3M Brand Composite Conductor
Connector Current Cycle Qualification Test
for
795 kcmil Compression Connectors

3M Company
Purchase Orders 0000797063 and 0000866974

NEETRAC Project Number: 03-071

September, 2003

A Research Center of
The Georgia Institute of Technology

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Summary:

3M contracted with NEETRAC to perform qualification tests on connectors for 795 kcmil 3M Brand Composite Conductor. A total of 21 compression connectors supplied by Alcoa Conductor Accessories (ACA) were connected in a series loop with 795 kcmil 3M Composite Conductor. The ANSI C119.4 methods and acceptance criteria were modified to reflect the operating temperature limits for the 3M Composite Conductor. All connectors performed well after 500 cycles from room temperature to 240^{o} C. After meeting the ANSI 500-cycle criteria, the connectors were subjected to an additional 100 additional cycles at 300^{o} C. All connectors were in good condition at the end of the test. One splice was installed using an experimental ACA high-temperature inhibitor compound. That sample ran marginally cooler than the identical connectors with standard filler compound.

Samples:

1) 40 meters (130 feet) of 795 3M Composite Conductor
2) Four (4) ACA full-tension splice connectors for 795 3M Composite Conductor (special design), catalogue number B9095-B.
3) Four (4) ACA full-tension dead-end terminal connectors for 795 3M Composite Conductor (special design), catalogue number B9085-B.
4) Four (4) ACA partial-tension jumper splice connectors for 795 3M Composite Conductor (special design), catalogue number B9112-B.
5) Four (4) ACA jumper terminal connectors (tubular to 4-bolt NEMA pad) for 795 3M Composite Conductor (special design), catalogue number B9102-B.
6) Four (4), ACA compression repair sleeves, installed over conductor damage simulated by cutting nine (9) of the outer aluminum strands, catalogue number C9121-B.
7) One (1), ACA bolted parallel groove tap connector, catalogue number 584.4P.

References:

1) NEETRAC – 3M Proprietary Information Agreement Dated 3/27/01
2) 3M Purchase Orders 0000797063 and 0000866974
3) PRJ 03-071, NEETRAC Project Plan
4) ANSI C119.4-1998

Equipment Used:

1) Connector lab high-current DC power supply
2) HP 3421A/PC/National Instruments control and data acquisition interface (controls the test, and records temperatures and resistance readings, Control #'s CQ 0224 and CQ0225.

Procedure:

Testing was conducted in accordance with a NEETRAC procedure entitled "PRJ03-071, CONFIDENTIAL – MMC Conductor Evaluation, Connector Current Cycle Test. The procedure controls all technical and quality management details for the project.

Personnel from ACA and 3M visited NEETRAC for connector installation. NEETRAC's Tommy McKoon assisted Wayne Quesnel and Kamal Amin on the connector installation process. ACA-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. Welded equalizers (aluminum plates) were used between each connector in the series loop 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^o C. Current measured 1500 Amperes for the required steady-state temperature. Loop current was adjusted during the test to maintain the control conductor surface temperature at 240^o C. Cycle timing was set for 90 minutes on and 90 minutes off. After 500 complete thermal cycles, the current was adjusted to raise the control conductor surface temperature to 300^o C. One hundred thermal cycles were completed at the higher temperature, for a total of 600 cycles.

The profile differs from the ANSI C119.4 in the following respects:

1) Control conductor temperature was 240^o C, instead of 100^o C rise above ambient (typical control conductor temperature is 123^o C).
2) At the end of the standard 500 thermal cycles, 100 additional cycles were completed with the control conductor maximum temperature of 300^o C.
3) Heat-up and cool-down data were recorded.

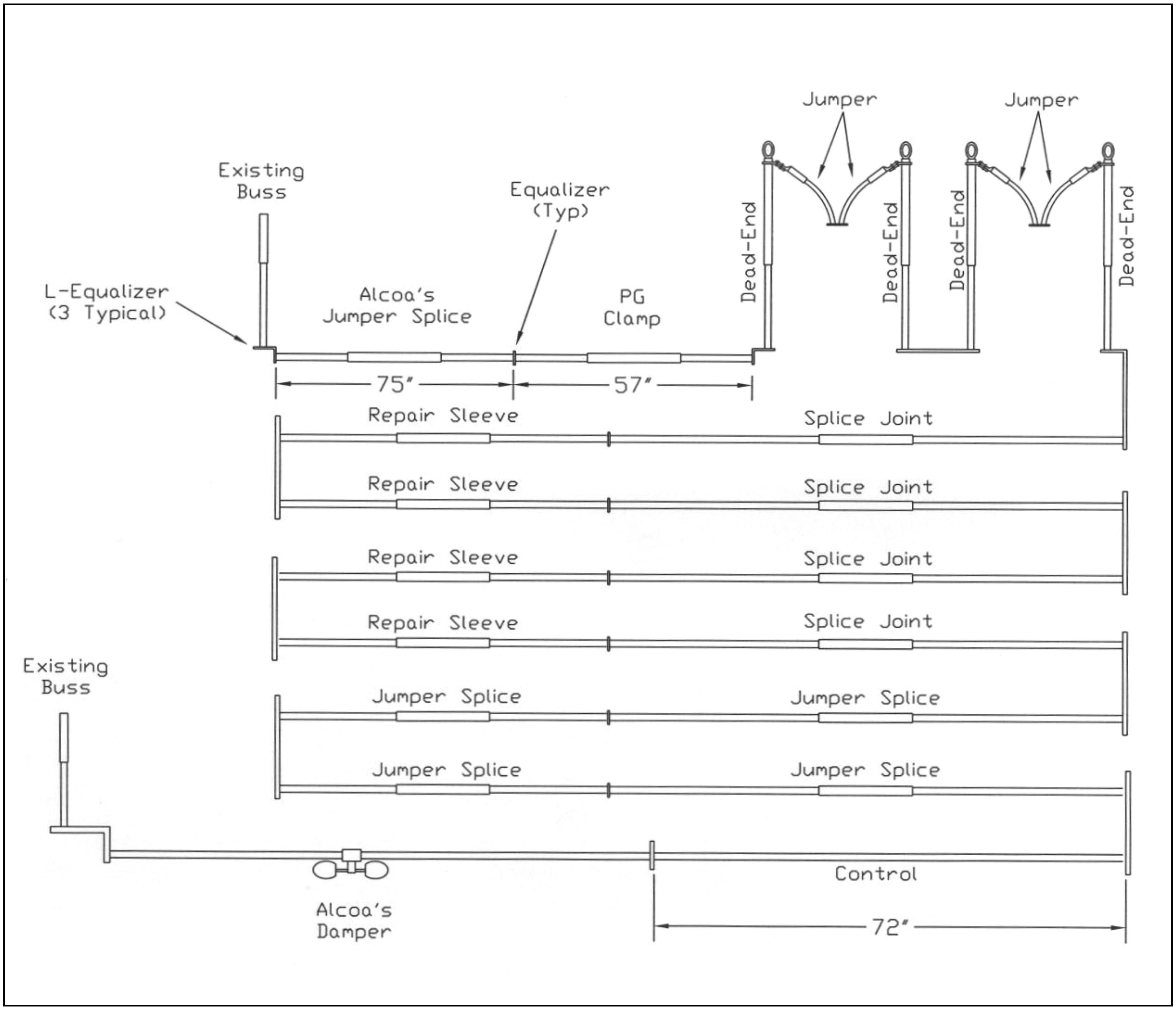

Figure 1
Sketch showing connector test loop arrangement

Connector temperature and resistance data were recorded by an automatic data acquisition. Switching of the power supply for the 90 minute "on" and 90 minute "off" cycle was also under automatic control during the test. Splice resistance was 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. Photograph 1 shows the connector test loop during the test.

Photograph 1
795 kcmil 3M Composite Conductor connector test loop

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 2 through 7 for charts illustrating the behavior of each connector. Data for three of the four jumper splice samples is missing because of an undetected error in setting up the data acquisition system. The samples were exposed to the same current cycles as the other samples, and none of them exhibited any significant resistance change. Therefore it is reasonable to conclude that the jumper splices pass the test for criterion 1. Connectors of each type are on a single graph. It is difficult to isolate an individual connector, as the temperature of each connector closely matched its cohorts in every case.

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

   Results and Discussion: See Figures 8 through 13 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. The data show what appears to be marginal stability, but that is not the case. The ANSI temperature stability criterion is based on a 100^{o} C rise for the control conductor above room temperature (123 ^{o} C versus 240 ^{o} C and 300 ^{o} C used for this test). Further, the ANSI standard forbids adjustment of the heating current after cycle 25. In this test, the current was adjusted to maintain the target temperature as the ambient temperature changed. Temperature control was complicated by a very large test loop with 1351 kcmil conductor and connectors. The heat load was such that ambient temperature oscillated over a range of 10.9 degrees. The changes in the connector ΔT are almost entirely due to changes in ambient temperature and adjustments in heating current. Extremely stable performance was exhibited in the last 100 cycles, which were run at 300 ^{o} C. The reason is that the adjacent large test was complete, and there were no adjustments in the heating current. The behavior during the last 100 cycles is, therefore, the correct result for this connector and conductor system. Again, the temperature data for three of the jumper splices is missing after cycle 305. Results from the sample with complete data, resistance results, and comparison with similar full-tension splices makes it reasonable to conclude that the jumper splice design also meets this criterion.

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

Results and Discussion: See Figures 14 through 20 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 21 connectors in the test exceeded the ANSI C119.4 acceptance criteria. The parallel-groove connector technically does not qualify because only one sample was tested. ANSI C119.4 requires a minimum of four samples. However, the performance of the one sample, and comparison with the other results makes 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 03-071

Current Cycle Test for 795 3M Composite Conductor Connectors

Appendix

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

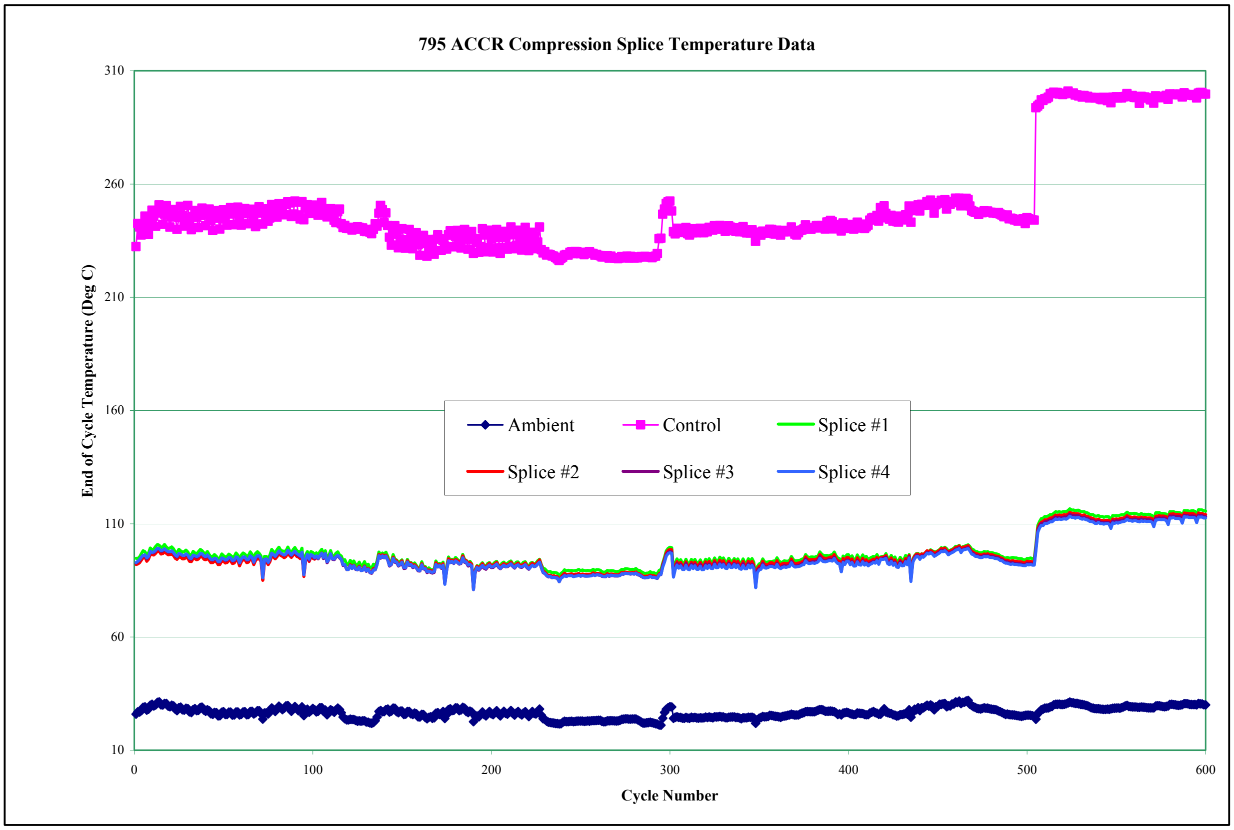


Figure 2, end-of cycle temperature data for compression splice test samples

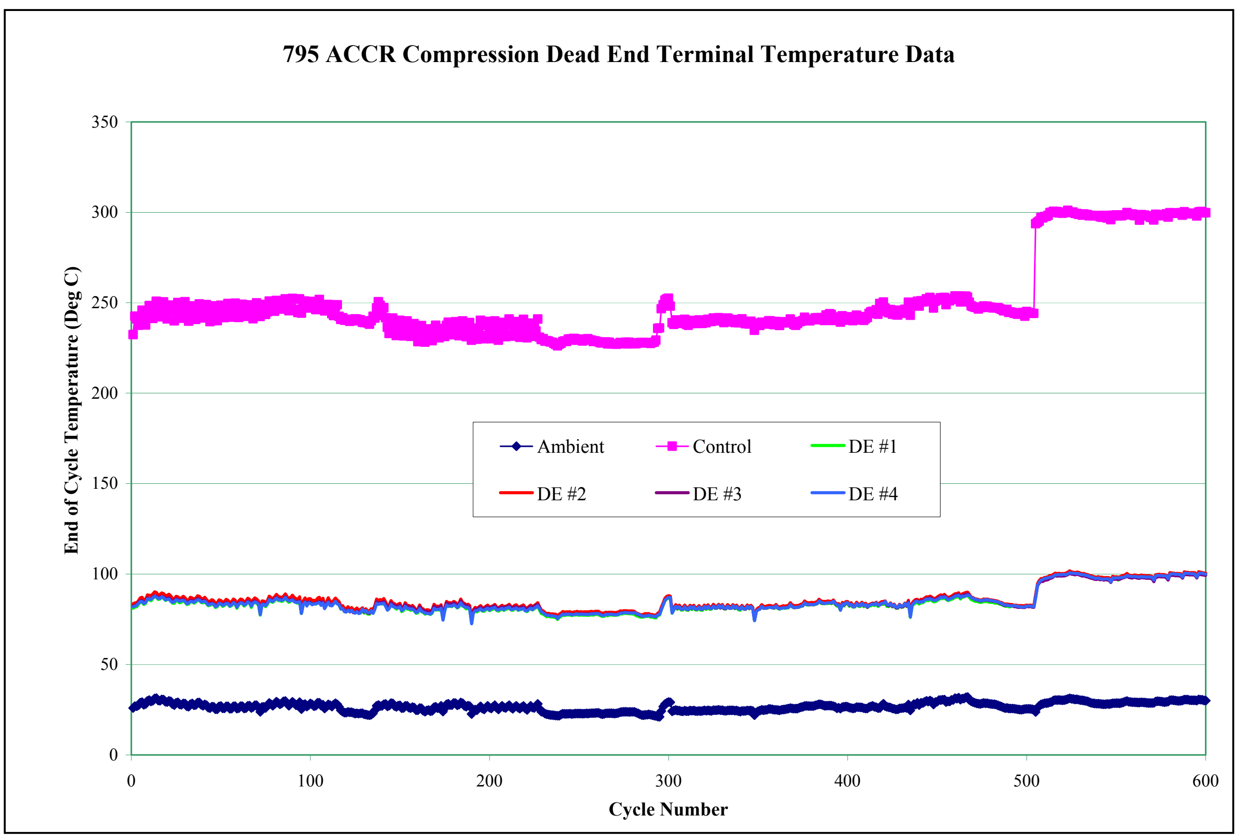


Figure 3, end-of-cycle temperature data for dead end terminal samples

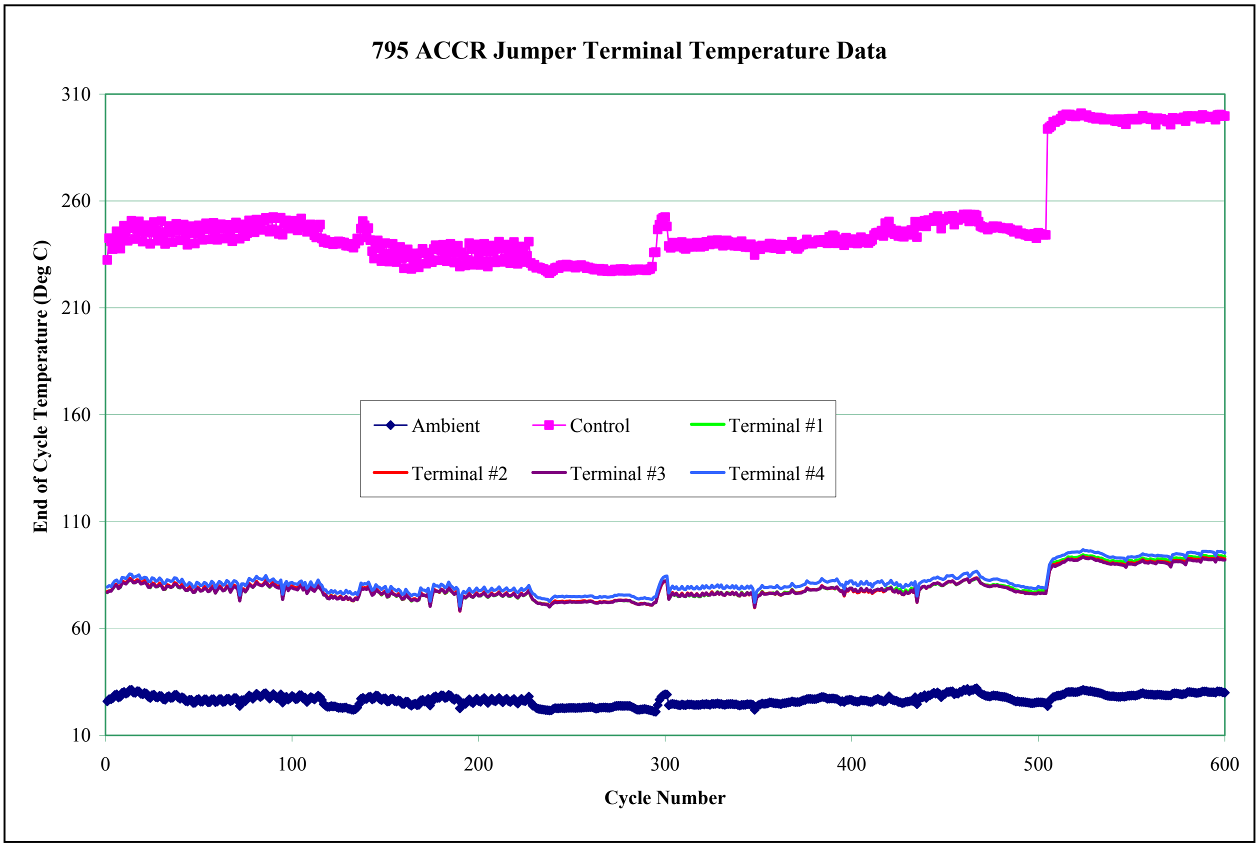


Figure 4, end-of-cycle temperature data for compression jumper terminal connectors (compression to 4-bolt NEMA terminal)

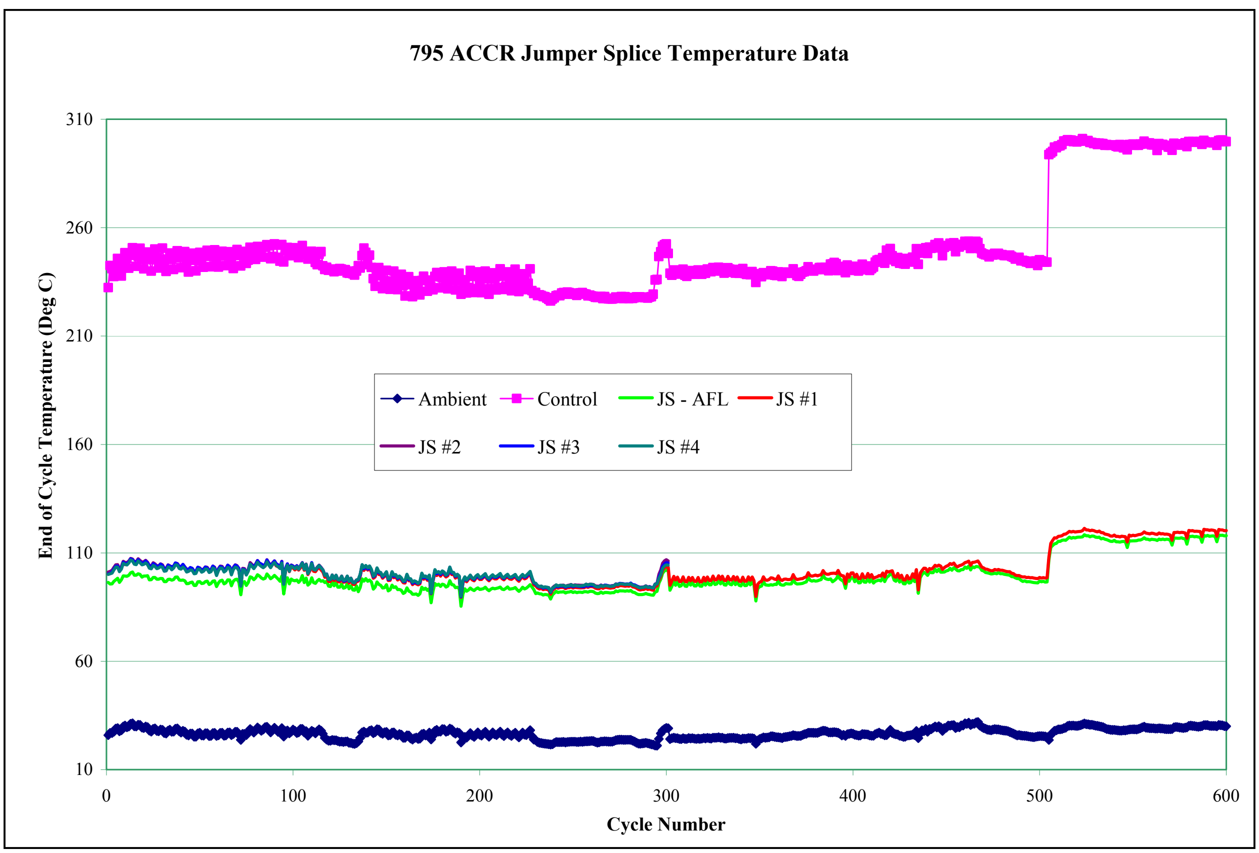


Figure 5, end-of-cycle temperature data for jumper splices

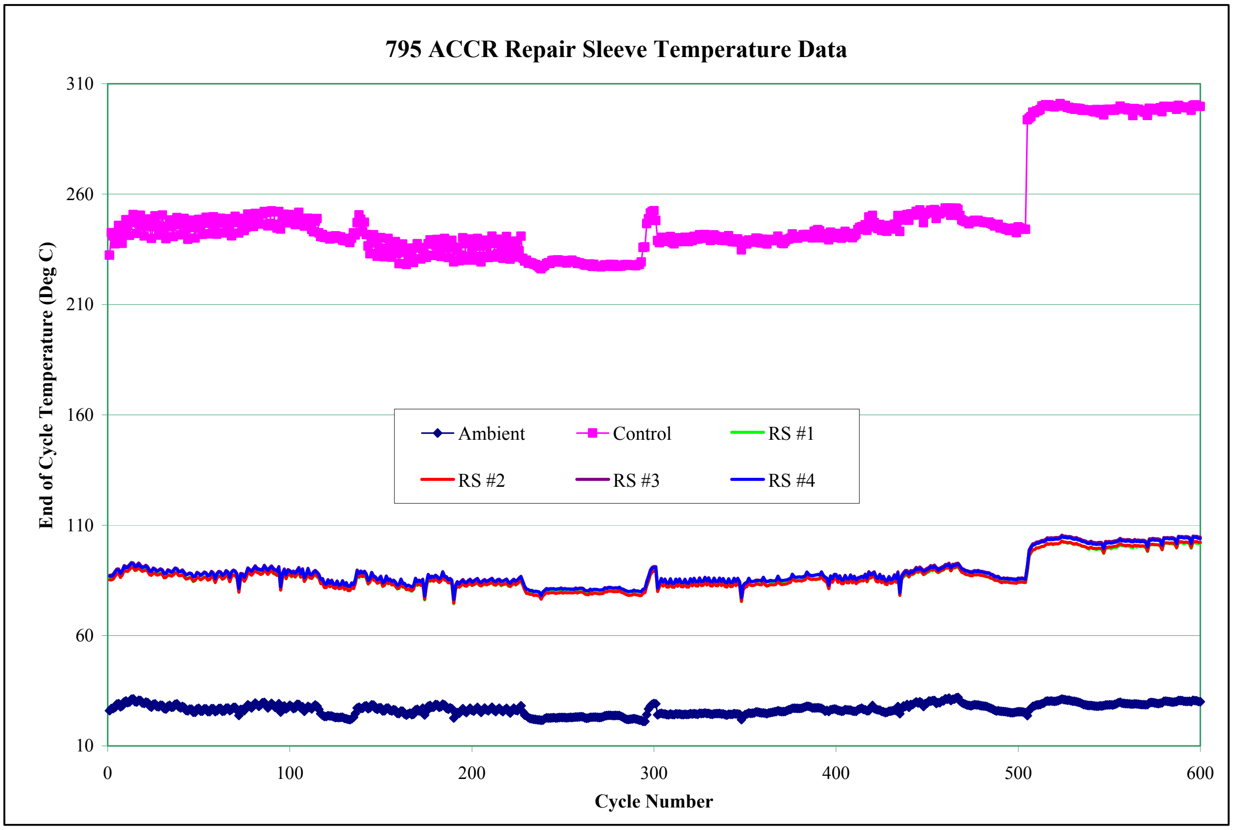


Figure 6, end-of-cycle temperature data for repair sleeves

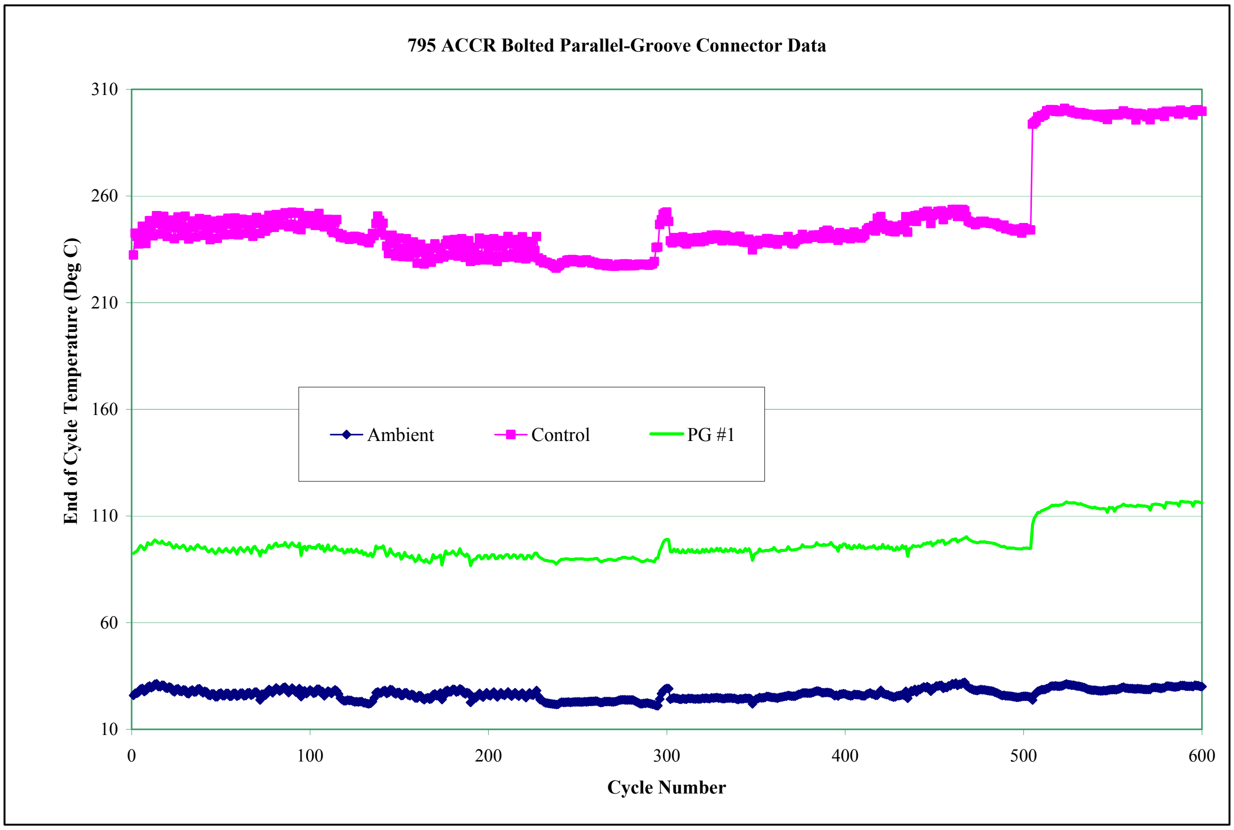


Figure 7, end-of-cycle temperature data for bolted parallel groove clamp (one sample only)

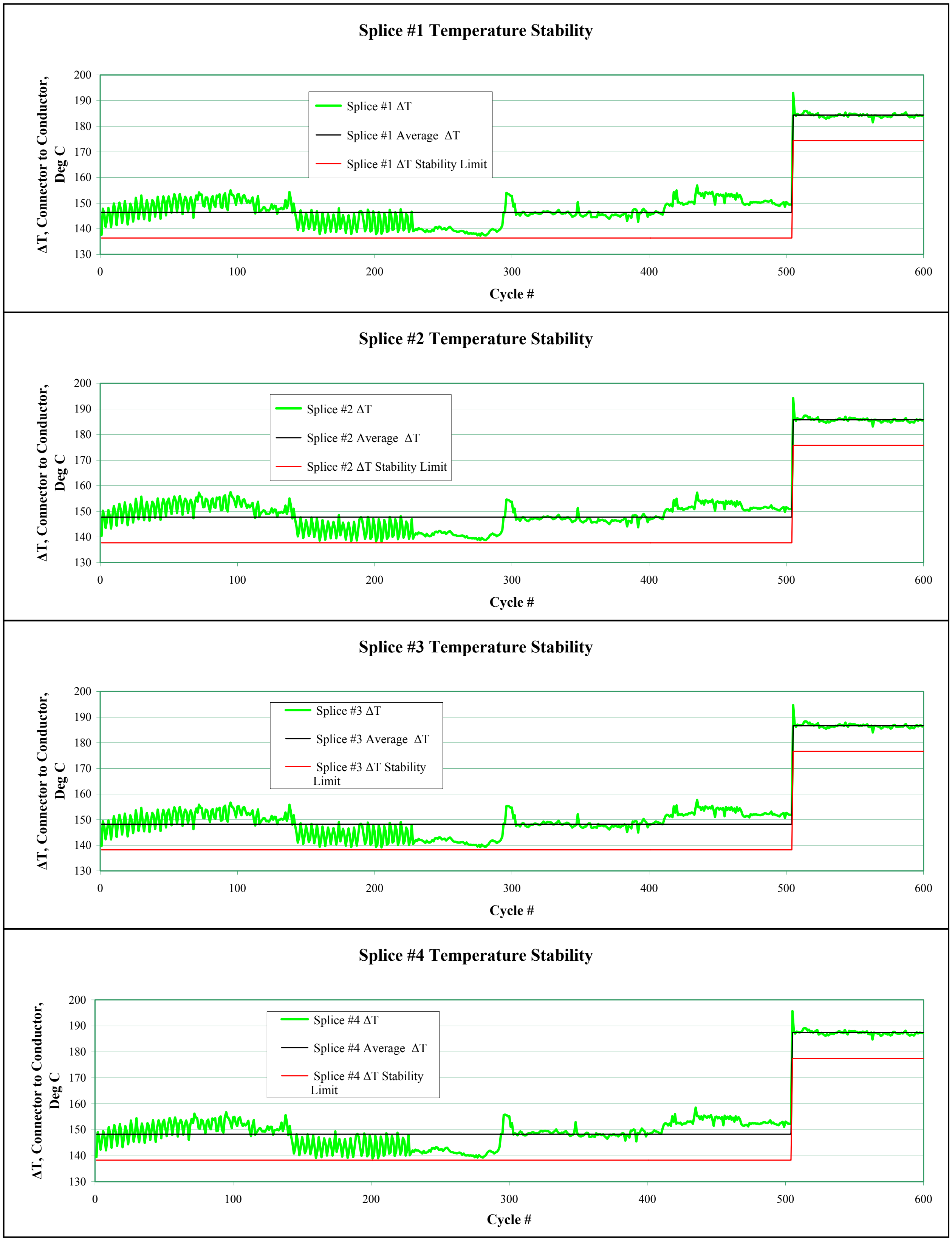


Figure 8, Temperature Stability Results for Compression Splice Samples

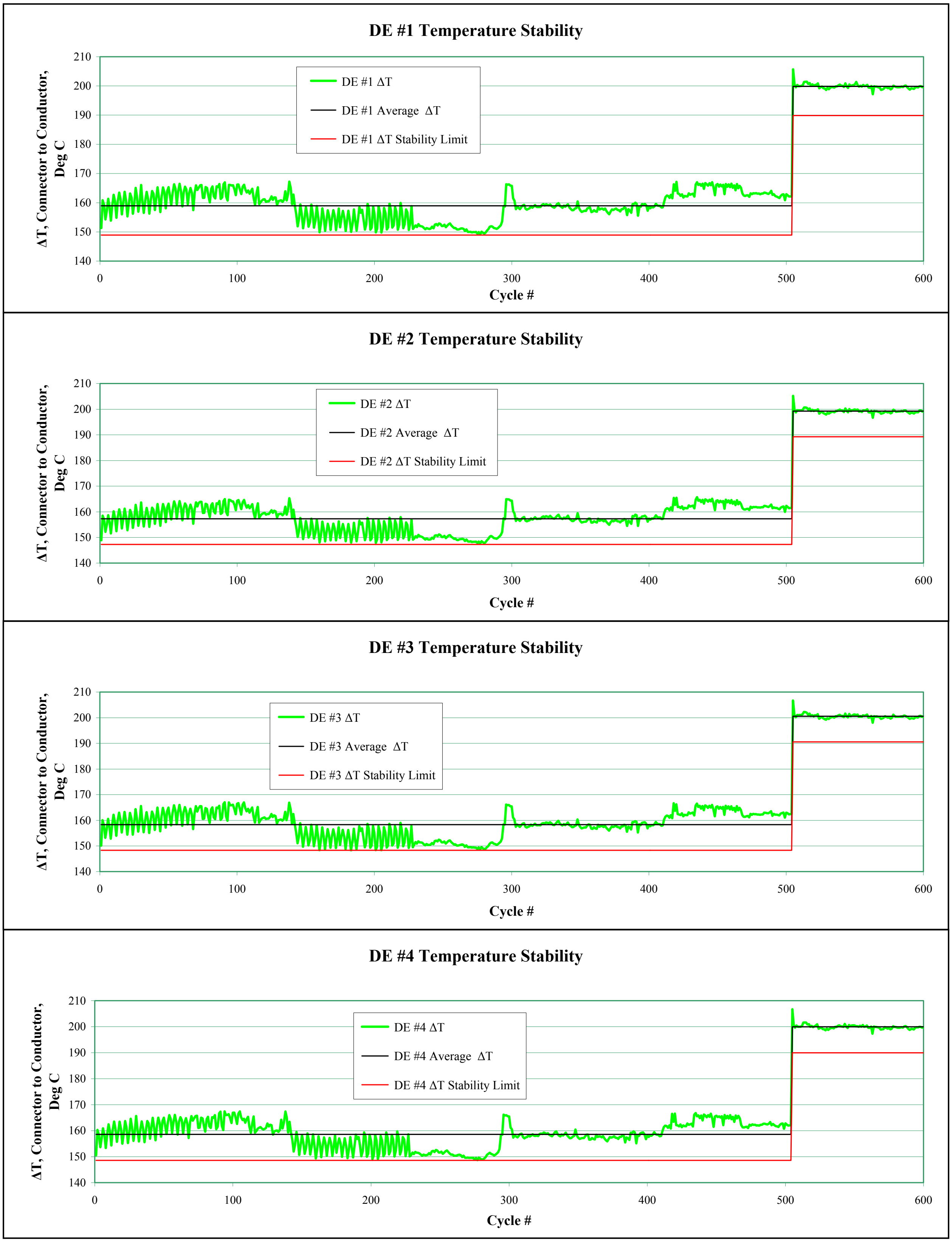


Figure 9, Temperature Stability Data for Compression Dead End Connectors

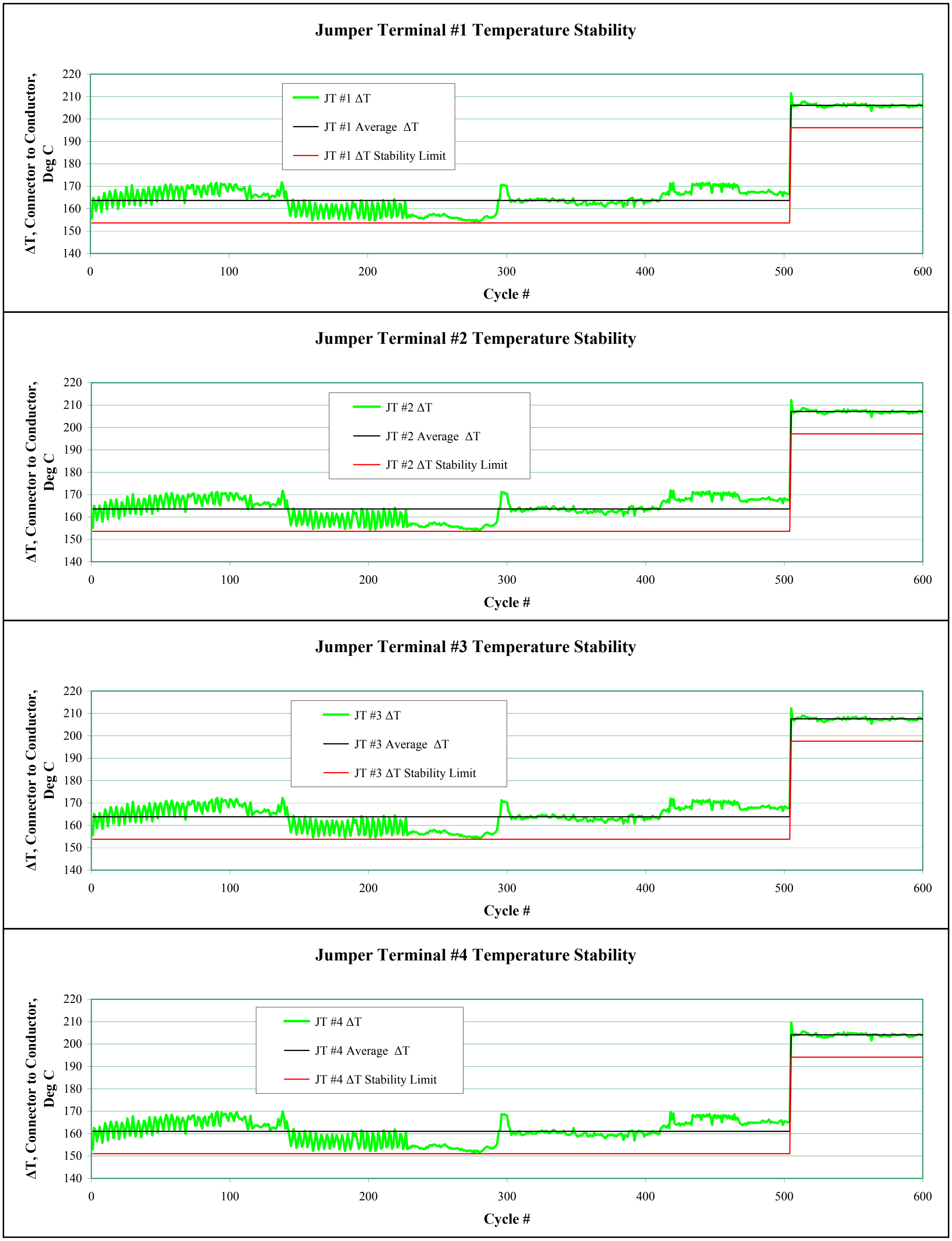


Figure 10, Temperature Stability Results for Jumper Terminals (compression to 4-bolt NEMA)

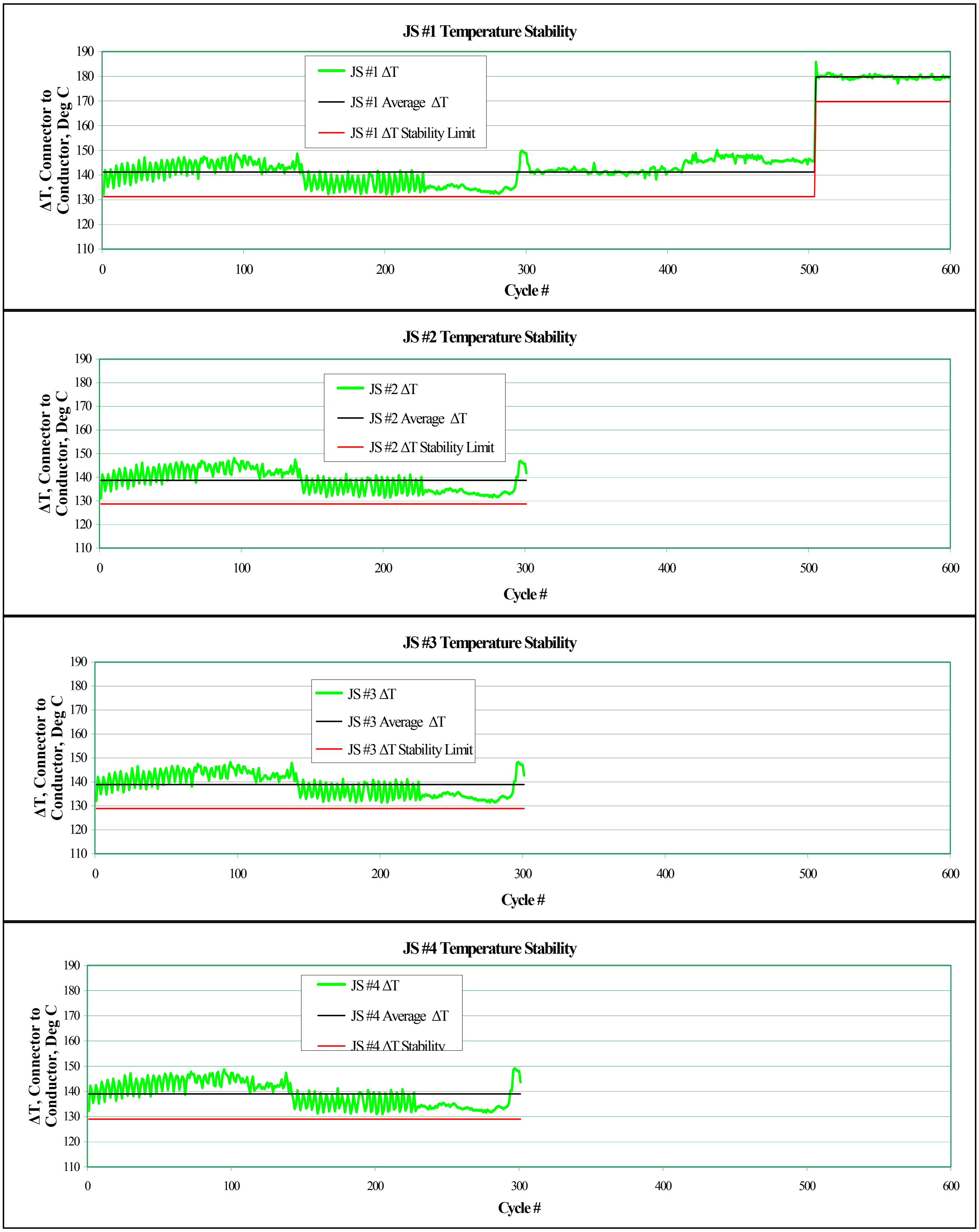


Figure 11, Temperature Stability Results for Compression Jumper Splices

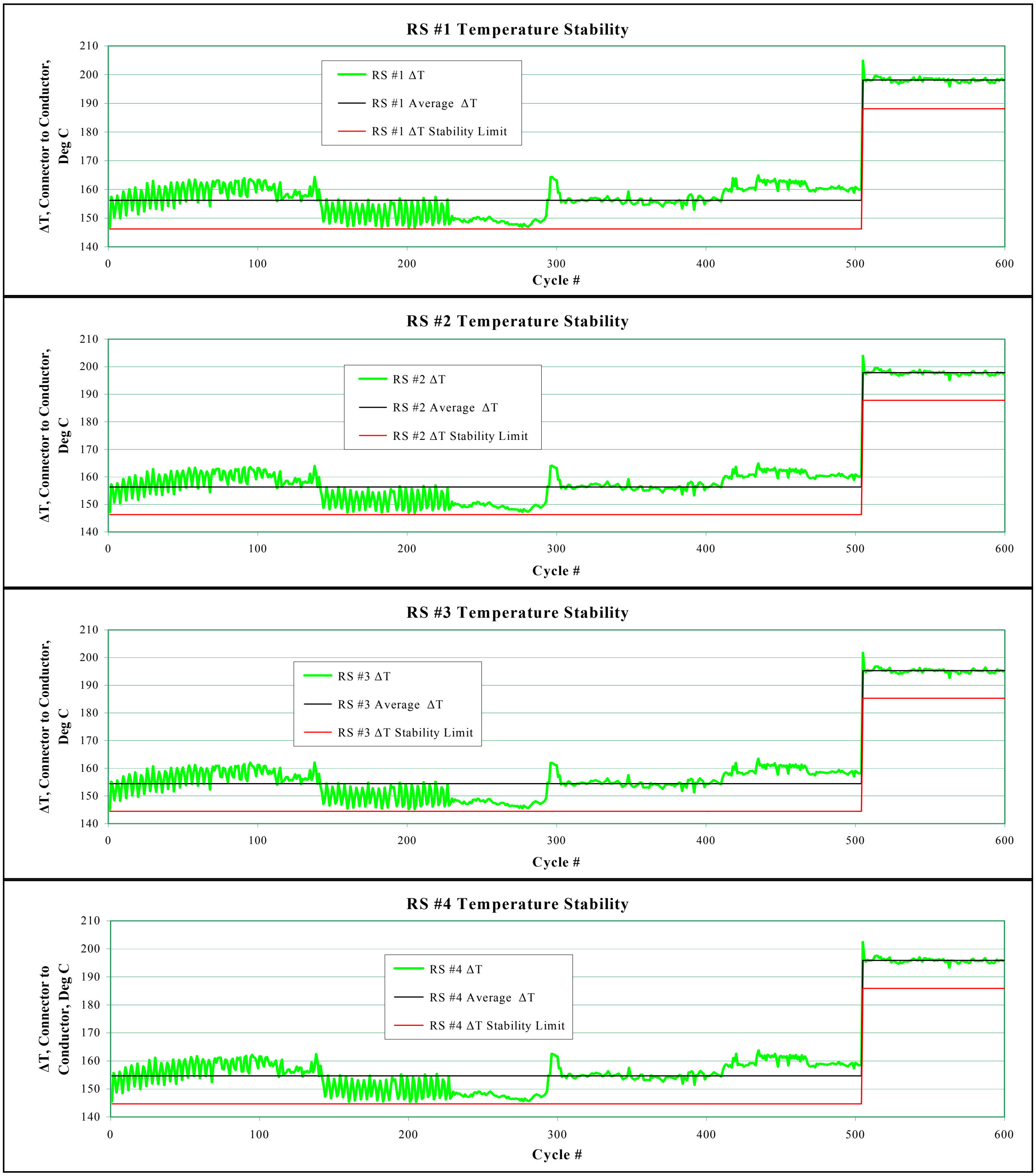


Figure 12, Temperature Stability Results for Repair Sleeves

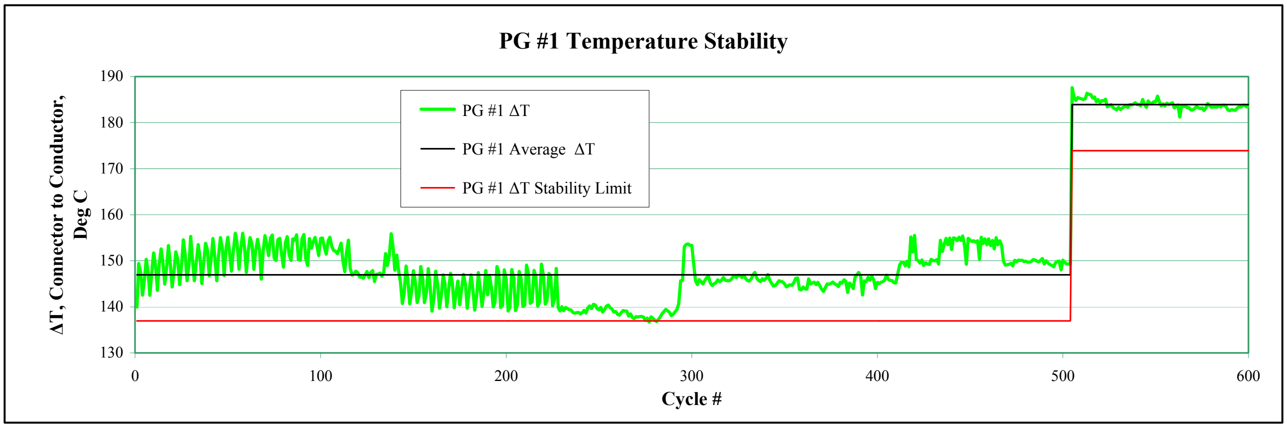


Figure 13, Temperature Stability Results for Bolted Parallel-Groove Tap Connector

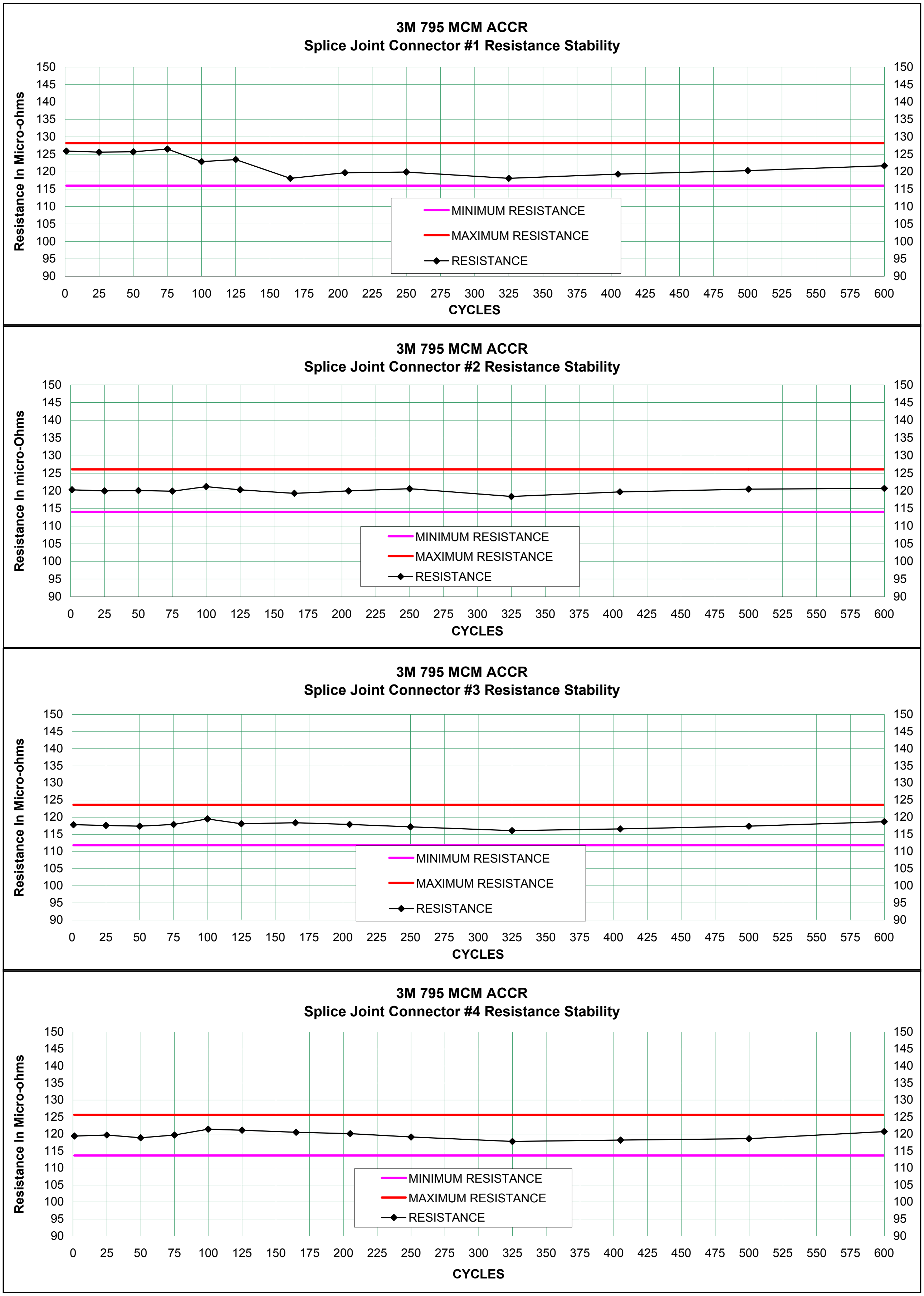


Figure 14, Resistance Stability Charts for Splice Connectors

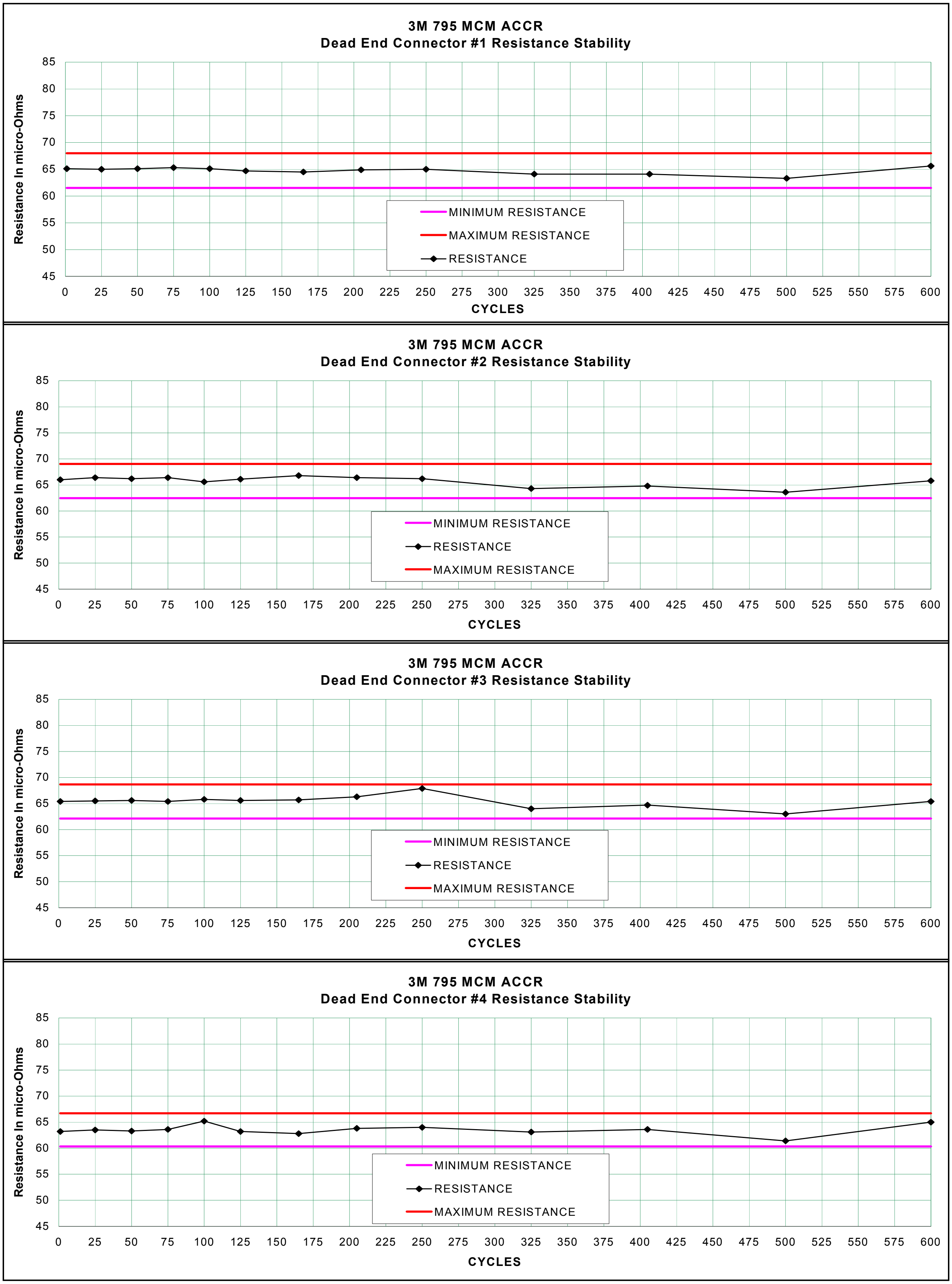
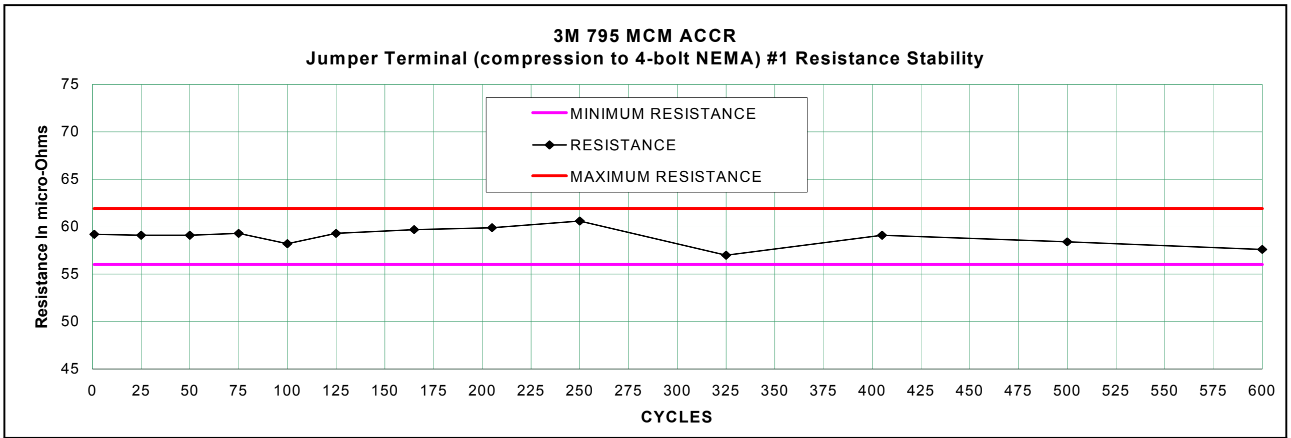
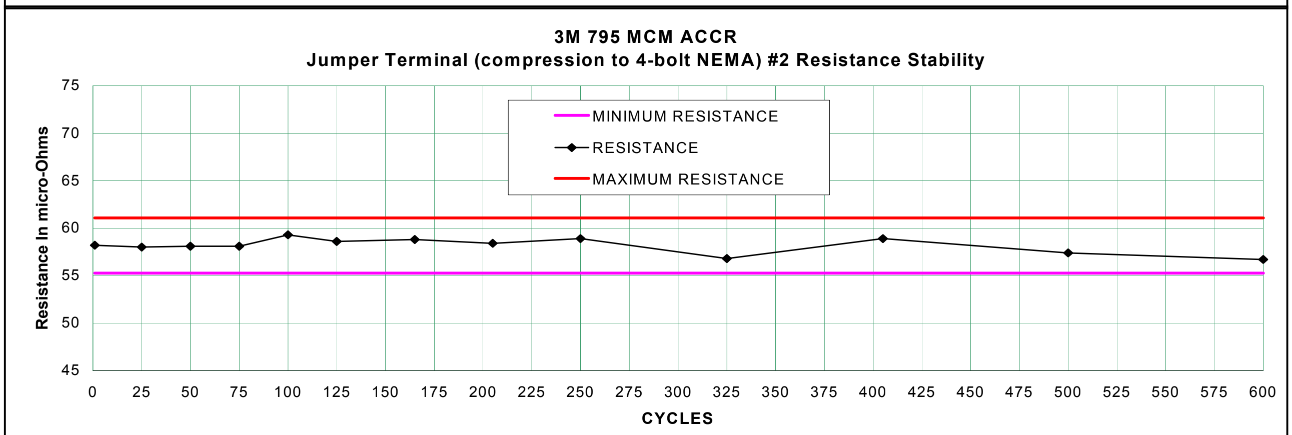
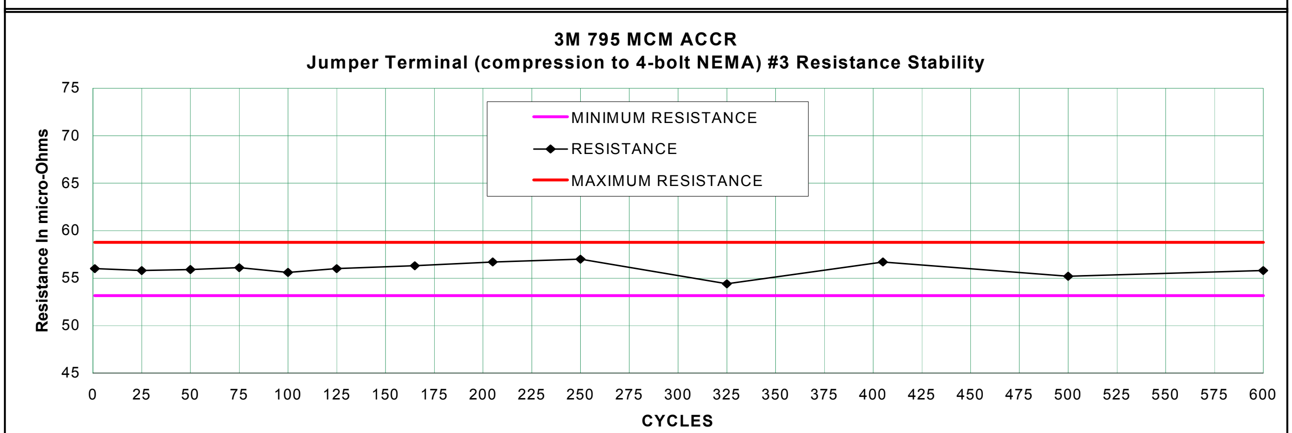


Figure 15, Resistance Stability Charts for Dead End Connectors







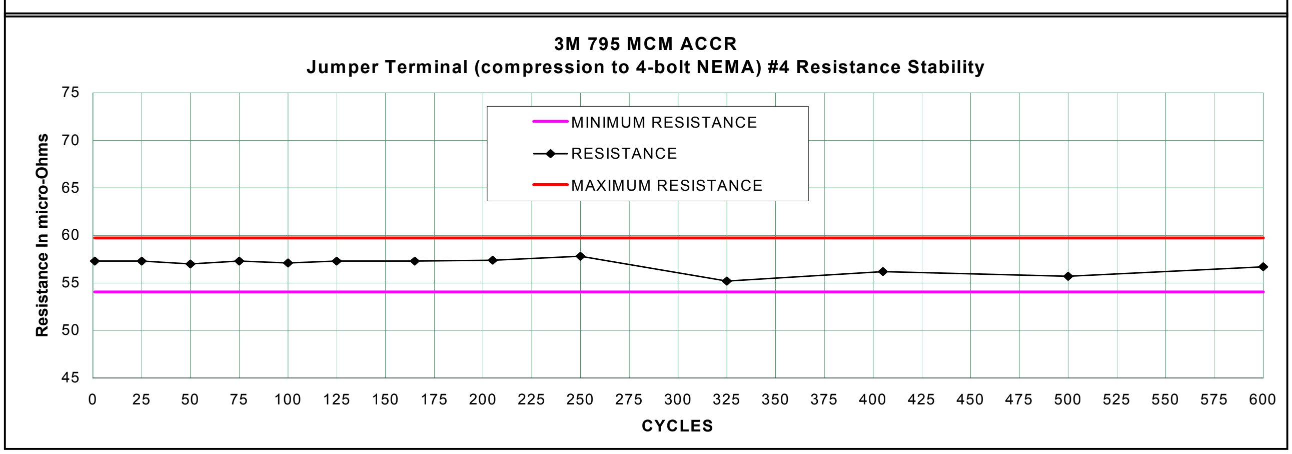


Figure 16, Resistance Stability Charts for Jumper Terminal Connectors (tubular to 4-bolt NEMA)

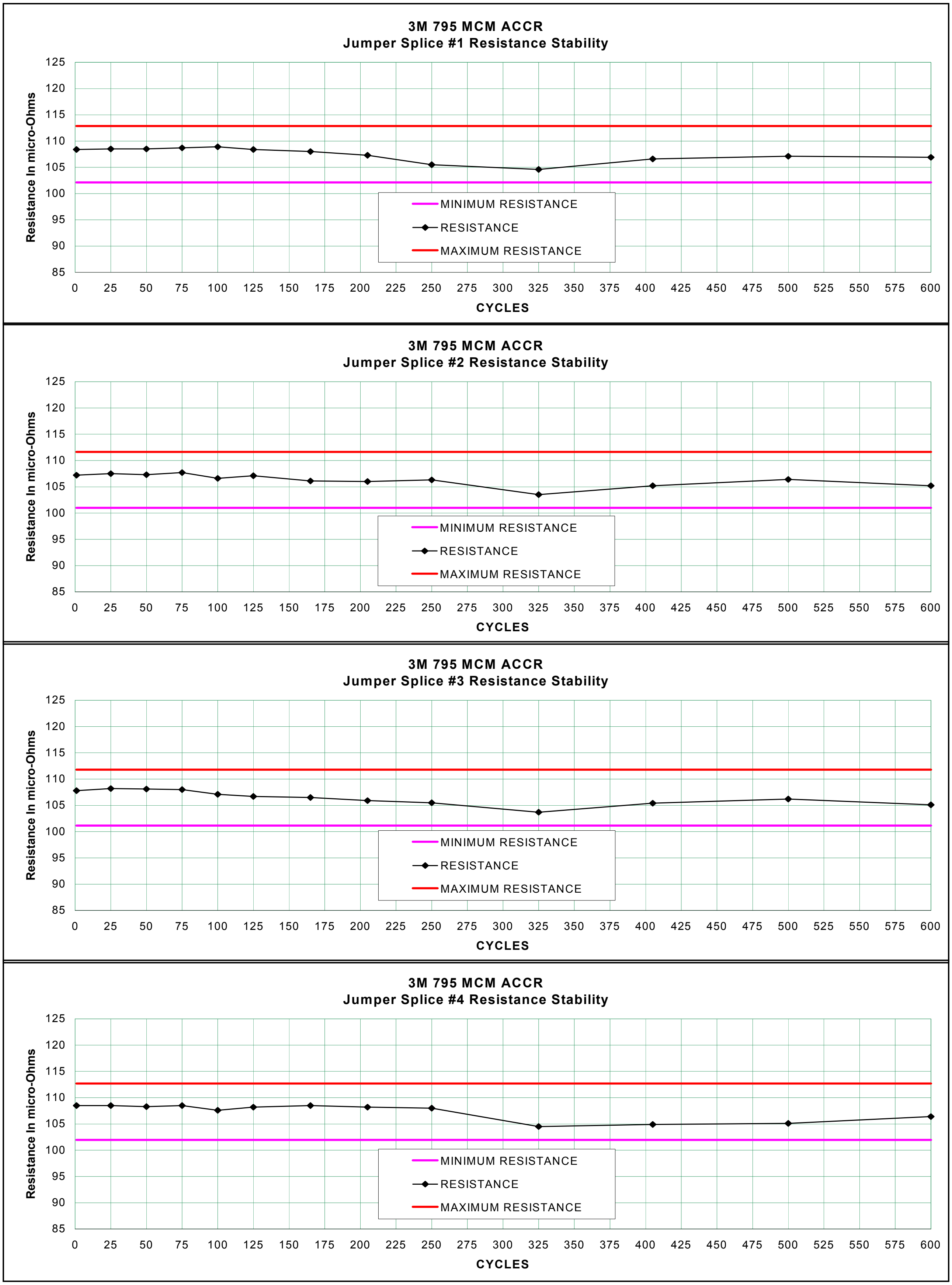


Figure 17, Resistance Stability Chart for Jumper Splice (partial tension) Connectors

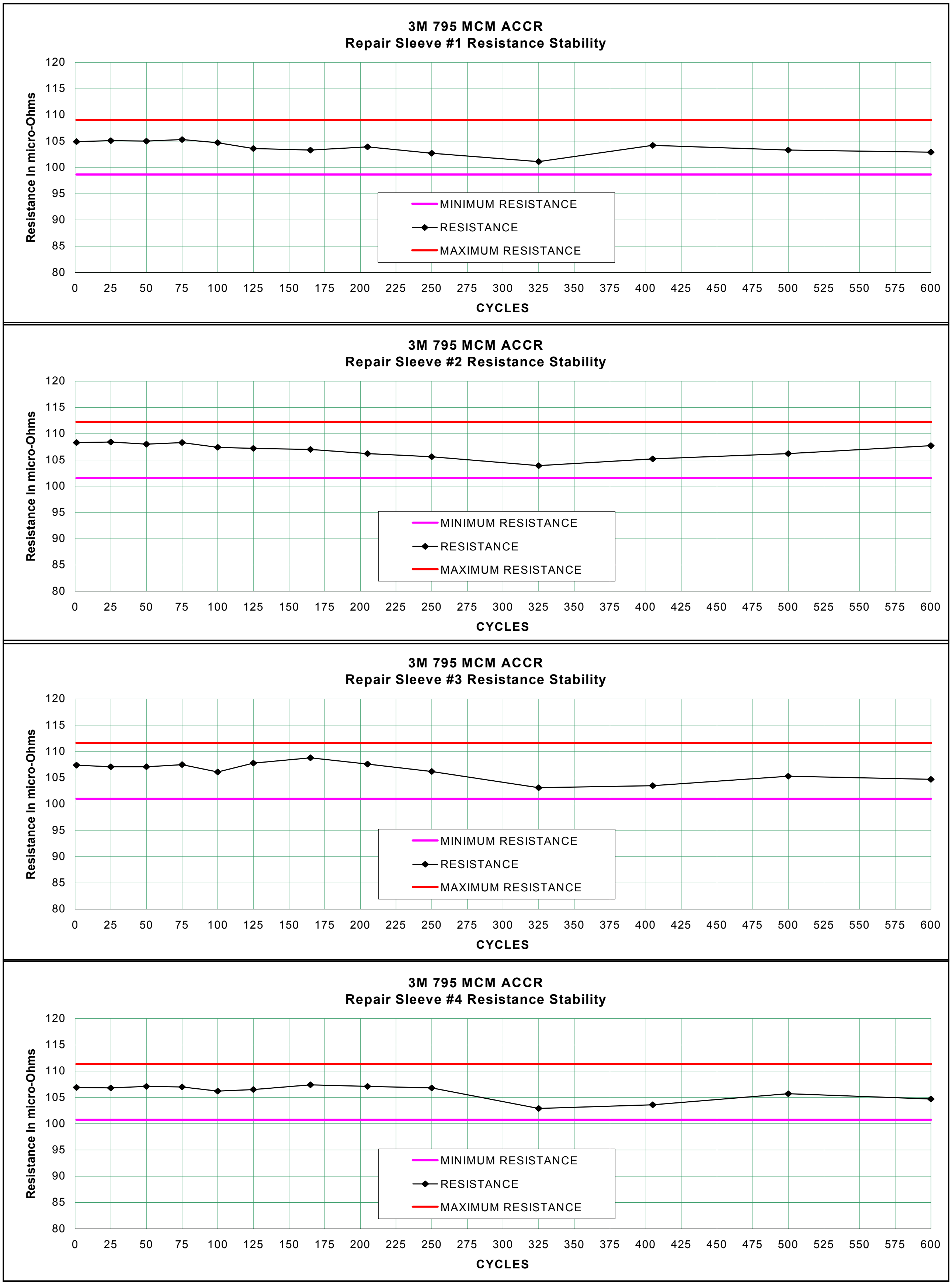


Figure 18, Resistance Stability Charts for Repair Sleeves

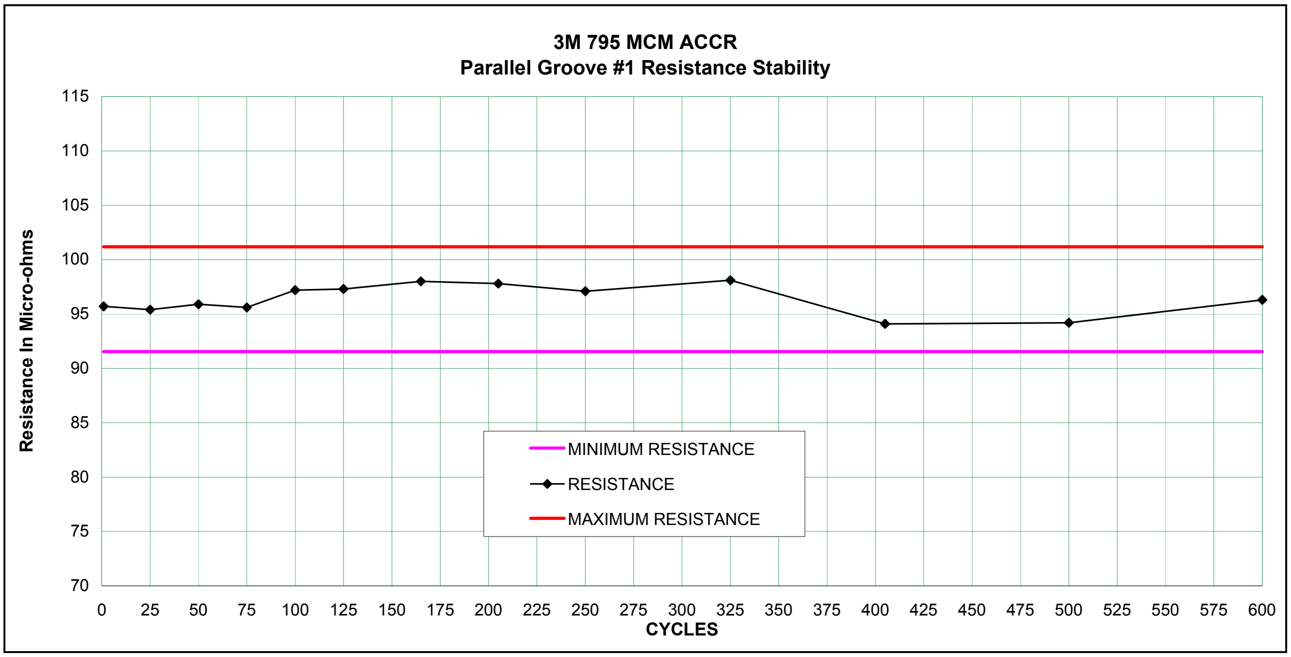


Figure 19, Resistance Chart for Parallel-Groove Tap Connector