Resistance Measurement

for

477 kcmil and 1272 kcmil 3M Brand Composite Conductor

3M Company
Purchase Order 0000795479

NEETRAC Project Number: 03-028

June, 2003

National Electric Energy Testing, Research & Applications Center
NEETRAC
A Research Center of
The Georgia Institute of Technology

Requested by: Mr. Colin McCullough
3M

Principal Investigator: ______________________
Paul Springer

Reviewed by: ______________________
Thomas Parker

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Summary:

3M contracted with NEETRAC for testing to determine the DC resistance of 477 kcmil and 1272 kcmil 3M Brand Composite Conductors. All results conform to the nominal values published by 3M in the conductor specifications.

Background:

Conductor resistance is a major factor in overhead line ampacity. Nominal resistance is calculated in accordance with ASTM or other conductor specifications, using requirements for the size of the conductor components, resistivity of conductor materials, and stranding lay lengths. Actual conductor resistance may be calculated from measurement of the conductor dimensions and measurement of the volume resistivity of the conductor components. Alternately, resistance may be measured directly on a conductor sample. All low resistance experimental methods require great care to ensure that the results properly represent conductor resistance in overhead lines. In this case, a direct measurement was made on the finished conductor. See "Procedure" for details of how the measurement was accomplished.

Samples:

1) Seven (7) meters of 477 kcmil, type 16, 3M Brand Composite Conductor, from reel received on 8/16/2002

2) Seven (7) meters of 1272 kcmil, type 13, 3M Composite Conductor, from reel received on 12/02/2002

References:

1) "Proprietary Information Agreement …." Dated 3/27/01
2) 3M Purchase Order 0000795479
3) PRJ 03-028, NEETRAC Project Plan

Equipment Used:

1) AVO (Biddle) digital low-resistance Ohmmeter, Control # CQ 0218
2) Brooklyn Reference Thermometer, -8 to +32^o C in 0.1^o C increments, Calibration Control # CQ 0155
3) Tettex resistance fixture

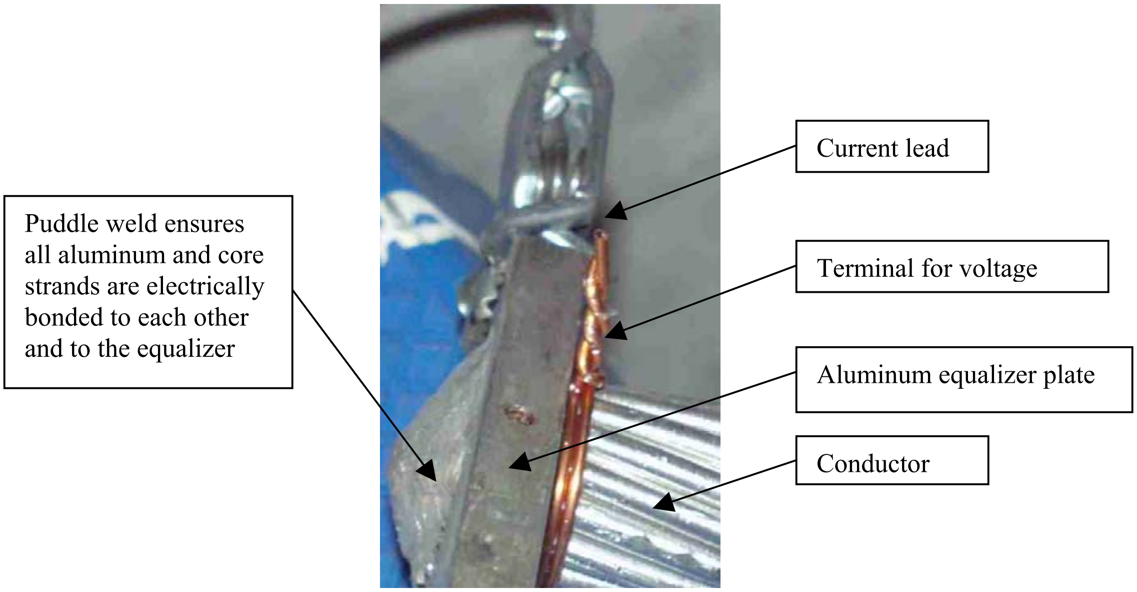
Procedure:

Samples were cut from the reel after hose clamps were securely fastened around the conductor on both sides of the cut. The hose clamps ensure that the "as manufactured" position of all strands is preserved during sample handling.

All resistance measurements were made using 4-wire digital resistance meter with an internal 10 Ampere dc current supply. A 4-wire instrument has plus (+) and minus (-) leads for current, and independent plus and minus leads for voltage measurement. The purpose for separating the current and voltage leads is to ensure that voltage drops due to resistance in the instrument leads and connections to the sample are not reflected in the resistance measurement. Because the voltage sensing leads and connections have negligible current flow, there is no significant voltage drop to affect the voltage measurement. Voltage drop in the current leads and current connections is significant, but can be ignored as long as all connections to the sample are located such that the voltage sensing leads are remote from any influence of the current leads.

To ensure uniform current flow in all layers of the conductor, flat aluminum plates, called equalizers, are welded to each end of the conductor using a puddle welding technique that electrically bonds each conductor and core strand to the aluminum plate. Voltage terminals were located near the equalizer plates by wrapping #16 AWG solid copper wire securely around the conductor. Wrapped wire for the voltage sensing defines the section of conductor under measurement. Resistance measurements were made on a nominal 20-ft conductor section. After the large sample was measured, a crosscheck was made using a Tettex resistance fixture with a precise 3-foot gage section. The 1272 conductor would not fit the Tettex fixture, which has a diameter limit. The 477 results agree reasonably well with the measurements on the long sample. See "Results" for values.

Photograph 1 shows the end termination used for the resistance measurement.



Photograph 1, **Current and voltage terminals, typical each sample end**

Error Analysis:

The RMS error for the resistance measurement is estimated to be +/- 0.30% of reading. Conductor resistance measurement accuracy depends on the accuracy of the following measurements:

1) Basic resistance measurement:
The 4-wire instrument used for the resistance measurement is certified accurate within +/- 0.2% of reading. A spot check on a reference standard in the same order of magnitude as the conductor resistance showed actual calibration was within 0.1% of reading.

2) Measurement of the length of sample under test:
The steel tape used for the length measurement was used in a manner that avoided error due to end effects. The minimum scale degradation is 1/32 inch. Based on repeated measurements with at least two different people reading the length, the accuracy for the 477 Composite Conductor sample is +/- 1/8", or 0.05% of sample length. The 1272 Composite Conductor sample was stiff, and because of curvature, the length measurement error is estimated at +/- 3/8", or 0.14% of sample length.

3) Temperature measurement
The thermometer used to measure ambient temperature is certified accurate within +/- $0.02^{o}C$. However, warm humans near the sample, and room temperature gradients were found to affect the actual sample temperature. The sample temperature is conservatively assumed to be within 0.5^{o} C of the ambient temperature. Based on a nominal resistance-temperature coefficient of $0.36\%/^{o}C$, the resistance error due to temperature measurement is +/- 0.18%.

4) Temperature gradients in the sample
Human body heat, warming due to the 10 Ampere dc current, and room temperature gradients effects were minimized by running a fan in the room to ensure mixing of the

air and maximize coupling between the room ambient and the sample. Temperature gradients, therefore, are small relative to the error for the sample temperature measurement.

5) Control of voltage gradients in the sample

Welded equalizers at each end of the sample ensure that all layers of the conductor are at the same voltage when the resistance is measured. The wrapped-copper voltage terminals on the conductor OD near the equalizers ensure consistent voltage measurement at a defined place on the conductor. The effect of voltage gradients is considered negligible provided this technique is used.

Results:

Table 1 summarizes the readings, temperature corrections, and computations for the 477 Composite Conductor sample with the 20 ft gage section. Table 2 shows the same information for the test using the Tettex resistance fixture with a 3 ft gage section. Table 3 summarizes results for the 1272 Composite Conductor sample. It was not possible to fit the 1272 conductor in the Tettex fixture.

Table 1, Summary of 477 Composite Conductor Resistance Data
20 - ft gage section, twisted copper voltage terminals, puddle-welded current terminals

Measurements:	Value			Units
Temperature:	21.9			deg C
Test section length:	21.380			ft
Resistance (at room temperature)	739.1	739.0	739.0	µOhms
Calculations:	**Value**			**Units**
Average resistance (at room temperature)	739.03			µOhms
Ohms/ft (at room temperature):	3.4566E-05			Ohm/ft
Ohms/ft (corrected to 20°C):	3.4339E-05			Ohm/ft
Ohms/mi (at room temperature)	0.18251			Ohm/mile
Ohms/mi @ 20C:	**0.18126**			Ohm/mile
3M nominal	0.18317			Ohm/mi
Change from nominal:	-1.04			percent

Table 2, Summary of 477 Composite Conductor Resistance Data 3 - ft gage section, Tettex knife-edge voltage terminals, puddle-welded current terminals				
Measurements:	**Value**			**Units**
Temperature:	21.2			deg C
Test section length:	3.000			ft
Resistance (at room temperature)	103.0	103.0	103.0	µOhms
Calculations:	**Value**			**Units**
Average resistance (at room temperature)	103.00			µOhms
Ohms/ft (at room temperature):	3.4566E-05			Ohm/ft
Ohms/ft (corrected to 20^{o}C):	3.4330E-05			Ohm/ft
Ohms/mi (at room temperature)	0.18128			Ohm/mile
Ohms/mi @ 20C:	**0.18004**			Ohm/mile
3M nominal	0.18317			Ohm/mi
Change from nominal:	-1.71			percent

Table 3, Summary of 1272 Composite Conductor Resistance Data 20 - ft gage section, twisted copper voltage terminals, puddle-welded current terminals				
Measurements:	**Value**			**Units**
Temperature:	20.9			deg C
Test section length:	21.849			Ft
Resistance (at room temperature)	291.1	291.1	291.0	µOhms
Calculations:	**Value**			**Units**
Average resistance (at room temperature)	291.07			µOhms
Ohms/ft (at room temperature):	1.3322E-05			Ohm/ft
Ohms/ft (corrected to 20^{o}C):	1.3279E-05			Ohm/ft
Ohms/mi (at room temperature)	0.07034			Ohm/mile
Ohms/mi @ 20C:	**0.07011**			Ohm/mile
3M nominal	0.06999			Ohm/mi
Change from nominal:	0.17			percent

Conclusions:

Direct measurement confirms the 3M Composite Conductor resistance is in accordance with nominal specifications. The 477 kcmil Composite Conductor measures 1.0 and 1.7% lower than the 3M specifications, depending on the measurement method. Lower resistance is desirable, because ampacity limits for ground clearance or conductor temperature have more conservatism if the conductor resistance is below the nominal value. The 1272 kcmil Composite Conductor measures 0.17% above the nominal specification. This value is approximately half the expected measurement error of 0.3%, and in any case would have minimal affect on line ampacity. As-found values above or below the nominal values imply that either conductor area or resistivity are above or below the nominal specifications.

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