

**3M Brand Composite Conductor
Connector Current Cycle Qualification Test
for
596/TW ACCR Connectors**

**3M Company
Purchase Order 0000996088**


NEETRAC Project Number: 03-144

January, 2004



Requested by: Mr. Colin McCullough
3M

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Summary:

3M contracted with NEETRAC to perform qualification tests on connectors for 3M's 596/TW Composite Conductor. This has a diameter equivalent to a standard 477-kcmil 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). The ANSI C119.4 CCT methods and acceptance criteria were modified to reflect the higher operating temperature limits for ACCR conductor. All 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 for the 100° C conductor temperature rise test, and were in good condition at the end of the test.

Samples:

- 1) 24 meters (80 feet) of 596/TW 3M Brand Composite Conductor. This may also be referred to as 596 ACCR/TW or even as 477 ACCR/TWD (477-kcmil diameter equivalent), where ACCR stands for Aluminum Conductor Composite Reinforced.
- 2) Four (4) Alcoa Fujikura (AFL) full-tension splice connectors (catalogue # B9095-D) for 596/TW 3M Composite Conductor.
- 3) Four (4) AFL full-tension dead-end terminal connectors (catalogue # B9085-C) for 596/TW 3M Composite Conductor.
- 4) Four (4) AFL jumper terminal connectors (tubular to 4-bolt NEMA pad, catalogue # B9102-D) for 596/TW 3M Composite Conductor.
- 5) Four (4) AFL jumper splice connectors (partial-tension, catalogue # B9112-D) for 596/TW 3M Composite Conductor.

References:

- 1) NEETRAC – 3M Proprietary Information Agreement Dated 3/27/01
- 2) 3M Purchase Order 0000996088
- 3) PRJ 03-144, NEETRAC Project Plan
- 4) ANSI C119.4-2003

Equipment Used:

- 1) Connector lab high-current AC power supply
- 2) HP 3421A/PC/National Instruments control and data acquisition interface (controls the test, and records temperatures, Control #'s CQ 0224 and CQ0225)
- 3) AVO/Biddle DLRO digital low-resistance Ohmmeter, Control #'s CQ 1083

Procedure:

Testing was conducted in accordance with a NEETRAC procedure entitled “PRJ03-144, CONFIDENTIAL – MMC Conductor Evaluation, 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 and Kamal Amin 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 AC power supply was connected to the loop. Current was adjusted to obtain a steady-state control conductor surface temperature of 240° C. Current measured 1260 Amperes for the required steady-state temperature. Loop current was adjusted during the test to maintain the control conductor surface temperature at 240° C. Cycle timing was set for 90 minutes on and 90 minutes off in accordance with the ANSI C119.4 Standard. After 333 cycles, there were ambient temperature problems when a large test loop was started in the adjacent space. The cycle time was adjusted for 90 minutes on, and 150 minutes off to synchronize the two loops, and prevent excessive ambient temperature excursions that occurred when both loops ran at the same time. 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.
- 3) The cooling cycle time was increased to help stabilize ambient temperatures in the lab space. There was no effect on the test results from this change, except that stable ambient temperatures improve apparent temperature stability results.

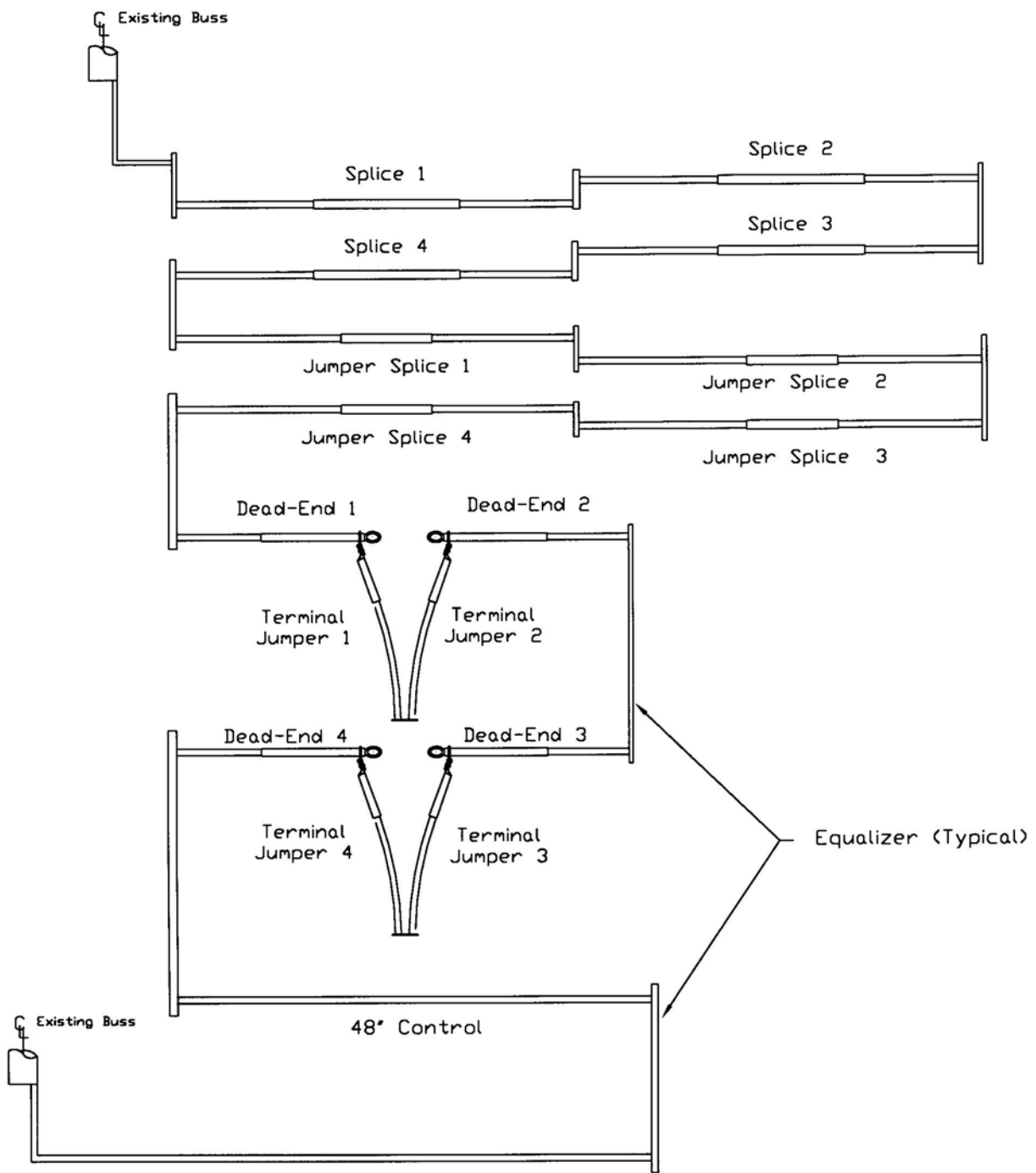
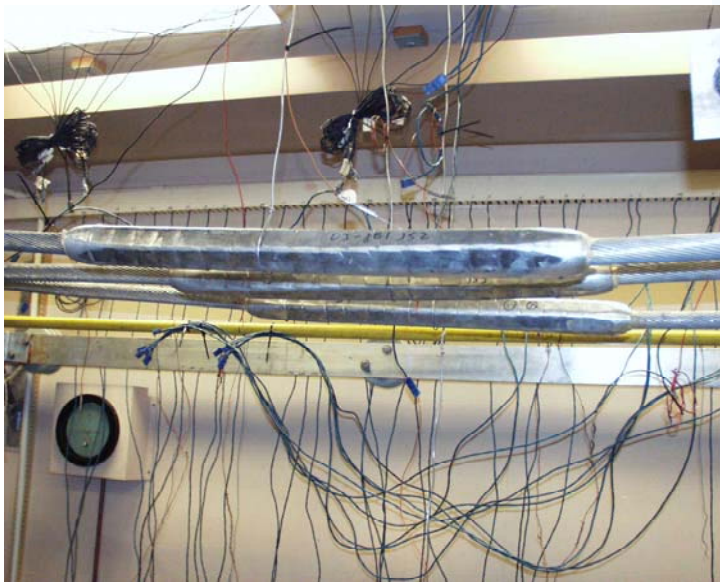


Figure 1 Sketch showing connector test loop arrangement

Connector temperature and resistance data were recorded by an automatic data acquisition. Switching of the power supply for the on and off cycle was also 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 and 2 show the connector test loop during the test.



Photograph 1, Jumper splices
(larger loop in foreground is 1272 ACCR connector test which is reported separately)



Photograph 2, dead ends and jumper connectors

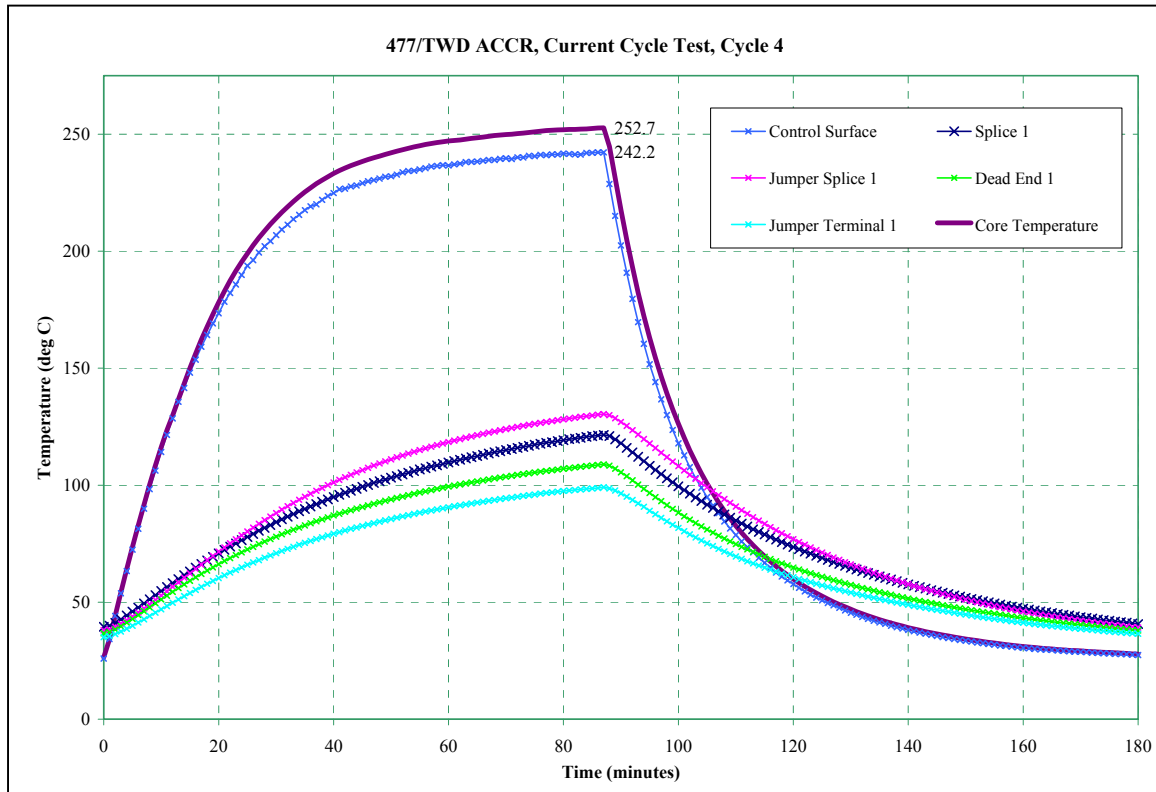


Figure 2, Temperatures for connectors and conductor during a typical current cycle

Results:

To qualify under the ANSI C119.4 standard, a connector must display the following three attributes:

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

Results and Discussion: See Figures 3 through 6 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. 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 7 through 10 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 11 through 14 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 16 connectors in the test exceeded the ANSI C119.4 acceptance criteria. These results make it reasonable to conclude that all connectors will provide reliable service in transmission line service.

Acknowledgement:

This material is based upon work supported by the U.S. Department of Energy under Award No. DE-FC02-02CH11111.

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 03-144

Current Cycle Test for 596/TW 3M Composite Conductor Connectors

Appendix

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

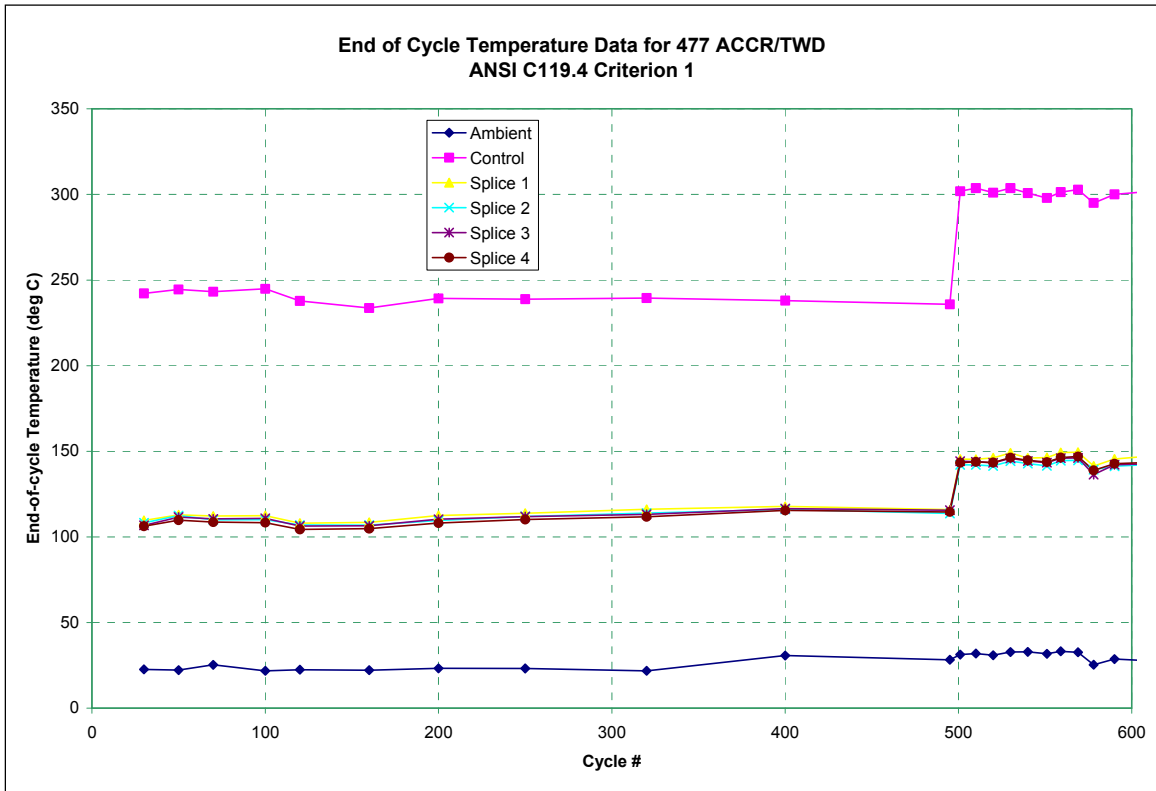


Figure 3, end-of cycle temperature data for compression splice test samples

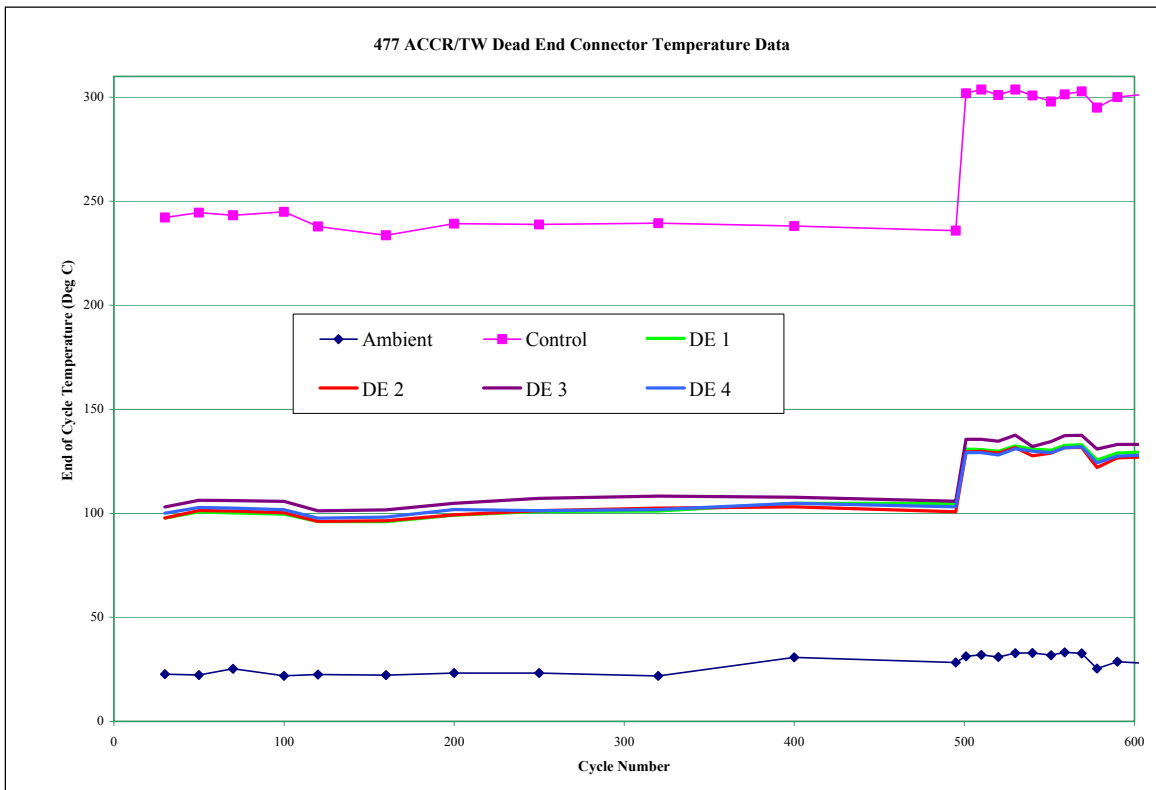


Figure 4, end-of-cycle temperature data for dead end terminal samples

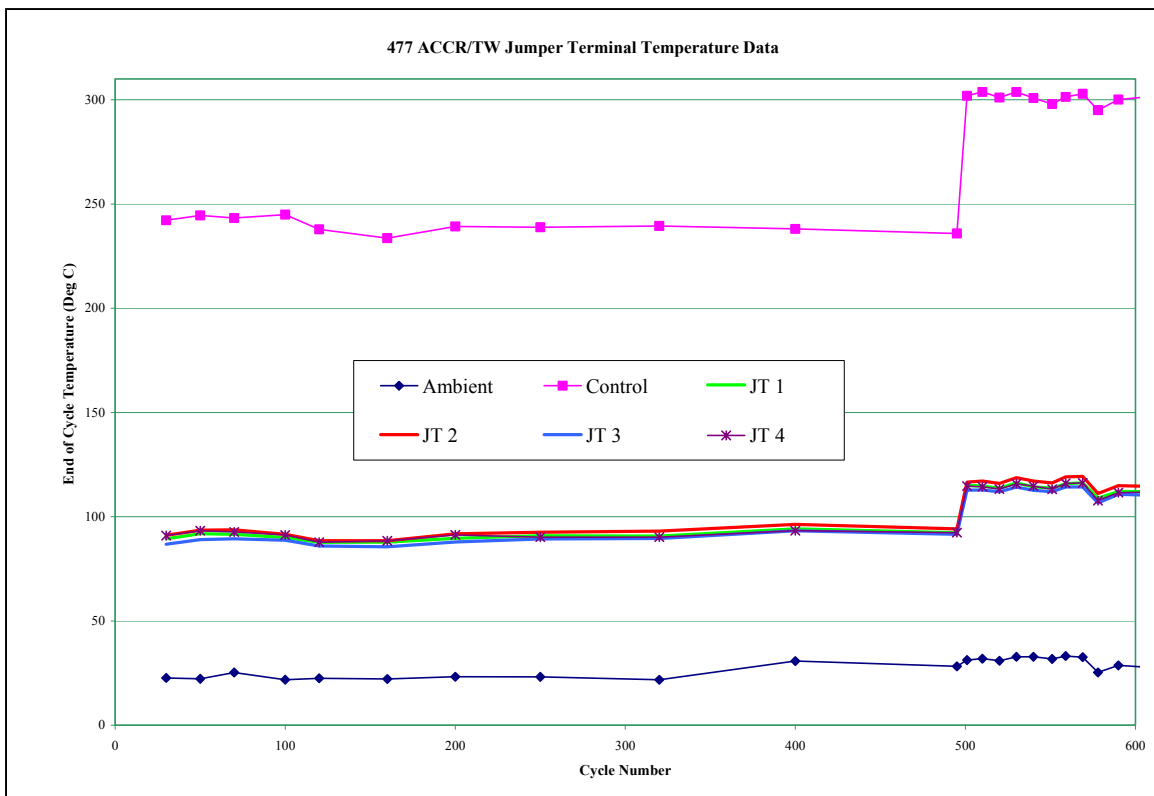


Figure 5, end-of-cycle temperature data for compression jumper terminal connectors (compression to 4-bolt NEMA terminal)

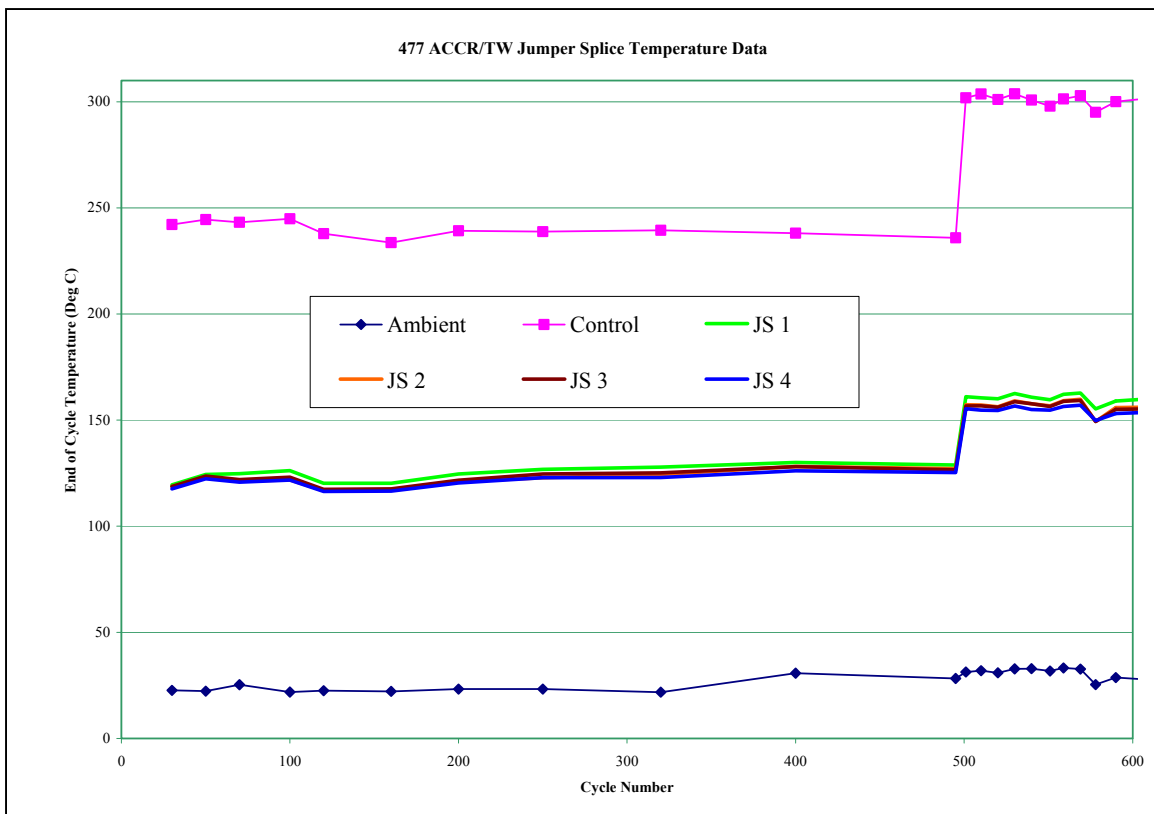


Figure 6, end-of-cycle temperature data for jumper splices

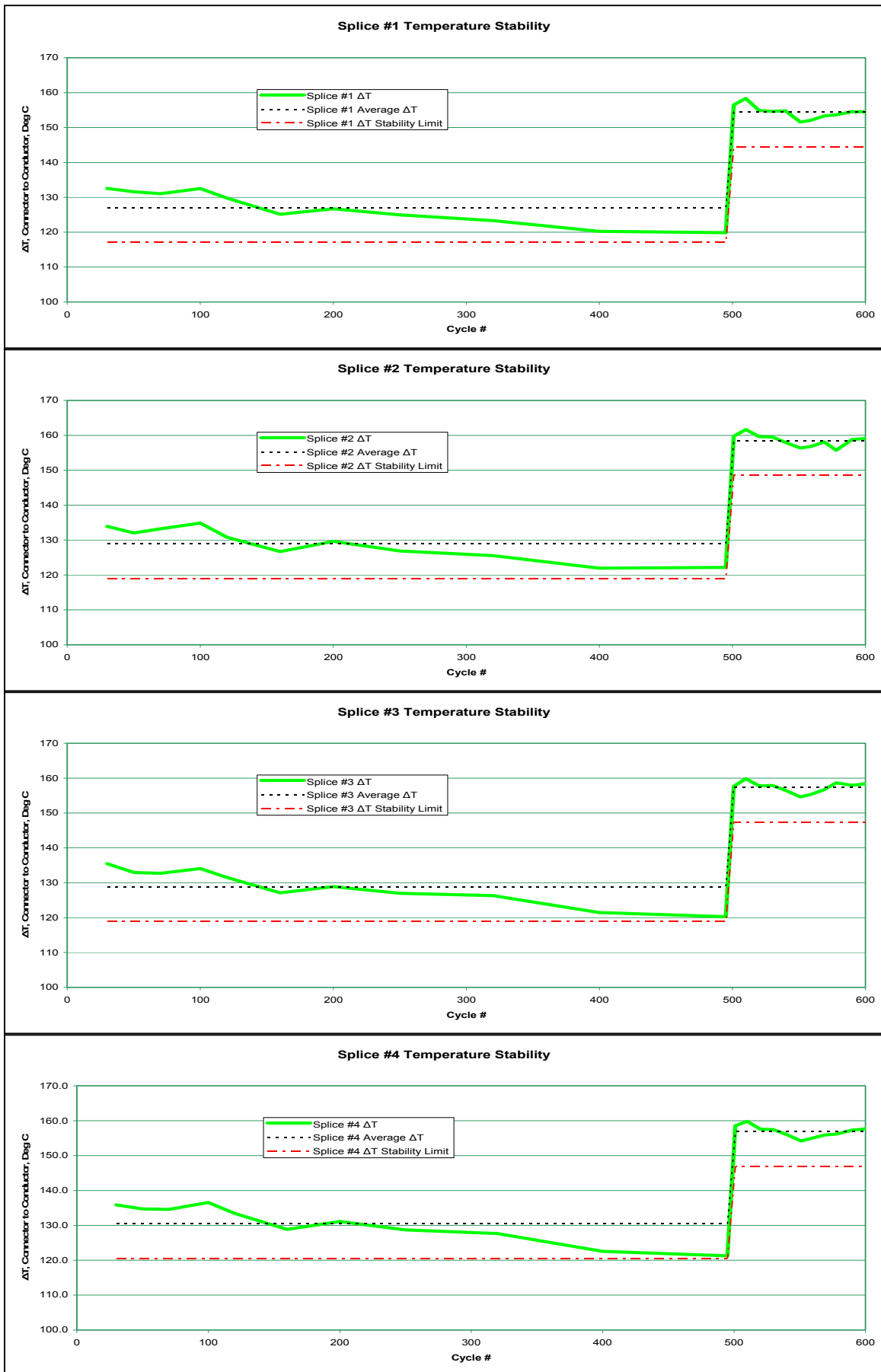


Figure 7, Temperature stability results for compression splice samples

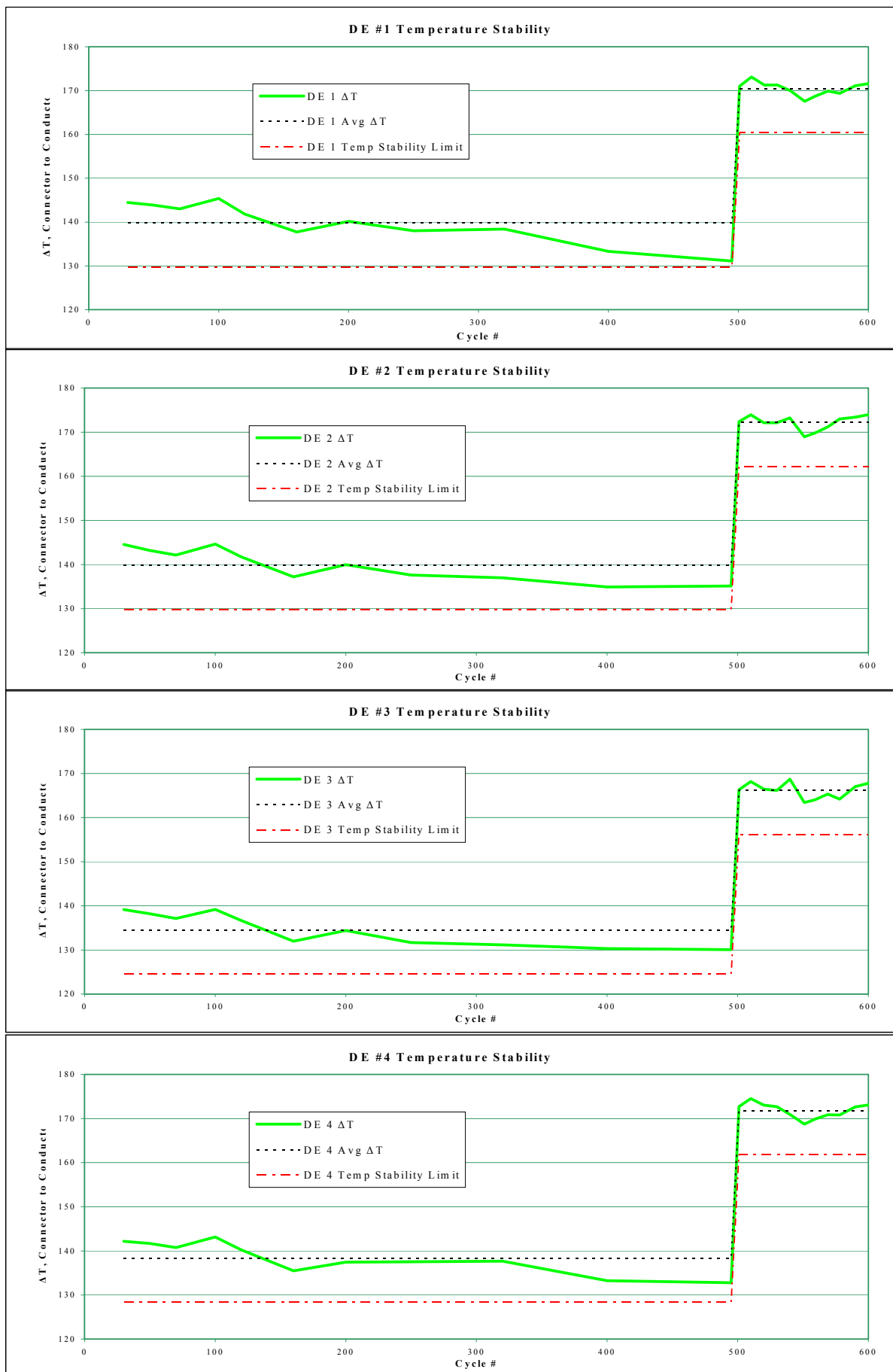


Figure 8, Temperature stability data for compression dead end connectors

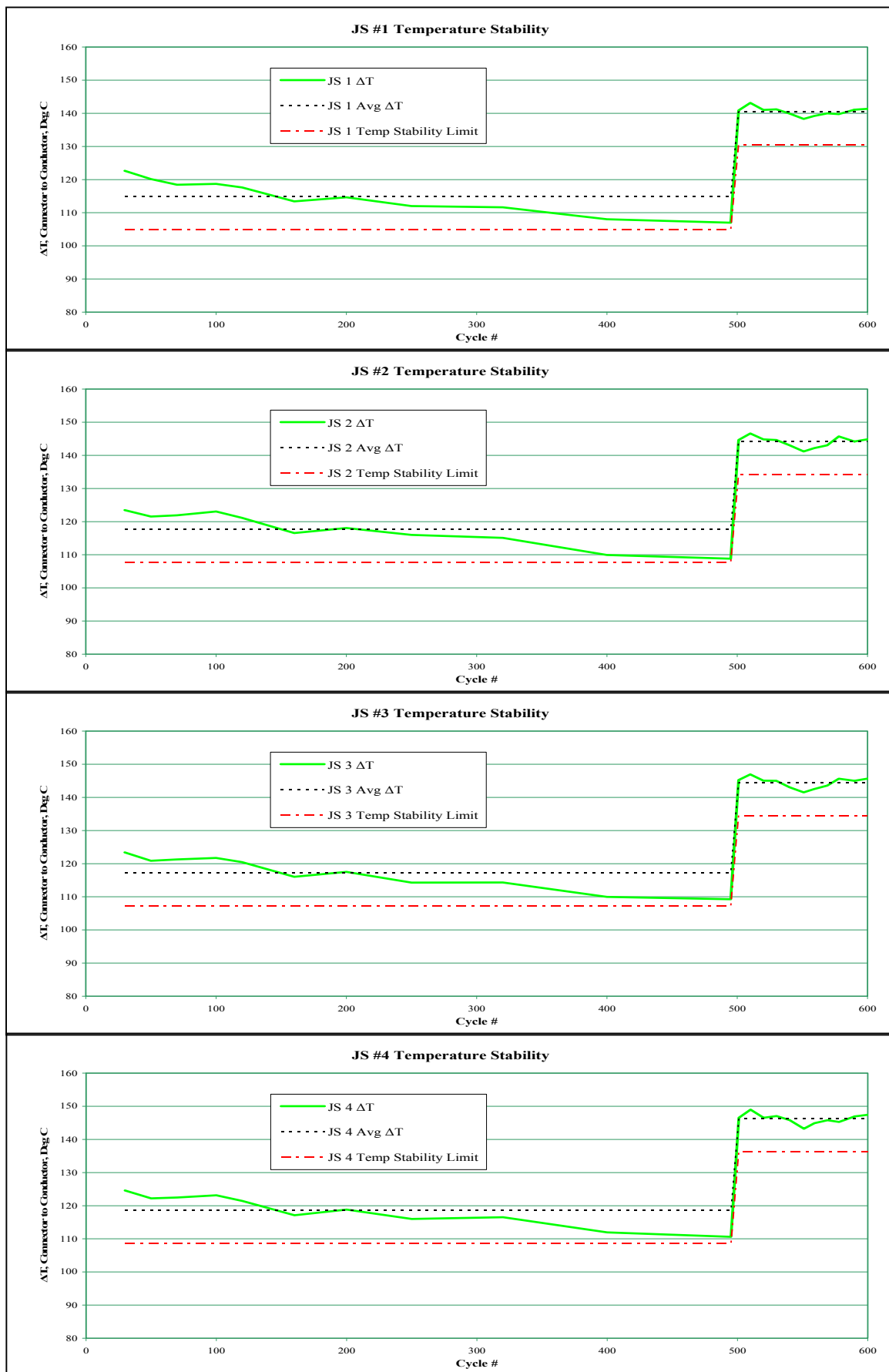


Figure 9, Temperature stability results for compression jumper splices

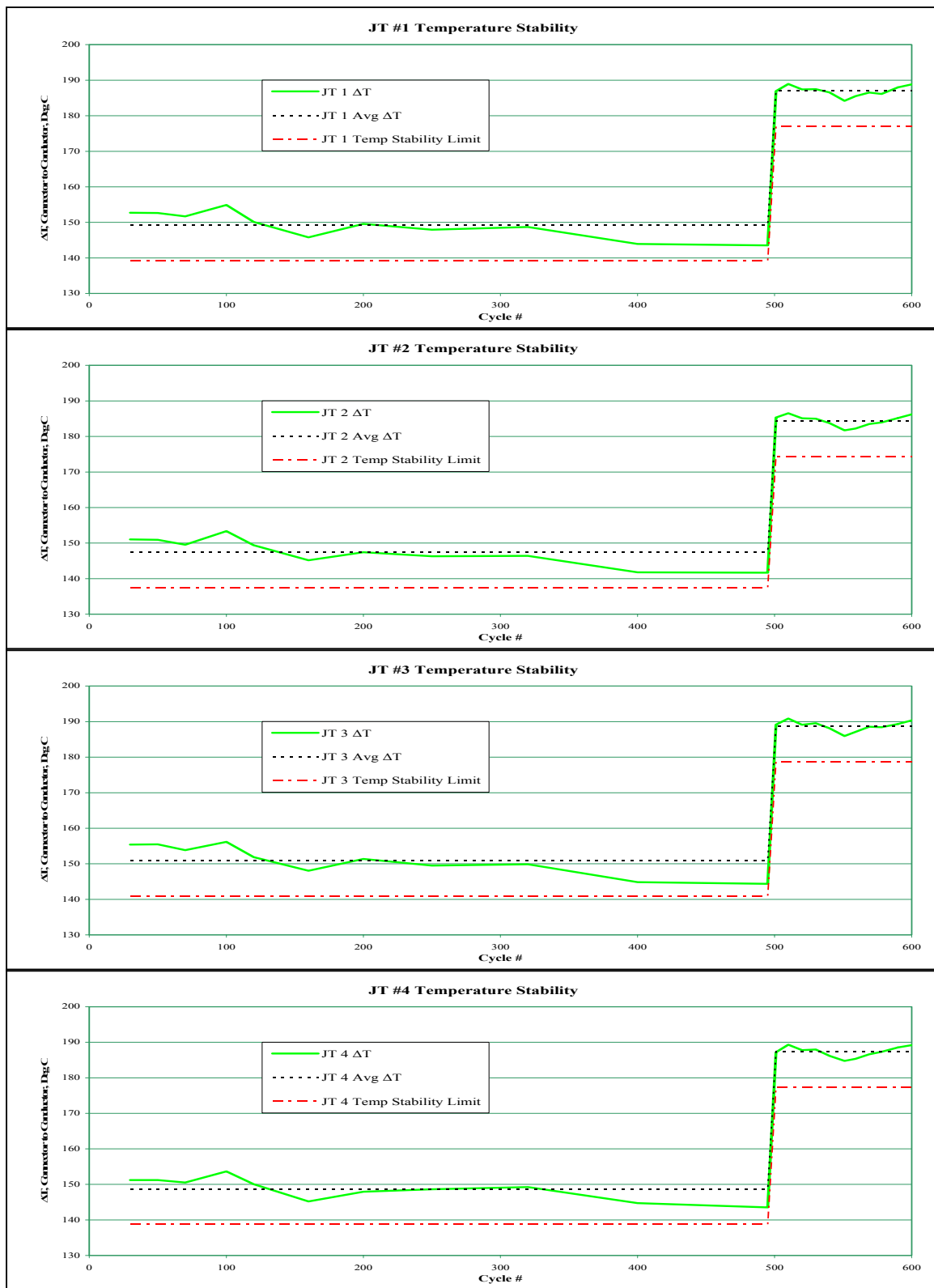


Figure 10, Temperature stability results for jumper terminals (compression to 4-bolt NEMA)

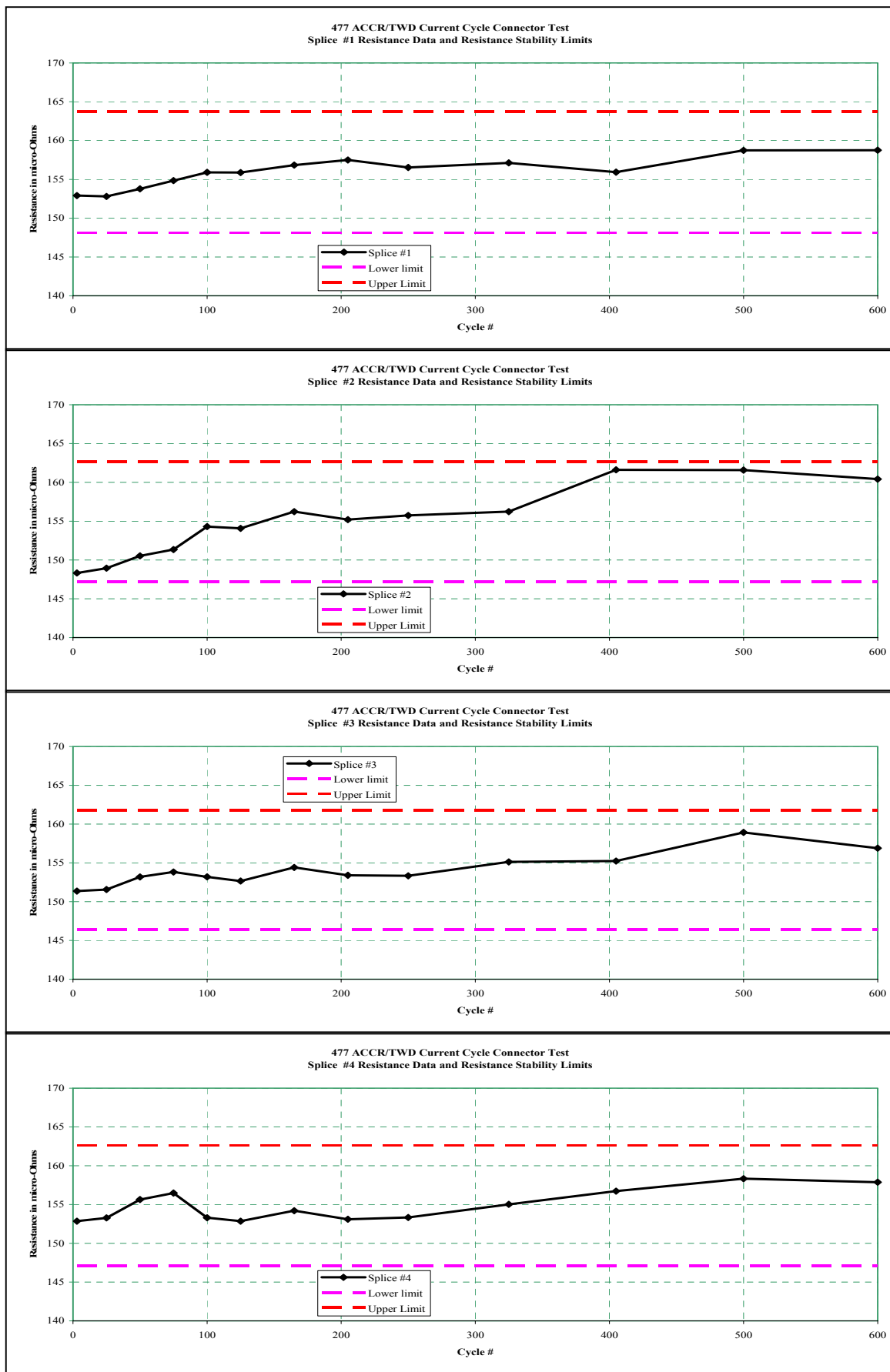


Figure 11, Resistance stability charts for splice connectors

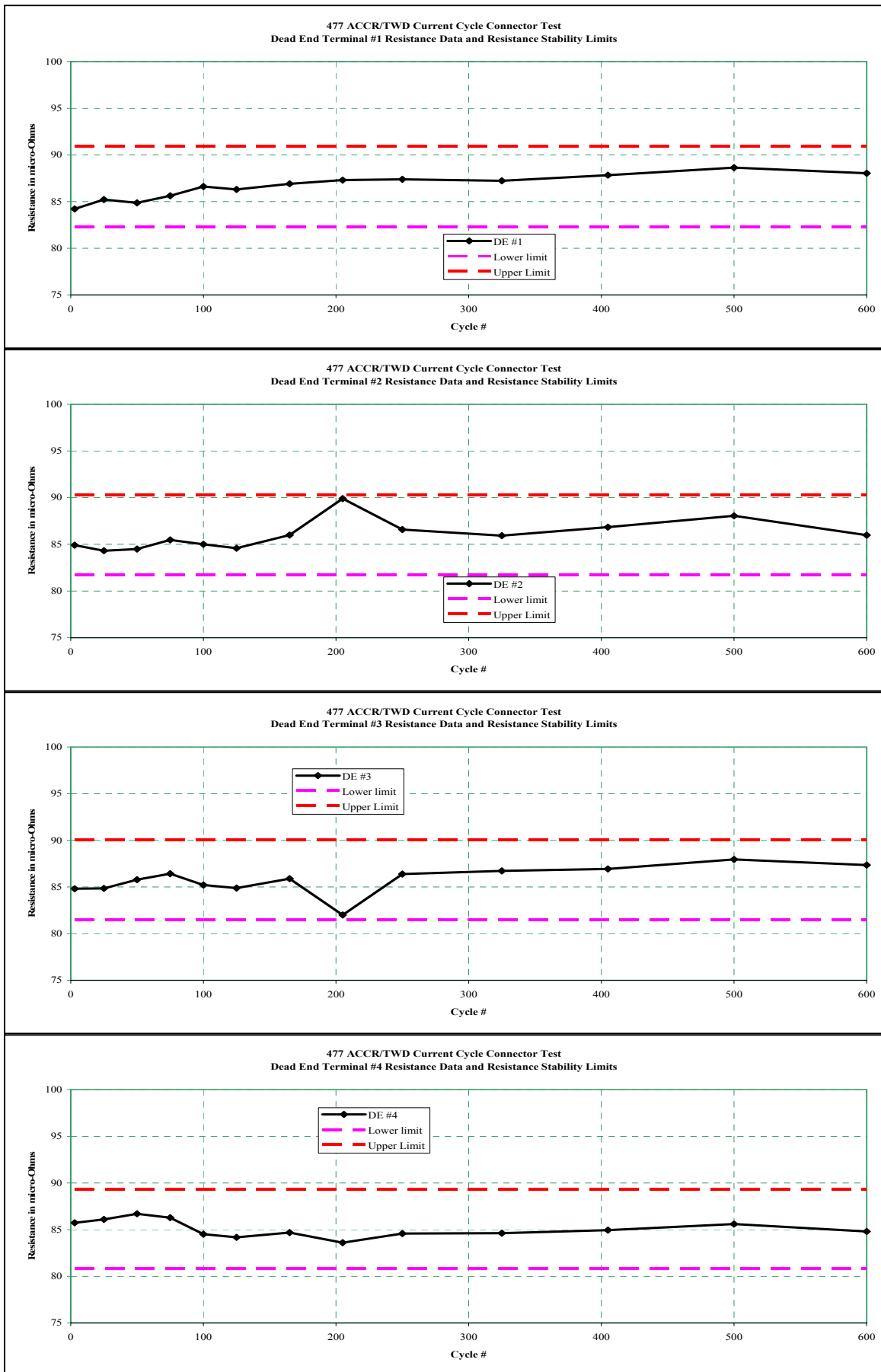


Figure 12, Resistance stability charts for dead end connectors

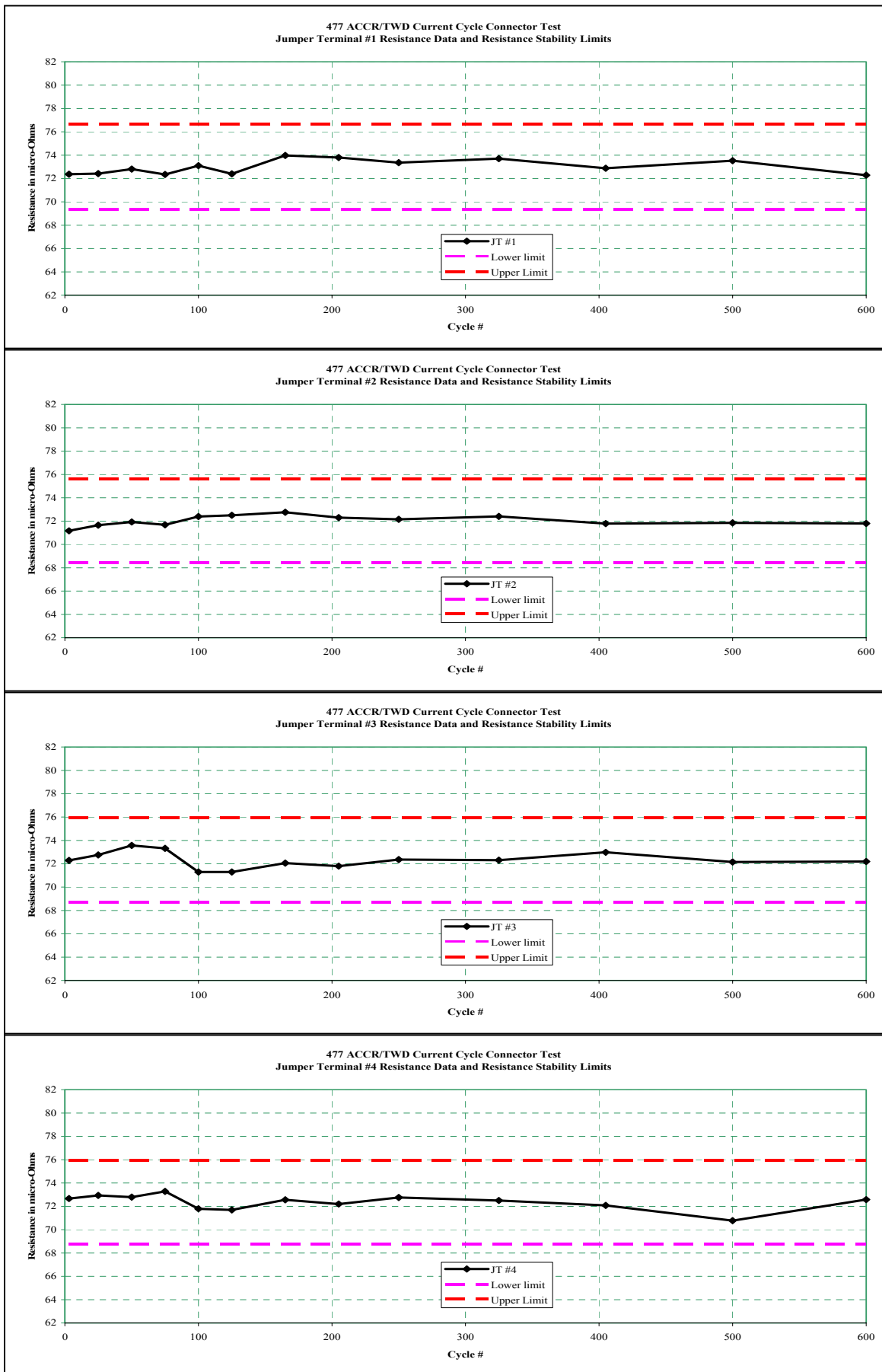


Figure 13, Resistance stability charts for jumper terminal connectors (tubular to 4-bolt NEMA)

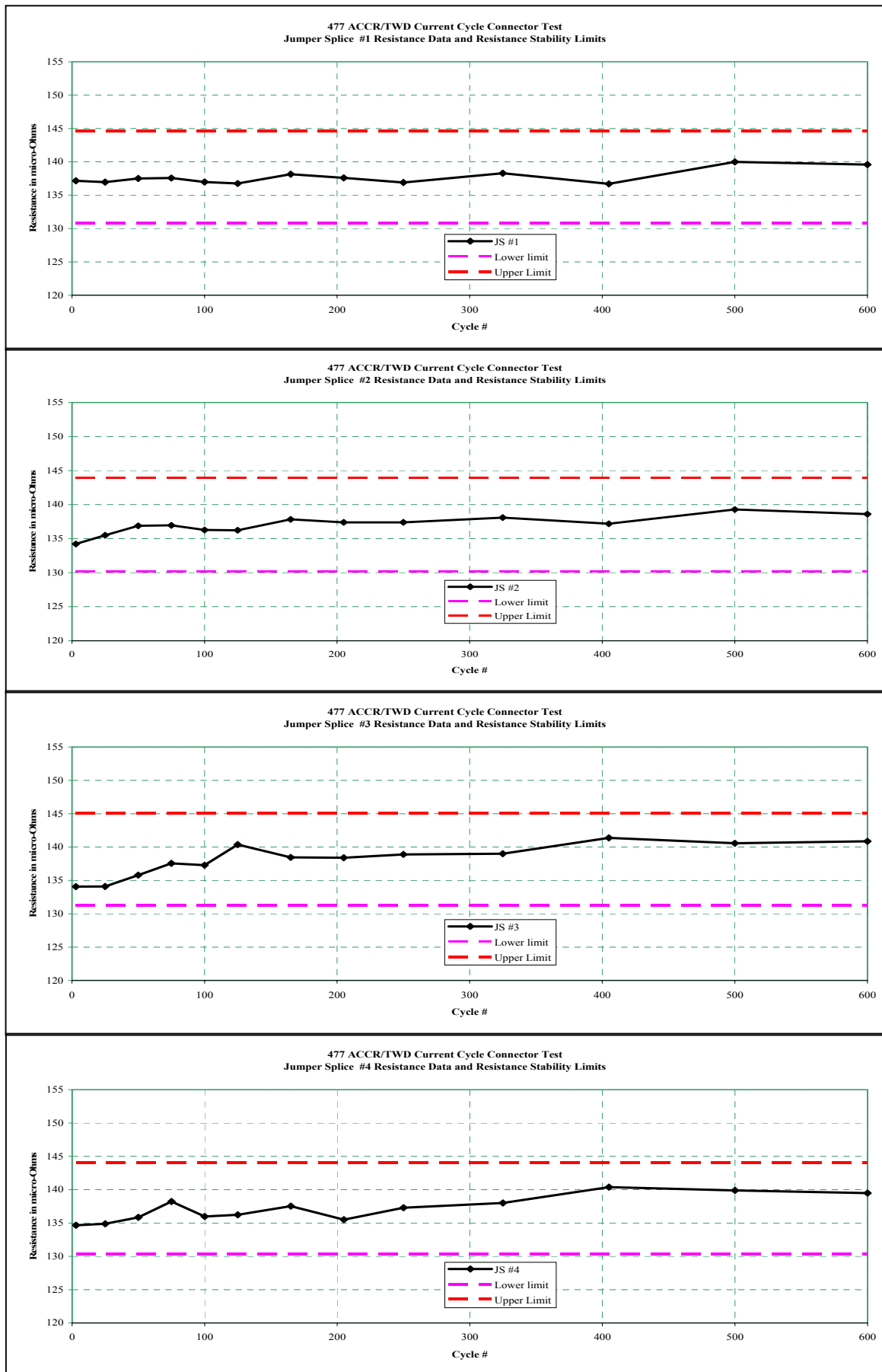


Figure 14, Resistance stability charts for jumper splice (partial tension) connectors