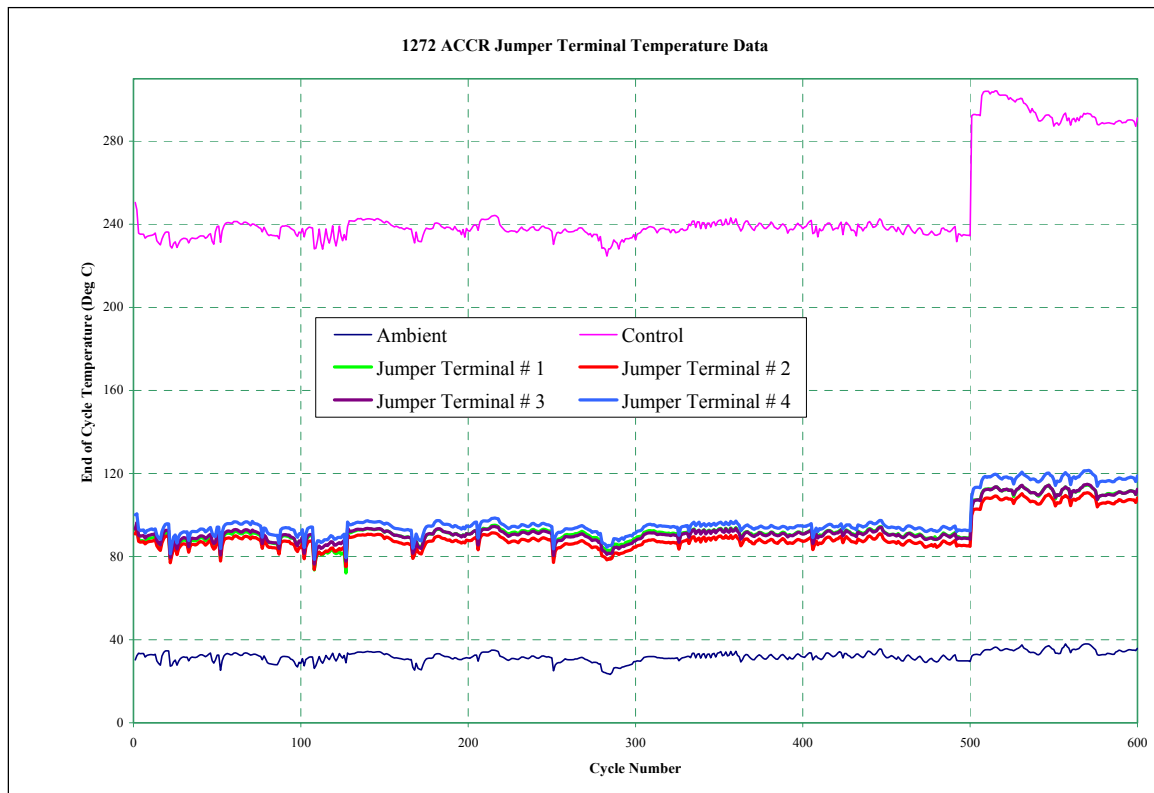


Figure 9, end-of-cycle temperature data for compression jumper terminal connectors (compression to 4-bolt NEMA terminal)

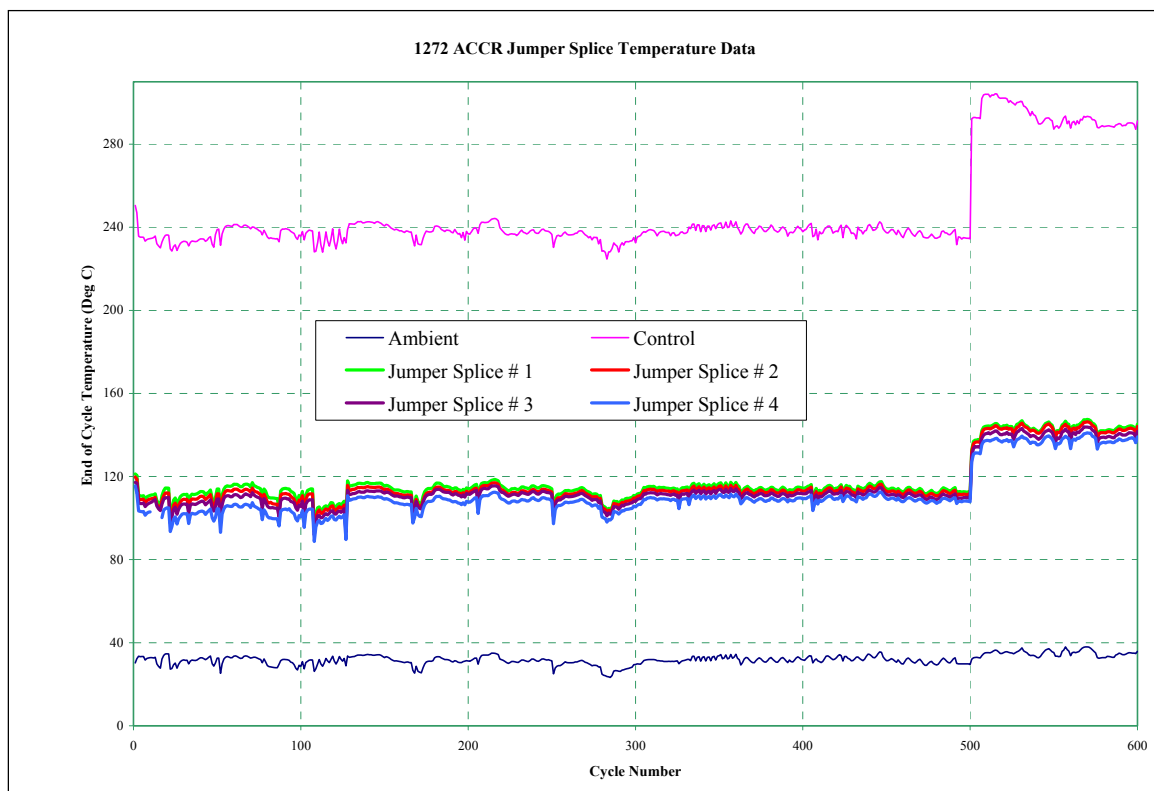


Figure 10, end-of-cycle temperature data for jumper splices

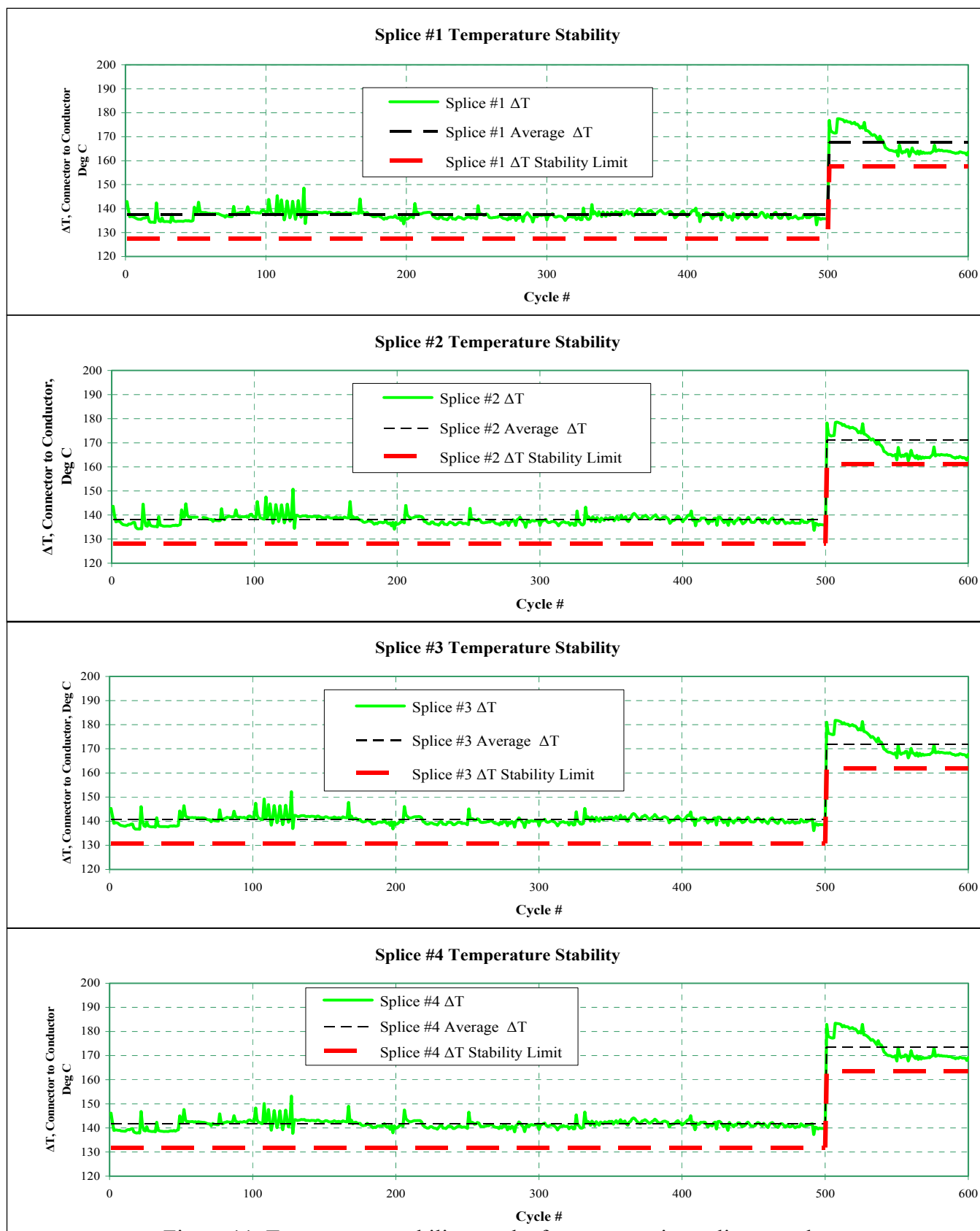


Figure 11, Temperature stability results for compression splice samples

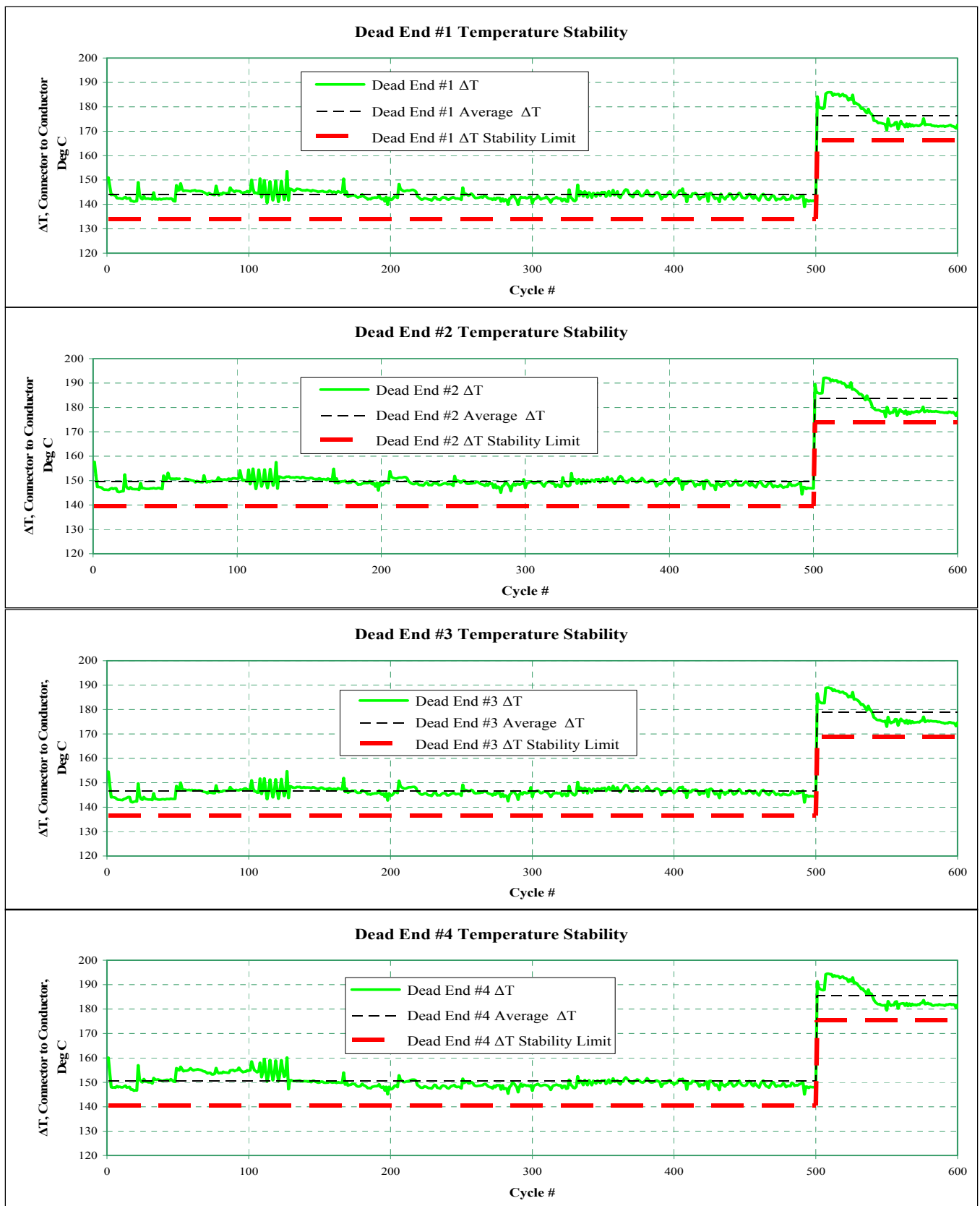


Figure 12, Temperature stability data for compression dead end/terminal connectors

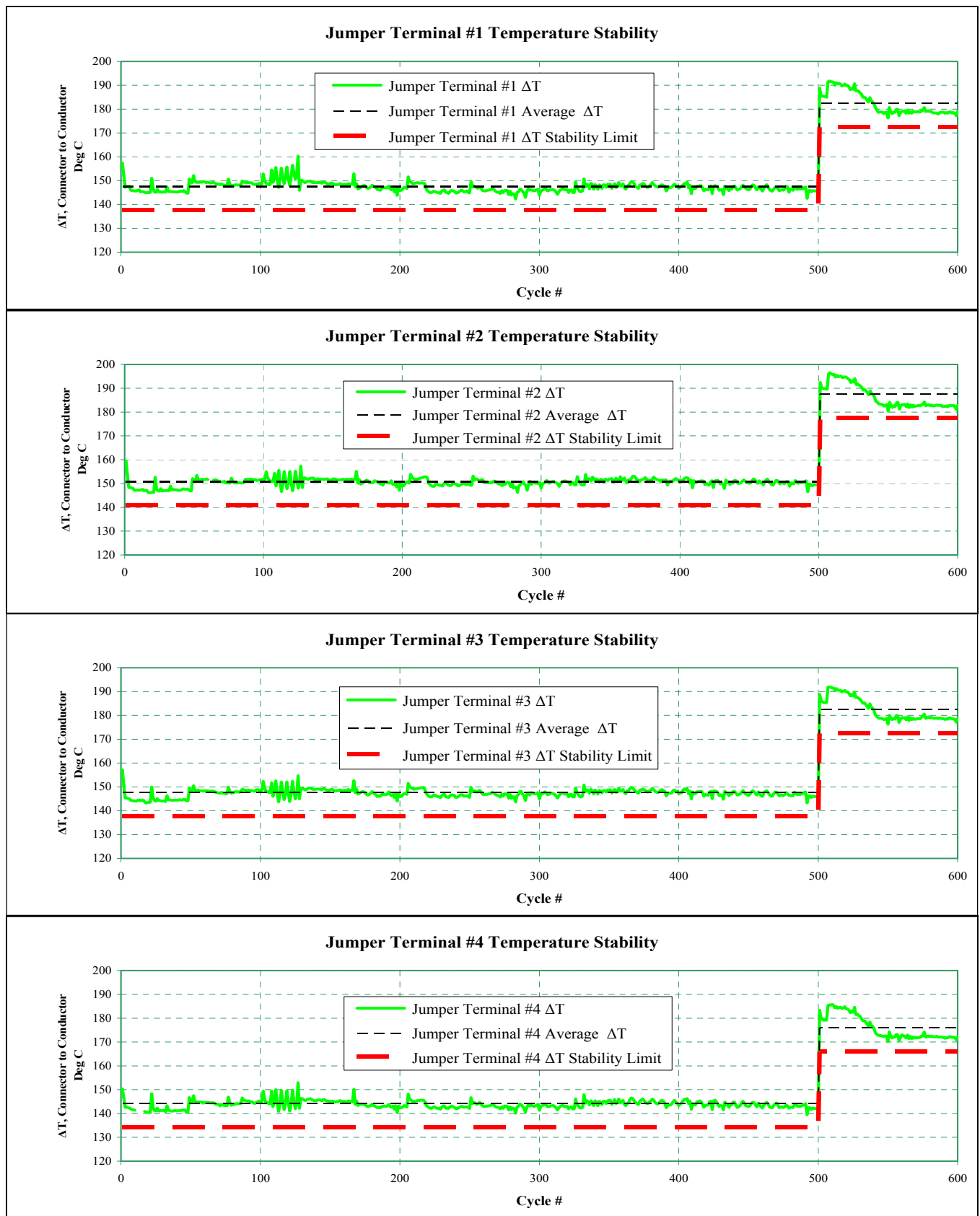


Figure 13, Temperature stability results for compression jumper terminals (tubular to 4-bolt NEMA pad)

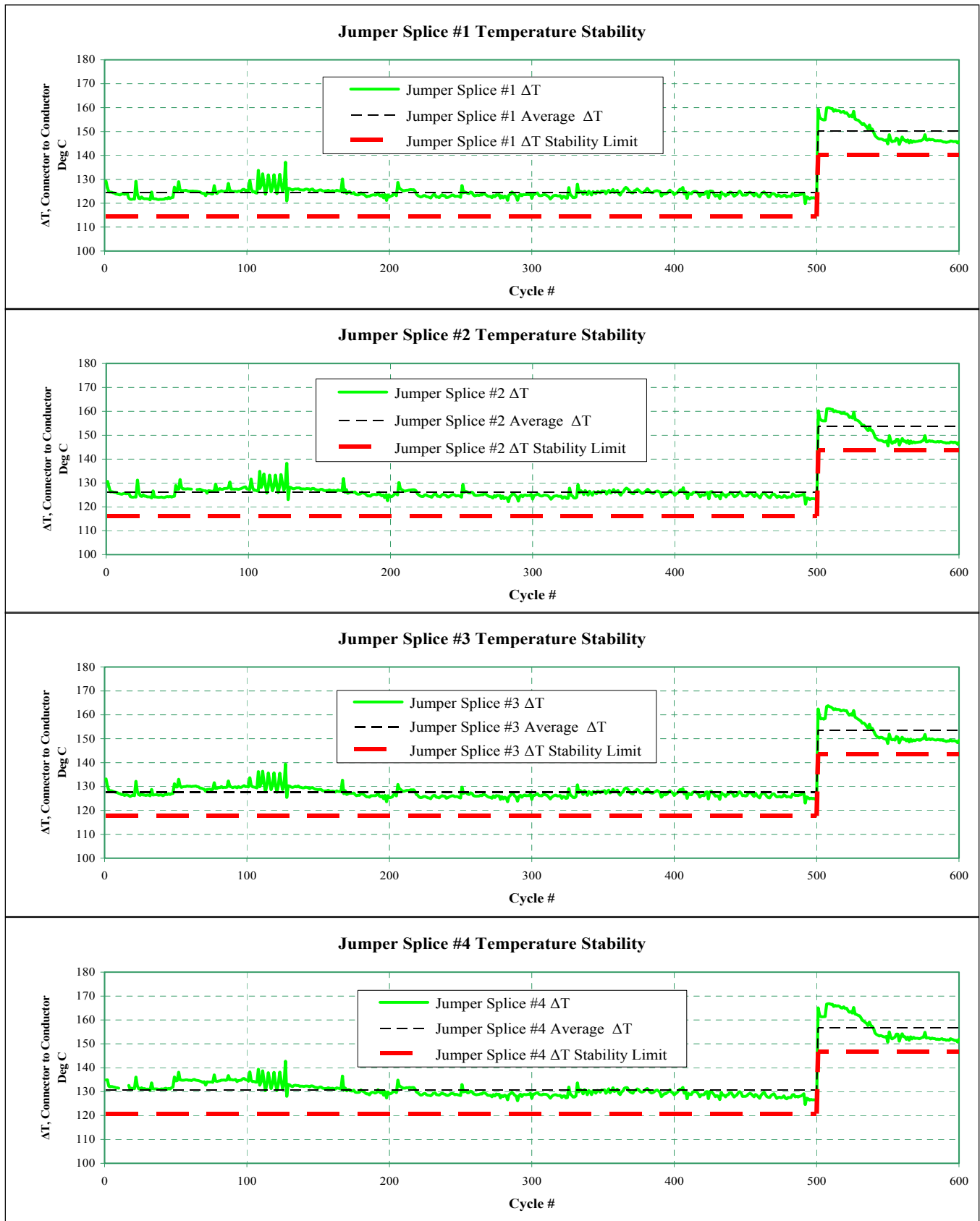


Figure 14, Temperature stability results for jumper splices (partial tension splice)



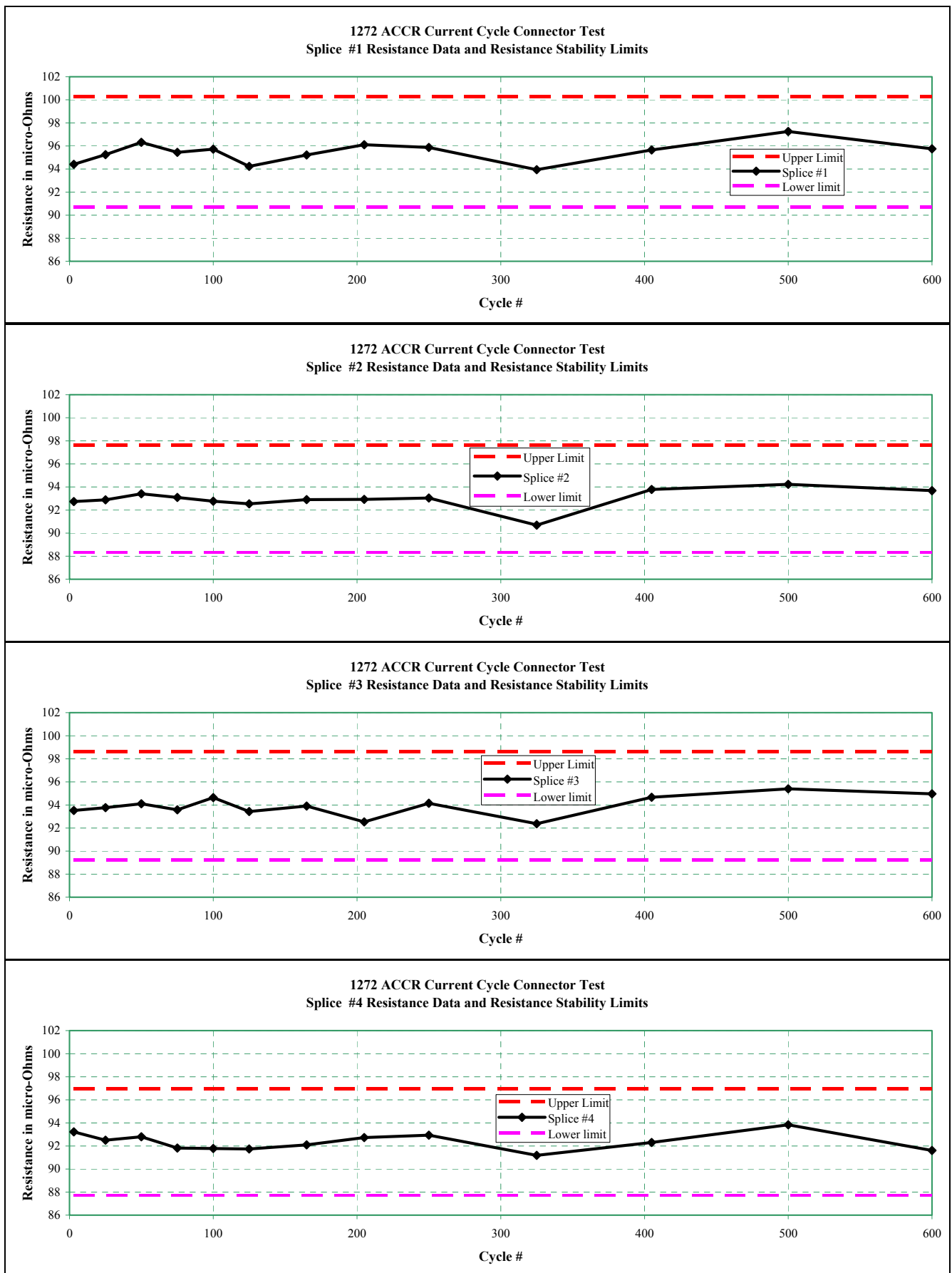


Figure 15, Resistance stability charts for splice connectors

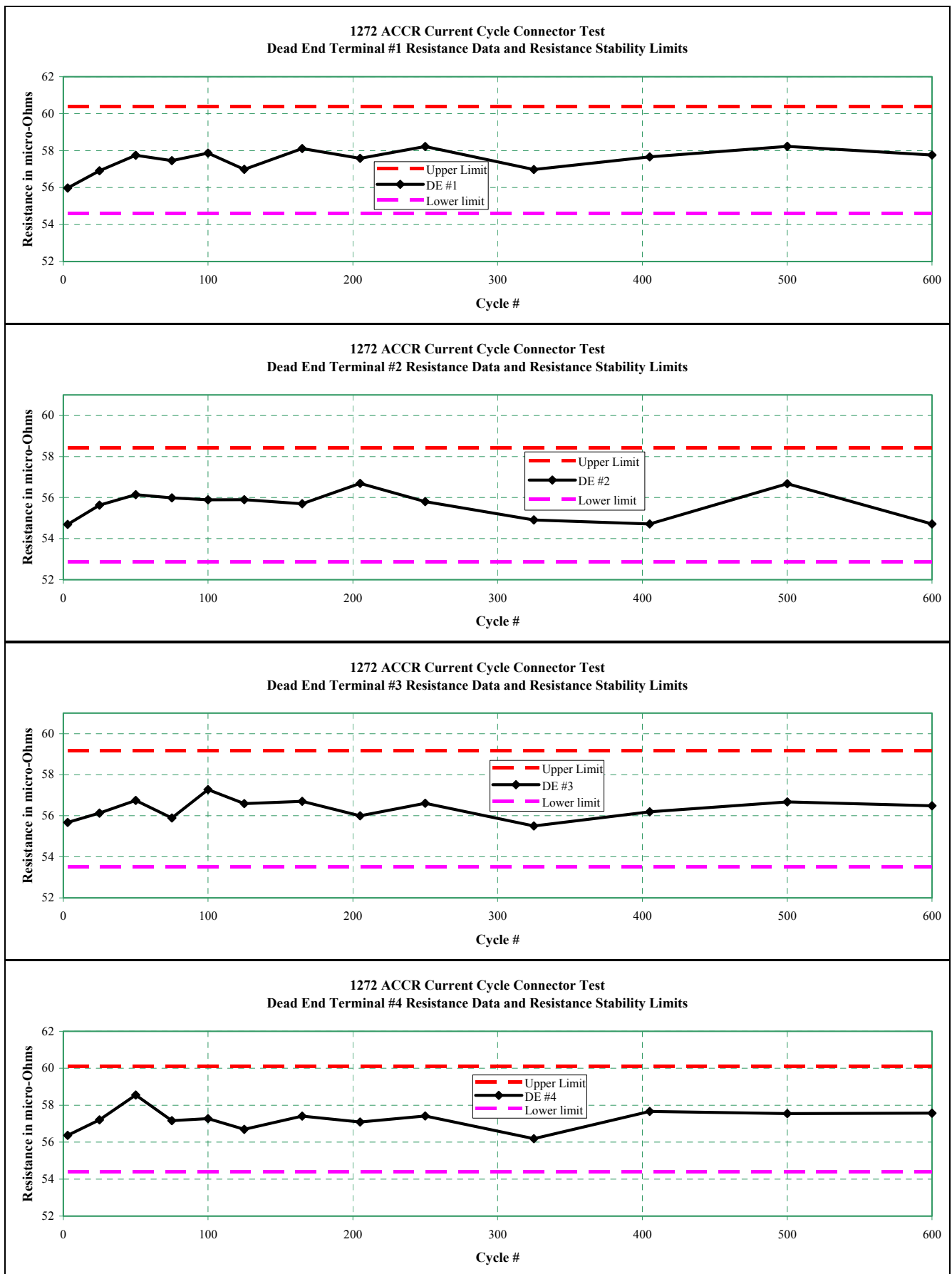


Figure 16, Resistance stability charts for dead end connectors

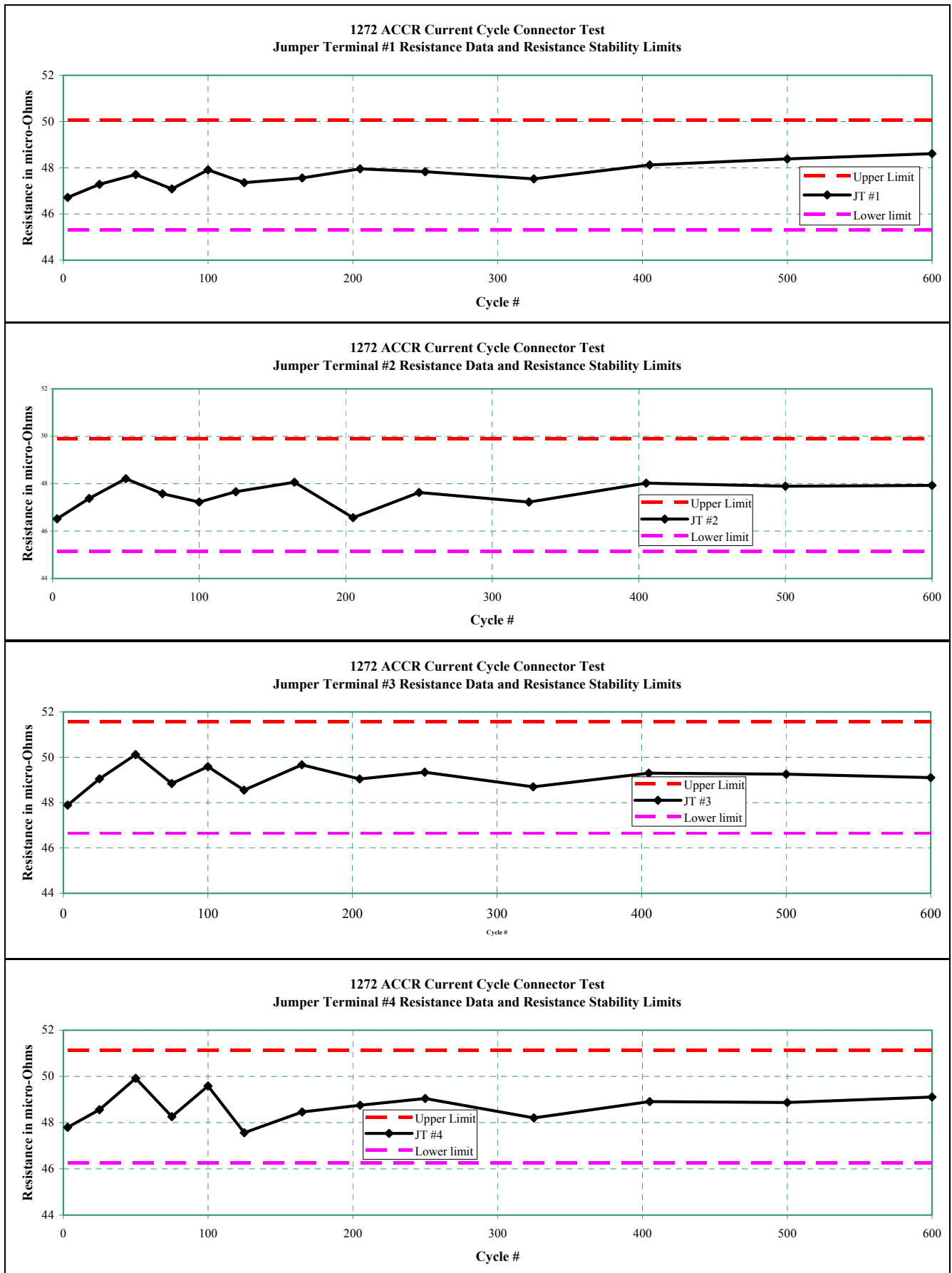


Figure 17, Resistance stability charts for jumper terminal connectors (tubular to 4-bolt NEMA)

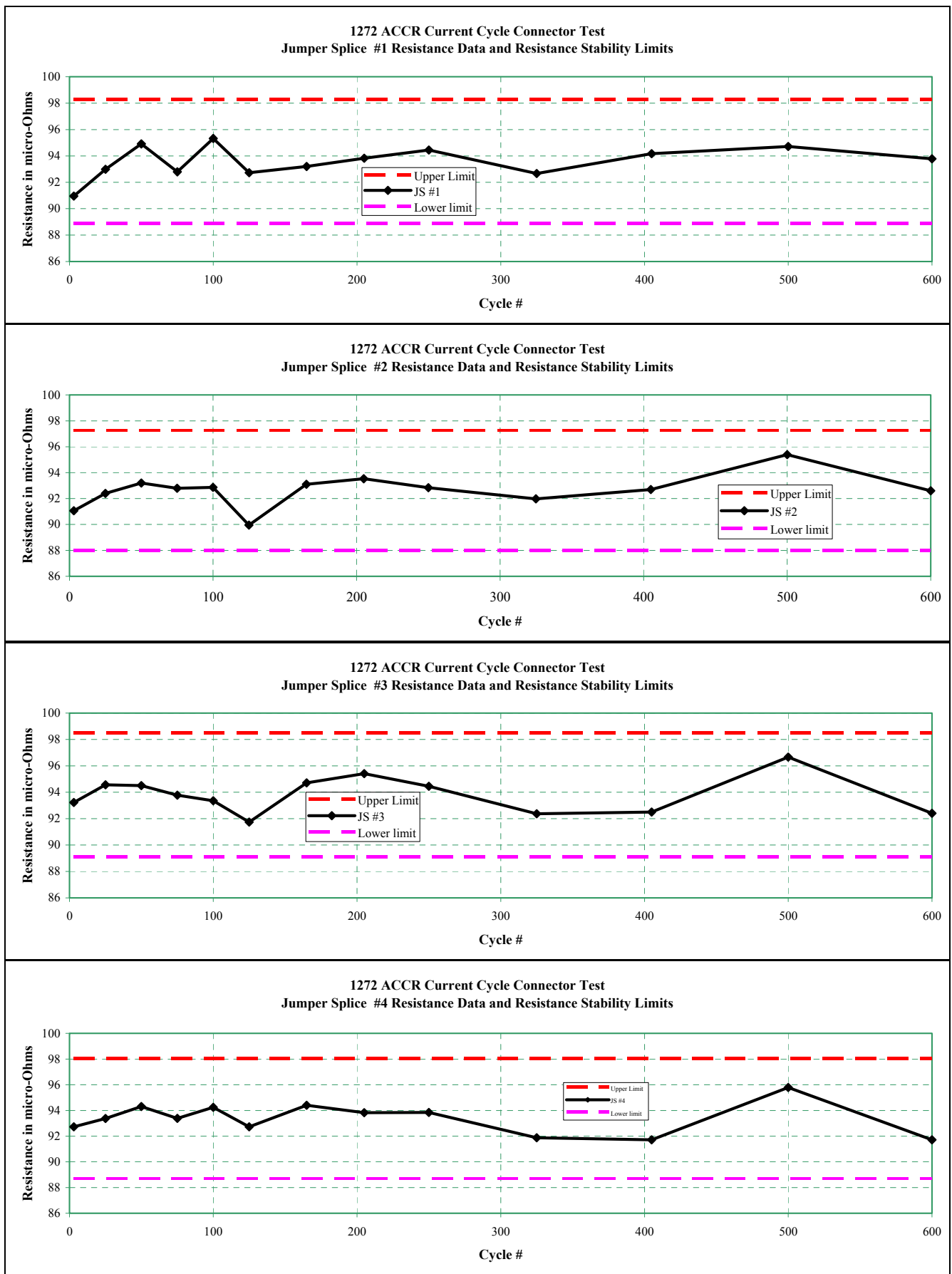


Figure 18, Resistance stability charts for jumper splice (partial tension) connectors