774 –T53 ACCR Conductor
Torsion and Resistance

NEETRAC Project Number: 04-235a
3M Purchase Order #0001562911

May 2006

NEETRAC
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A Research Center of the
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SUMMARY

Tests were performed to evaluate electrical resistance and torsional deflection characteristics for 3M's 774-T53 ACCR conductor. Room-temperature conductor resistance measurements agree with the published values within the experimental measurement error. The torsion test shows there is significant damage to the aluminum strands prior to the first indication of damage to the MMC core strands. ACCR conductor subjected to torsion over-loads sustains damage similar to ACSR and other conventional conductors subjected to the same overload. Therefore, the alternative material for the core does not introduce a new failure mode during torsion overloading.

KEY FINDINGS

1) Conductor resistance measures at a value slightly above the nominal value, but within the measurement error. Tension up to 25% RBS does not have a significant effect on resistance.
2) Torsional deflection in excess of ¼ turn per linear foot of conductor was needed to damage the MMC core. First core strand breaks were heard at + 54 degrees per conductor foot. At that point, there was severe distortion of both aluminum layers. Residual strength of the conductor was 92% of nominal rating after the 54 degrees per foot twist. Torsion withstand to +/- 30 degrees per conductor foot was demonstrated when the residual strength measured 104% of nominal RBS. Extreme torsional deflections severely damage the aluminum layers before the core sustains damage.

SAMPLES

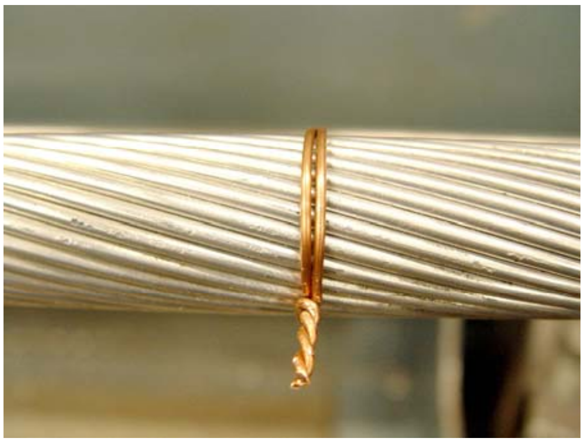
1) 774-T53 conductor on a reel received from 3M in April, 2004.

PROCEDURE

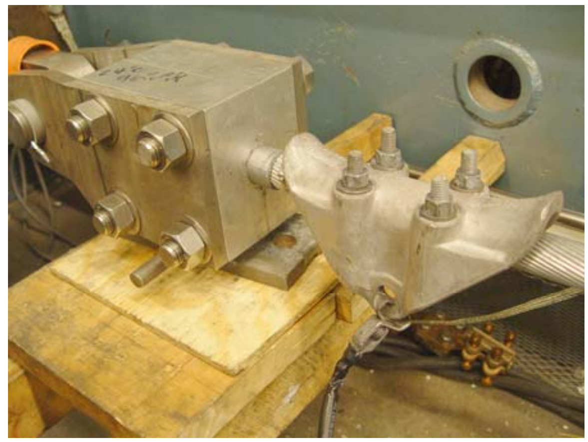
The scope of the project included the following tests:

I) Conductor resistance:

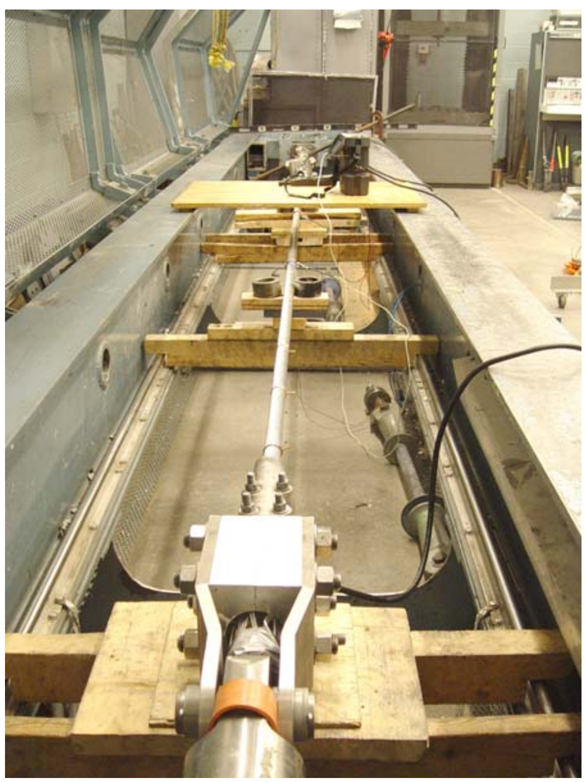
The sample was placed in the tensile testing machine, and supported to prevent any sag. In lieu of welded equalizers, the ends are terminated in cast resin. To ensure proper voltage equalization, bolted suspension clamps were attached to provide terminals for the current leads of a 4-wire resistance instrument. Copper strands were wrapped around the conductor OD to provide precisely-spaced terminals for the voltage leads of the 4-wire instrument. A series of cross-checks were performed to ensure that stable and valid measurements were achieved. It was found during previous experiments on the ACCR conductor that proper equalization of both the core and aluminum layers was needed to obtain valid measurements. This has no significance for in-service transmission lines, but is a laboratory problem that needs to be accommodated before resistance measurements properly reflect service conditions. The problem of inconsistent resistance values was seen again on the 774-T53 sample. The discrepancies were resolved by moving the voltage terminals closer to the center of the sample (and more remote from the current connections). Resistance was measured at 400 lb, 1,000 lb, 3,000 lb, 5,000 lb, 10,000 lb, and 17,750 lb (25% RBS). Photographs 1, 2, and 3 show the arrangement for the resistance test.



Photograph 1, voltage terminal (2 places)



Photograph 2, bolted current terminal (2 places)



Photograph 3, long view of resistance test

II) Torsion test:

An 18-ft conductor section was terminated with cast resin fittings using a procedure designed to ensure the "as manufactured" stresses in the conductor layers are preserved. The sample was placed in a tensile testing machine. One end was braced to prevent rotation. The other end was terminated on a rotation bearing that transmitted tensile load, but permitted the end to be rotated. A system of levers and a force gage was used to measure the torque applied to the conductor. The angular rotation was measured by reference to marks on the fixed and rotating elements of the rotation bearing. The procedure was designed in cooperation with 3M, and included the following steps:

i. Set tension to 25% RBS (17,750 lb)
ii. Increase torque in positive direction (tighten the outer layer) in 25 ft-lb steps up to 125 ft-lb. Record angular displacement at each step.
iii. Return to zero torque, and record the angular displacement
iv. Torque in negative direction (loosen outer layer) in 25 ft-lb steps to 125 ft-lb.
v. Return to zero torque, and record the angular displacement
vi. Reduce tension to 10% RBS (7,100 lb). Repeat positive and negative torsion test.
vii. Reduce tension to 5% RBS (3,550 lb). Repeat positive and negative torsion test.
viii. Remove the damaged aluminum layers.
ix. Perform a tensile test on the core only.

Photograph 4 shows the rotation bearing used for the torsion test. Photograph 5 shows the blocking to prevent rotation at the opposite end.

Photograph 4, rotation bearing

Photograph 5, end opposite rotation bearing

RESULTS

I) Resistance:

The following resistance values were recorded:

Tension:	400 lb
Conductor Temperature:	21.9° C
Test Section:	3.503 ft
Resistance Readings:	65.5 μΩ, 65.5 μΩ, 65.5 μΩ
Average of 3 Readings	65.50 μΩ
Ω/ft at 21.9° C:	1.8700E-05 Ω/ft
Ω/mile at 21.9° C:	0.098738 Ω/mile
Ω/ft corrected to 20° C:	1.8572E-05 Ω/ft
Ω/mile corrected to 20° C	0.098063 Ω/mi (101% of 0.0970 Ω/mile nominal resistance)

Tension:	1,000 lb
Conductor Temperature:	21.5° C
Test Section:	3.503 ft (not adjusted for tension change)
Resistance Readings:	65.4 μΩ, 65.2 μΩ, 65.4 μΩ
Average of 3 Readings	65.33 μΩ
Ω/ft at 21.5° C:	1.8653 E-05 Ω/ft
Ω/mile at 21.5° C:	0.098487 Ω/mile
Ω/ft corrected to 20° C:	1.8525E-05 Ω/ft
Ω/mile corrected to 20° C	0.097955 Ω/mi (101% of 0.0970 Ω/mile nominal resistance)

Tension:	3,000 lb
Conductor Temperature:	21.3° C
Test Section:	3.503 ft (not adjusted for tension change)
Resistance Readings:	65.0 μΩ, 65.3 μΩ, 65.2 μΩ
Average of 3 Readings	65.17 μΩ
Ω/ft at 21.3° C:	1.8605 E-05 Ω/ft
Ω/mile at 21.3° C:	0.098235 Ω/mile
Ω/ft corrected to 20° C:	1.8478 E-05 Ω/ft
Ω/mile corrected to 20° C	0.097776 Ω/mi (101% of 0.0970 Ω/mile nominal resistance)

Tension:	5,000 lb
Conductor Temperature:	21.3° C
Test Section:	3.503 ft (not adjusted for tension change)
Resistance Readings:	65.2 μΩ, 65.1 μΩ, 65.2 μΩ
Average of 3 Readings	65.17 μΩ
Ω/ft at 21.3° C:	1.8605 E-05 Ω/ft
Ω/mile at 21.3° C:	0.098235 Ω/mile
Ω/ft corrected to 20° C:	1.8478 E-05 Ω/ft
Ω/mile corrected to 20° C	0.097776 Ω/mi (101% of 0.0970 Ω/mile nominal resistance)

Tension:	10,000 lb
Conductor Temperature:	21.2° C
Test Section:	3.503 ft (not adjusted for tension change)
Resistance Readings:	65.3 μΩ, 65.2 μΩ, 65.1 μΩ
Average of 3 Readings	65.20 μΩ
Ω/ft at 21.2° C:	1.8615 E-05 Ω/ft
Ω/mile at 21.2° C:	0.098286 Ω/mile
Ω/ft corrected to 20° C:	1.8487 E-05 Ω/ft
Ω/mile corrected to 20° C	0.097861 Ω/mi (101% of 0.0970 Ω/mile nominal resistance)

Tension:	17,750 lb
Conductor Temperature:	21.2° C
Test Section:	3.503 ft (not adjusted for tension), 3.510 ft (measured at tension)
Resistance Readings:	65.2 μΩ, 65.1 μΩ, 65.1 μΩ
Average of 3 Readings	65.13 μΩ
Ω/ft at 21.2° C:	1.8554 E-05 Ω/ft
Ω/mile at 21.2° C:	0.097967 Ω/mile
Ω/ft corrected to 20° C:	1.8427 E-05 Ω/ft
Ω/mile corrected to 20° C	0.097544 Ω/mi (101% of 0.0970 Ω/mile nominal resistance)

II) Torsion Test:

Design of the torsion test was based on experience with torsion testing for other ACCR conductors, where torque as high as 125 ft-lb destroyed aluminum strands, but did not damage the core. All previous cases involved 7-strand or 19-strand MMC cores. In this case, the core is 37 strands, and there is proportionately far less aluminum in the conductor.

The test sequence is summarized in the table below:

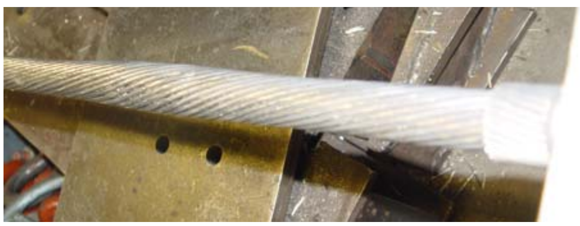
Tension (lb)	Torque (ft-lb)	Rotation angle (degrees)*	Observations
17,750	0	0	Start of 25% RBS torsion test
"	25	15	Outer layer aluminum strands tighten
"	50	60	Same
"	75	95	Same
"	100	170	Yield "felt"
"	125	250	Further yield
"	0	67	No appearance change
"	- 25	-10	Open bird cage, outer layer
"	- 50	-85	Large bird cage in outer layer
"	- 75	-440	Continued bird cage
"	-100	-720	Continuous yield, - no torque increase
"	0	-370	Outer layer loose, inner aluminum layer bird caged

Tension (lb)	Torque (ft-lb)	Rotation angle (degrees)*	Observations
7,100	0	-370	Start of 10% RBS torsion test
	25	-125	Visible bird cage in inner layer
"	50	- 80	Outer layer tight, but inner layer still open
"	75	20	Same
"	100	92	Yield "felt"
"	117	200	Yield, unable to reach 125 ft-lb target
"	0	- 10	Both aluminum layers disrupted
"	- 25	-390	Aluminum strands bird caged, outer layer "tight"
"	- 50	-585	Same
"	- 75	-870	Heard popping sound, possibly core strand breaks
"	0	-530	Outer layer loose, inner aluminum layer bird caged
3,550	0	-460	Start of 5% RBS torsion test
	25	-115	All aluminum strands displaced
"	50	- 45	Same
"	75	80	Same
"	100	240	Yield "felt"
"	125	360	Continued yield, conductor shape irregular
"	0	100	Same
"	- 25	0	Aluminum strands bird caged, outer layer "tight"
"	- 50	-370	Same
"	- 75	-710	Gross yield, unable to further increase torque
"	0	-405	All aluminum strands out of place

* Zero reference is the conductor position at 17,750 lb load. Positive is direction that tightens the outer aluminum layer.

Following the torsion test, the aluminum strands were removed. No breaks could be seen on the outer layer of the core. A residual strength test resulted in an ultimate load of 53,240 lb (92% of the nominal 57,885 lb core rating). All strand breaks were in the free span, clustered at four main locations.

Photographs 6 and 7, initial bird cage after relaxing first negative torque cycle



Photographs 8 and 9, bird caging of inner layer prevents conductor from returning to initial shape upon positive torque

Photograph 10, conductor following torsion test

Photograph 11, core following tensile test (aluminum layers have been removed)

The goal of the test was to identify the damage threshold for in-service torsional loads and deflections. A popping noise characteristic of breaks in the MMC core was heard at -870 degrees, and -75 ft-lb torque. Based on the 16 ft test section, the torsional deflection was 54 degrees per foot. Based on this observation, a second test was designed to demonstrate the torsion withstand of the core for zero damage. A deflection of +/- 30 degrees/ft was imposed at loads equal to 25%, 10%, and 5% of the core nominal rating. Following the torsion test, the residual strength was 60,460 lb (104% of rating). Figure 1 shows the load versus deflection data for the residual strength test.

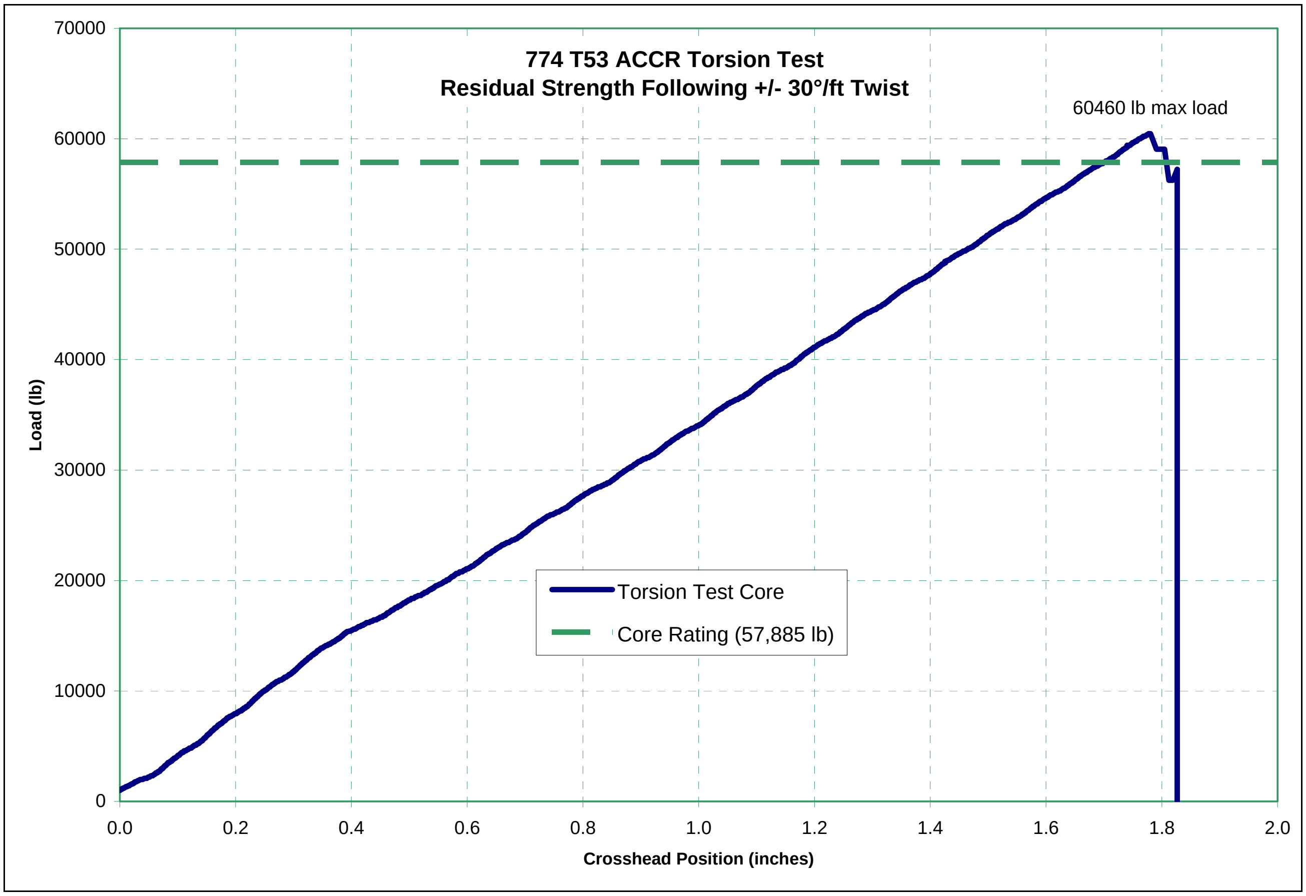


Figure 1, residual strength following torsion test

CONCLUSION

Resistance of the 774-T53 conductor measures within 1% of the published resistance. Changing the tension from 0.6% RBS to 25% RBS did not appear to change the conductor resistance.

The torsion test demonstrates the core sustains damage at torsional deflection of 54 degrees/ft and tension of 25% RBS. The core was deflected to 30 degrees/ft at tensions of 5% RBS, 10% RBS, and 25% RBS with no damage. The core strength following the 30 degrees/ft torsion test was 104% of rating. Torque required for a 30 degrees/ft wind-up is approximately 100 ft-lb, which is far in excess of expected service loads. The aluminum strands are permanently distorted well before the core damage threshold is reached. Therefore, it may be concluded that the ACCR conductor will perform under torsion loads and deflections essentially the same as ACSR and other conventional conductor designs.

EQUIPMENT LISTING

1) MTS Servo-hydraulic tensile machine, Control # CQ 0195 (load and crosshead data)
2) AVO/Biddle Digital Low Resistance Ohmmeter, Calibration Control #CQ 1092
3) Fluke 77 thermocouple reader, Calibration Control # CQ 0173
4) Chatillon hand-held force gage (torsion test), Calibration Control # CN 3009

REFERENCES AND STANDARDS LISTING

1) ASTM E4, (Calibration of Load Testing Machines)