3M Brand Composite Conductor
Connector Current Cycle Qualification Test
for
477-kcmil Composite Conductor Compression Fittings

3M Company
Purchase Order 0000478619

NEETRAC Project Number: 02-088

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A Center of
The Georgia Institute of Technology

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Summary:

3M contracted with NEETRAC to perform qualification tests on connectors for 3M’s 477-kcmil Composite Conductor. A total of 24 connectors were connected in a series loop with 477 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 242° C, followed by 100 additional cycles at 300° C. All connectors were in good condition at the end of the test. One splice was instrumented for internal pressure by installing a pressure gage in the inhibitor fill port. This was done to determine if 300 °C conductor temperature would pressurize the splice internals due to heating of inhibitor compound. No measurable overpressure occurred.

Samples:

1) 40 meters (130 feet) of 477-kcmil 3M Composite Conductor (ACCR – Aluminum Conductor Composite Reinforced) which equivalent in diameter to “Hawk” ACSR (Aluminum Conductor Steel Reinforced).

   Note: 4.3 meters was taken from a reel marked “stress-strain testing”. The remainder, including all conductor used on connectors, was from a reel marked “Received 08/16/02. Both reels contained 477 Composite Conductor received from 3M.

2) Four (4) Alcoa Fujikura Limited (AFL) full-tension splice connectors for 477-kcmil 3M Composite Conductor (special design), catalogue number B9095-A.

3) Four (4) AFL full-tension dead-end terminal connectors for 477-kcmil 3M Composite Conductor (special design), catalogue number B9085-A.

4) Four (4) AFL partial-tension jumper splice connectors for 477-kcmil 3M Composite Conductor (special design), catalogue number B9112-A.

5) Four (4) AFL jumper terminal connectors (tubular to 4-bolt NEMA pad) for 477-kcmil 3M Composite Conductor (special design), catalogue number B9102-A.
6) Four (4), AFL compression repair sleeves for 477-kcmil 3M Composite Conductor (special design), catalogue number C9121-A, installed over conductor damage simulated by cutting nine (9) of the outer aluminum strands.

7) Four (4), AFL bolted parallel groove tap connectors for 477-kcmil 3M Composite Conductor, catalogue number 583.3P.

References:

1) NEETRAC – 3M Proprietary Information Agreement Dated 3/27/01 (copy located in 01-121 project folder and at GTRC legal department)
2) 3M Purchase Order 0000478619
3) PRJ 02-088, 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 “PRJ02-088, 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. 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.

A high-current DC power supply was connected to the loop. Southwire’s ampacity program was run to estimate the current required for 240º C conductor temperature in still-air with no solar effects. The program estimated 1136 Amperes. Loop current was adjusted until the steady-state control conductor temperature was 240º C. Current measured 1142 Amperes for a control conductor surface temperature of 240º C. A spare channel was used to measure the temperature at the surface of the MMC core strand. With the surface temperature at 240.6º C, the surface of the core measured 246.9º C. Figure 3 shows a detail of the surface and core temperature during the first heat-up cycle.

Loop current was adjusted during the test to maintain the control conductor surface temperature at 240º 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 300º 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°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) Heat-up and cool-down data were recorded.

4) The internal pressure of one compression splice was monitored.

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 also measured automatically 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 overall test loop. Photographs 2 and 3 show connectors with the temperature sensors.

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

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

**Test results:** all connectors passed the test by operating cooler than the conductor for all cycles. See Figure 1 for heat-up data, and Figure 2 for typical end-of-cycle temperature data for the control conductor and connectors.

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

**Test results:** all connectors passed the test by operating at a stable temperature relative to the control conductor. Charts in the appendix show the temperature stability performance for each connector relative to the ANSI requirements.

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

**Test results:** all connectors passed the test by remaining at a stable resistance value for the duration of the test. Charts in the appendix show the resistance stability performance for each connector relative to the ANSI requirements.

Criterion 1 ensures that a connector’s size (convection cooling area), and resistance (heat generation) is 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.

A chart was prepared for each connector showing performance relative to each of the criteria. The detail charts are in the appendix. Charts summarizing data collected during the test are shown in the body
of this report as Figures 1 through 3. Detailed temperature and resistance graphs for each connector are in the appendix. Note that the temperature data exhibit small gaps starting at approximately cycle 330. Gaps were caused by an intermittent hard failure in the data recording system. The failure had no effect on the connector test cycles or on any aspect of measurement accuracy. The system normally records data considerably in excess of the ANSI standard, which anticipates manual data recording. Even with the missing data, the record of the test exceeds the requirements for data recording in ANSI C119.4.
Figure 1
Temperature data recorded during the initial heat-up of the test loop
Figure 2
End of cycle temperature, example for each connector type, control, and core

Figure 3
Detail showing heat-up of control conductor, surface and core temperatures
Conclusions:

All 24 connectors in the test passed the acceptance criteria specified in ANSI C119.4. The appendix contains the charts showing the temperature and stability performance for each connector, and the relevant ANSI criterion where applicable.

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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.
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Current Cycle Test for 477-kcmil 3M Composite Conductor Connectors

Appendix

Detail graphs showing end-of cycle temperature and resistance data for each connector
Temperature stability for 477-kcmil, Dead-end #1

Temperature stability for 477-kcmil, Dead-end #2
Temperature stability for 477-kcmil, Dead-end #3

Temperature stability for 477-kcmil, Dead-end #4
Temperature stability for 477-kcmil, Splice Joint #1

Temperature stability for 477-kcmil, Splice Joint #2
Temperature stability for 477-kcmil, Splice Joint #3

Temperature stability for 477-kcmil, Splice Joint #4
Temperature stability for 477-kcmil, Jumper #1

Temperature stability for 477-kcmil, Jumper #2
Temperature stability for 477-kcmil, Jumper #3

Temperature stability for 477-kcmil, Jumper #4
Temperature stability for 477-kcmil, Repair Sleeve #1

Temperature stability for 477-kcmil, Repair Sleeve #2
Temperature stability for 477-kcmil, Repair Sleeve #3

Temperature stability for 477-kcmil, Repair Sleeve #4
Temperature stability for 477-kcmil, Jumper Splice Connector #1

Temperature stability for 477-kcmil, Jumper Splice Connector #2
Temperature stability for 477-kcmil, Jumper Splice Connector #3

Temperature stability for 477-kcmil, Jumper Splice Connector #4
Temperature stability for 477-kcmil, Parallel Groove Clamp #1

Temperature stability for 477-kcmil, Parallel Groove Clamp #2
Temperature stability for 477-kcmil, Parallel Groove Clamp #3

Temperature stability for 477-kcmil, Parallel Groove Clamp #4
Resistance stability for 477-kcmil, Dead-end #1

Resistance stability for 477-kcmil, Dead-end #2
Resistance stability for 477-kcmil, Dead-end #3

Resistance stability for 477-kcmil, Dead-end #4
Resistance stability for 477-kcmil, Splice Joint #1

Resistance stability for 477-kcmil, Splice Joint #2
Resistance stability for 477-kcmil, Splice Joint #3

Resistance stability for 477-kcmil, Splice Joint #4
Resistance stability for 477-kcmil, Jumper #1

Resistance stability for 477-kcmil, Jumper #2
Resistance stability for 477-kcmil, Jumper #3

Resistance stability for 477-kcmil, Jumper #4
Resistance stability for 477-kcmil, Repair Sleeve #1

Resistance stability for 477-kcmil, Repair Sleeve #2
Resistance stability for 477-kcmil, Repair Sleeve #3

Resistance stability for 477-kcmil, Repair Sleeve #4
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3M 477 ACCR Hawk Equivalent
Sample Jumper Splice #1

Resistance stability for 477-kcmil, Jumper Splice Connector #1

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3M 477 ACCR Hawk Equivalent
Sample Jumper Splice #2

Resistance stability for 477-kcmil, Jumper Splice Connector #2

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Resistance stability for 477-kcmil, Jumper Splice Connector #3

Resistance stability for 477-kcmil, Jumper Splice Connector #4
Resistance stability for 477-kcmil, Parallel Groove Clamp #1

Resistance stability for 477-kcmil, Parallel Groove Clamp #2
Resistance stability for 477-kcmil, Parallel Groove Clamp #3

Resistance stability for 477-kcmil, Parallel Groove Clamp #4