Composite Conductor Field Trial Summary Report: ORNL ACCR 795Kcmil

Field trial location	Oak Ridge, Tennessee, USA

Line Characteristics

Organization	Oak Ridge National Laboratory
Point of Contact	John Stovall, ORNL
Installation date	June 14, 2005
Conductor Installed	ACCR 795
Length of line	1,200 feet (356.7 meters)
Conductor diameter	1.108 inch, (28.1 mm)
Voltage	400 VDC
Ruling span length	600 feet, (183 meters)
Structure Type	Steel Poles
Instrumentation:	(1) Load cell (2) Current, voltage (3) Weather station (4) Sag (5) Thermocouples on conductor and accessories

Hardware

Suspension Hardware	Preformed Line Product, THERMOLIGN^{TM} SUSPENSION-TLS-0108-SE
Termination Hardware	AFL compression dead end, Part# B9178-B AFL compression splice, Part# B9095-B
Insulator type	Polymer
Dampers	Alcoa Dampers Part# 1707-13
Terminals	AFL terminal connector (jumper terminal), Part# B9102-B Transition plates, Part# ACP-E
PLP terminations	PLP THERMOLIGN^{TM} DEAD END, Part# TLDE-0114 PLP THERMOLIGN^{TM} SPLICE, Part# TLSP-0114 DG- 4553

Results and Measurements

Temperature- cycling from -5^{o}C to 240^{o}C using currents ranging from 0 to 2300 amps.
Tension-temperature data from 0^{0}C to around 240^{0}C
Measured and computed thermal rating

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Abstract:

Under DOE funding Agreement No. DE-FC02-02CH11111, Oak Ridge National Laboratory, ORNL, jointly with The Tennessee Valley Authority, TVA, installed a 795 kcmil ACCR conductor on ORNL high temperature test line on June 14, 2005. The line is 1200 feet (365 meters) long, and the ruling span is 600 feet (183 meters).

ORNL subjected the line to extensive thermal cycling and high temperature load using 400 V DC and currents from 800 to 2300 A. The conductor was thermally cycled from ambient to up to 240^0 C for about 1000 hours between September 13 and November 30, 2005 and over 600 hours operation continuously above 200^0 C under changing wind and ambient temperature conditions.

The measured conductor tension-temperature response agrees with predictive models. The measured current-temperature response agrees well with the predicted values, (IEEE 738 model).

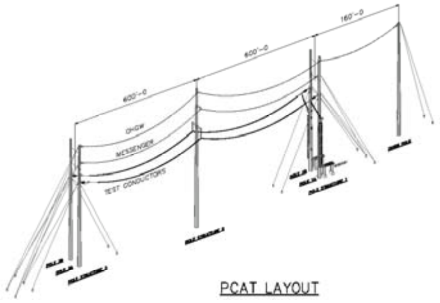
The accessories performed well during the high temperature cycling and ran at much cooler temperatures than the conductor. No visual changes were observed on the conductor and accessories. The conductor and accessories will be de-installed and tested when the thermal cycling is complete

1- Background:

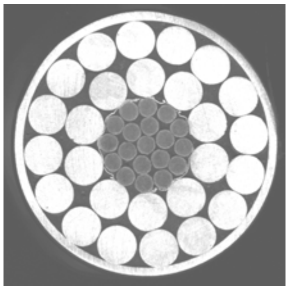
ORNL has built a fully instrumented low-voltage test line to evaluate the high-temperature operation of ACCR conductors by simulating numerous emergency cycles where the conductor temperature reached operating temperature up to 210^0 C under a range of weather and ambient temperature conditions.

The ORNL test line instrumentation includes a CAT-1 system for measuring conductor tension, ambient & solar temperature and weather. Multiple thermocouples were mounted at various locations on the conductor and all accessories.

This report summarizes the 795 ACCR conductor installation, thermal cycling and data analysis.



Arial view of the line



ACCR 795

Figure 1- ORNL test line view and conductor details

2- Installation and Conductor Stringing:

2-1 Overview:

A two span test line (from dead end to dead end) was constructed on the grounds of the Oak Ridge National Laboratory in Oak Ridge, TN, as a part of a Department of Energy program, Figure 1. Several sizes of ACCR composite conductors were installed and tested since then. ACCR 795 is the latest of such installations. The installation procedures used is typical of that used when installing ACSR. Tables 1 and 2 show the typical hardware and procedures used during installations and comparisons with ACSR installation hardware

2-2 Installation details:

The test line (Figure 1) consists of four 600 feet (183 meters) segments between a steel suspension pole and two guyed dual steel dead end poles. The test conductor forms a loop of two spans connected to a DC power supply station located on a trailer at one end of the line. Thermocouples were installed along the test conductor and on dead ends, suspension and splices to measure the temperature of these components during and after periods of high temperature operation.

Conductor was shipped to the installation site wound around wooden reels 84”x36” x44”. The installation followed the IEEE 524 installation guideline for overhead transmission conductors. Grounded stringing blocks were used at all the dead end structures.

Particular care was given to the stringing operation. The combination of bending and tension could damage the conductor if it exceeds the composite core allowable strength. Therefore stringing blocks and bull wheel were selected to keep the stringing loads well below the core strength. Table 1 specifies lined stringing blocks 28” diameter and a bull wheel of 54” diameter to meet such criteria.

The sagging procedure of ACCR conductor is similar to that used to install ACSR; a dynometer was used to verify the final tension of the conductor.

The following pictures show examples of some of the installation hardware.

Figure 2 PLP dead end installation using double 28” sheave at the first tower

Figure 3- An example of a Suspension System installed at middle tower

Figure 4 shows installed compression dead end and terminal connector

Figure 5 Conductor unwinding station

Figure 6 Thermocouples wiring for in-situ – temperature monitoring

Table 1- Installation Equipment

Equipment	ACCR
Stringing blocks	28" Suspension
Stringing blocks	60" roller array block- dead ends
Bull wheel	54"
Drum puller	Yes
Sock splice	Yes (no bands)
Conductor grips	DG grips
Cable spools	40" drum min
Cable cutter	Yes
Reel stand	Yes
Grounding clamps	Yes
Running ground	Yes

Table 2- Installation Procedure

Procedure	ACCR
Cable stringing	Tension
Sag tensioning	Dynometer, line of sight
Dead ending	Compression or Preformed.
Clipping	Thermolign suspension

2-3- PCAT-1 Instrumentation:

A CAT-1 system from The Valley group was installed on one of the dead end structures to monitor the conductor tension and weather conditions (temperature, wind speed, and direction). Two 10,000 pounds load cells were used for line tension. The CAT-1 system was equipped with an anemometer to measure wind speed and direction. Data acquisition was done at 1minute interval for all channels

The CAT-1 main unit is in a NEMA-enclosed, solar powered, data acquisition and processing unit, see figure 7. Net Radiation Temperature, (NRT), was measured by the net radiation sensor, (NRS).

7- A Load cell used to measure tension

7- B CAT-1 System

7- C Net Radiation Sensor Measures
No Load Conductor Temperature

Figure 7- CAT 1 System hardware

2-4 Conductor and Accessories Temperature Measurements:

A separate data acquisition system was used to collect the information from the thermocouples every minute, see example in Figure 8.. Thermocouples were mounted at various locations along the span on both conductor and all accessories. Both conductor surface and core temperatures were measured.

2-5 Controls:

The line was operated under either constant current and / or constant conductor temperature with thermal cycles lasting from one hour to several days each.
Multiple points along the length of the conductor were monitored this way using the installed thermocouples. To accommodate the multiplicity of points along the conductor and withstand the accumulated voltage drop, many fiber-connected, isolated measurement nodes were used. A thermocouple measurement node was fabricated using a multiplexer (ICPCON I-7018) and a RS-485-to-fiber modem (B&B FOSTCDR). Up to eight thermocouples were monitored per node. The node required 120 VAC power and was connected through a duplex fiber optic network. The multiplexer, fiber modem, and a power supply were housed in an enclosure.

The power supply used has a dual rating of 400 Vdc and 5000 amps or 600 Vdc and 3750 amps. The input voltage to the power supply is 4160 V, 3-phase. A dry-type ABB transformer was used to step down the voltage from a 13.8 KV distribution line.

2-6 Accessories:

Two types of accessories were installed; a compression type made by Alcoa (presently known as American Fujikura Limited, AFL) and formed wire type made by Preformed Line Products, PLP. The following specific parts were installed:

- Two ALCOA compression dead ends; Part # B9178-B
- One ALCOA full tension splice Part# B9095-B
- Four Alcoa jumper terminals (terminal connectors); Part# 9102-B

- Two transition plates, Part# ACP-E
- Two PLP THERMOLIGN^{TM,} DEAD ENDS, Part# TLDE-0114 (includes extension link and Thimble- Clevis)
- PLP THERMOLIGN^{TM} SPLICE Part # TLSP-0114
- Two THERMOLIGN^{TM} PLP SUSPENSIONS with Socket eye, Part # TLS- 0108-SE

3- Thermal Cycles and High Temperature Exposure:

3-1 Thermal cycles details:

The 795 Conductor was thermally cycled starting in September 2005, between ambient temperature and 200^0 C, sometimes above 240^0C, under wide range of weather and load conditions. Conductor surface temperature was measured at all locations while core temperature was measured at two positions on the mid span; see example of a single thermal cycle in figure 9. The conductor temperature dropped on rainy days by more than 40^0C. Figure 10 shows locations of the thermocouples used to measure both the conductor and accessories temperature. There were two thermocouples on each accessory, one to measure temperature at the tip of the accessory for the AFL compression accessories or at the inner rod for the PLP accessories). The second thermocouple measured the outer surface temperature for the compression accessories or outer rod temperature for the PLP accessories. Table 3 gives a summary of the cycles conducted from ambient to over 240^0C.

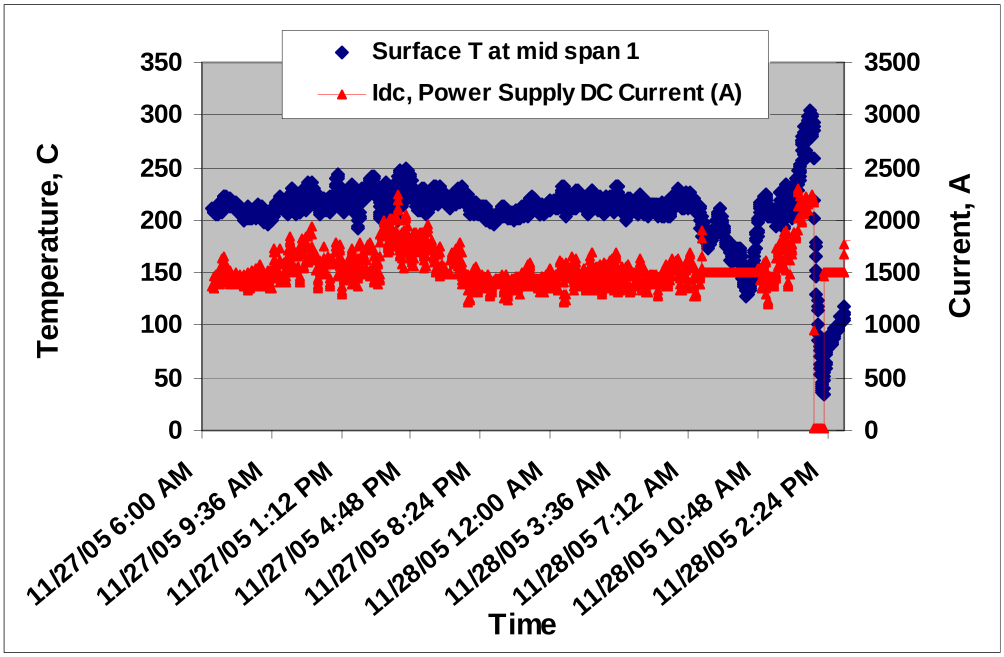


Figure 8 shows a single cycle at 200^0 C followed by a short cycle at 300^0C. Conductor’s surface temperature dropped with rain on 11-28-05.

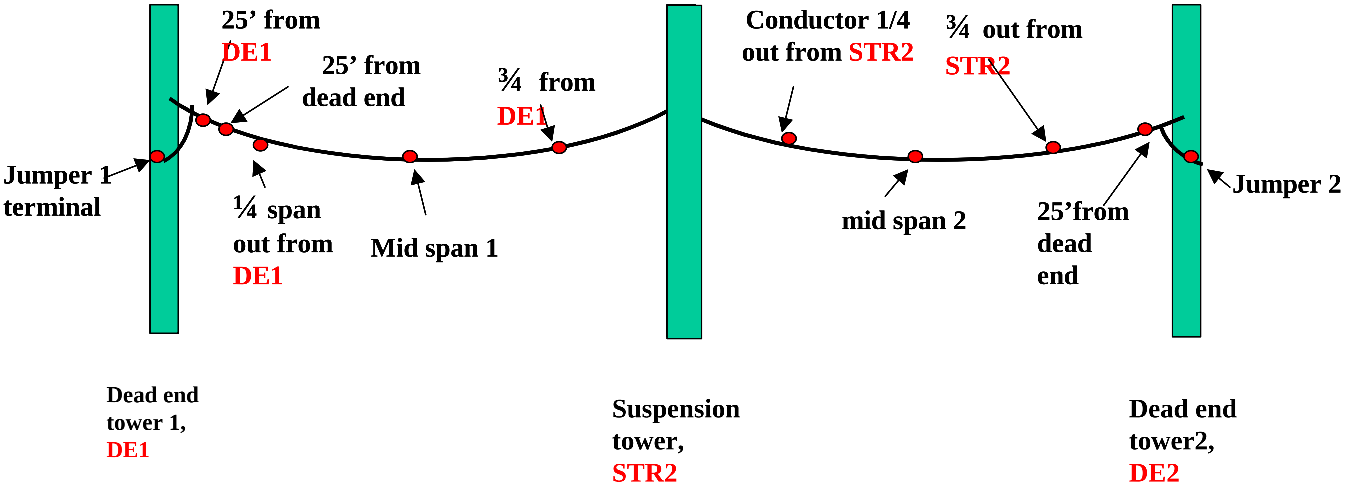


Figure 9- Schematics of thermocouples location along the test line spans from dead end tower DE1 to suspension tower, STR2 to dead end tower DE2.

The conductor was cycled from ambient to above 200^0 C using either constant current or constant temperature. It was given a short cycle from ambient to 300^0C on 11-28-05.

Figure 10 shows both a typical difference of about 5-10^{0}C between core and surface temperatures when the conductor temperature is above 200^{0}C.

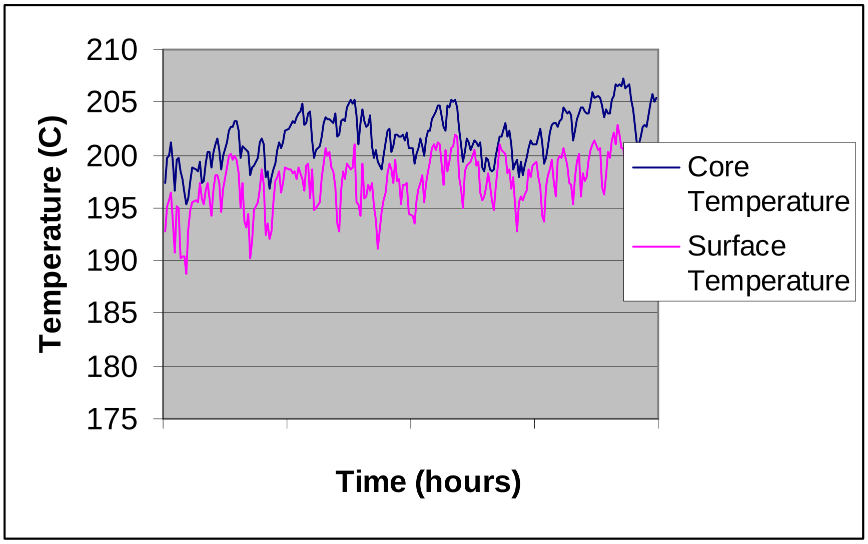


Figure 10 shows both surface and core temperature

November 2005 data was reduced to include only 0 fps wind speed and core temperature above 150^{0}C and plotted in figure 11. The data suggests that a larger temperature gradient occurs between core and surface at higher core temperatures.

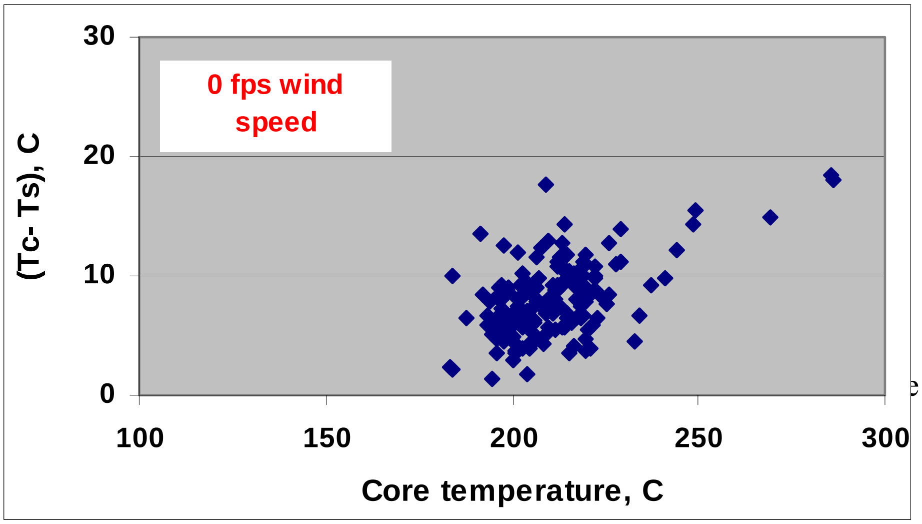


Figure 11 shows effect of conductor core temperature at 0 fps wind speeds on temperature gradient between core and surface

Data at wind speeds above zero was also examined and they show similar trend but higher difference, see figure 12.

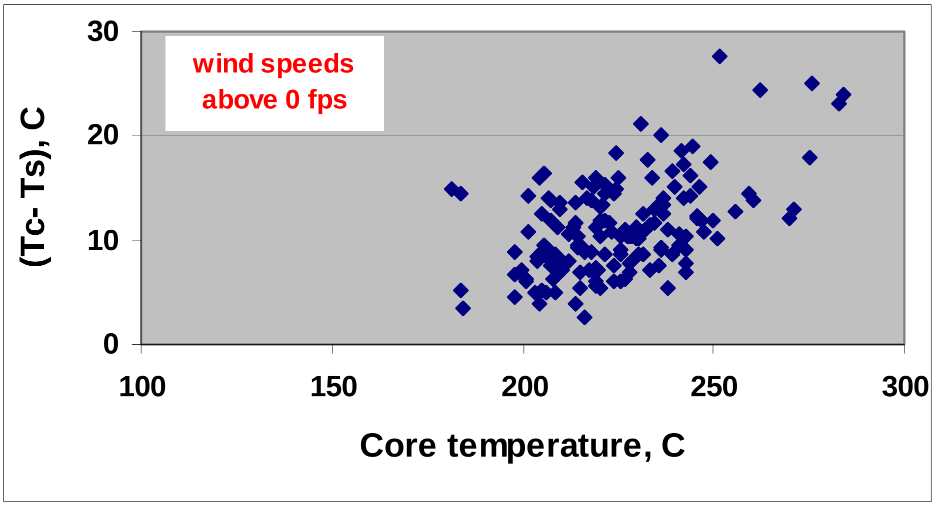


Figure 12- Temperature difference between conductor core and surface increases with increased core temperature at higher wind speeds

3-2 High temperature Cycle:

A high temperature cycle to 300^0C was conducted lasting about 40 minutes as shown in figure 13. No additional 300^0C cycles were performed because the thermocouple bond to the conductor deteriorated and some thermocouples were damaged.

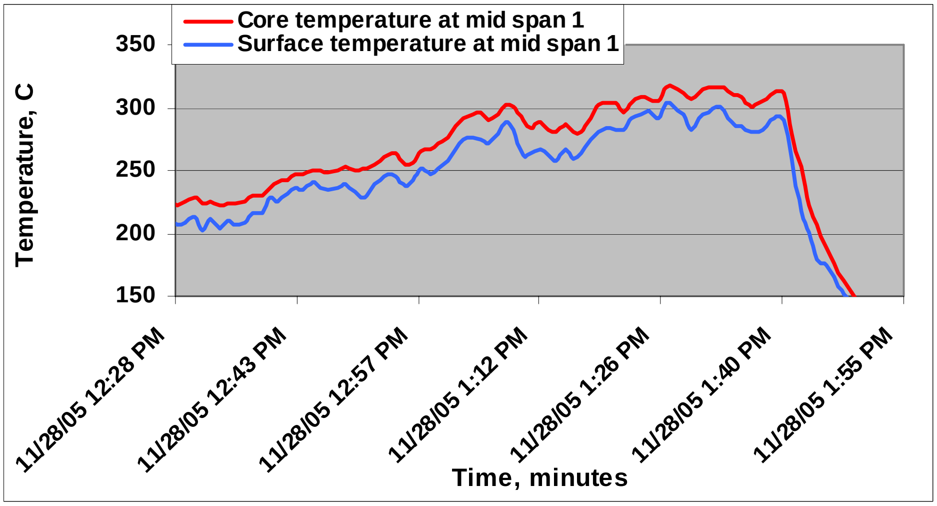


Figure 13- High temperature cycle, temperature difference between core and surface was about 15 to 200C at around 3000C core temperature

Table 3- Summary of thermal cycling of ACCR 795 at ORNL

Date	#Cycles Per day	Total # Cycles	Hours Per day	Total run hours	Nature of cycle	Maximum surface T, C	Average core T, C	Maximum Core T, C	Maximum current, A
6/16/2005	0	0	0	0	Conductor installed				
9/13/2005	1	1	1	1	Constant current, 1025A	127	122	130	1031
9/14/2005	1	2	13	14	Constant current,1200A	202	173	207	1226
9/15/2005	0	2	23	37	Constant current 1300A	196	177	199	1293
9/16/2005	0	2	20	57	Constant current1300A	211	187	216	1300
9/17/2005	0	2	1	58	Constant current, 1350A	207	205	211	1300
9/19/2005	1	3	16	74	Constant current 1300 A	208	183	214	1300
9/20/2005	0	3	24	98	Constant current 1300 A	213	192	221	1315
9/21/2005	0	3	24	122	Constant current, 1350A	246	208	252	1340
9/22/2005	0	3	24	146	Stepped current 1350A	226	200	230	1349
9/23/2005	0	3	4	150	Constant current, 1350A	205	203	208	1349
10/18/2005	1	4	2	152	Constant current, 1350A	156	156	160	1349
10/19/2005	1	5	15	167	Stepped current,1350A	199	156	201	1349
10/20/2005	0	5	24	191	Constant current, 1350A	222	210	228	1350
10/21/2005	1	6	24	215	Stepped current, 1350A	223	190	228	1350
10/22/2005	0	6	24	239	Constant current 1350 A	209	167	213	1350
10/23/2005	0	6	24	263	Tracking 175^{0}C all day	208	176	212	1350
10/24/2005	1	7	16	279	Tracking 190^{0}C, rain	253	199	253	1350
10/25/2005	0	7	24	303	Tracking 190^{0}C all day	247	195	252	1351
10/26/2005	0	7	24	327	190^{0}C then 100^{0}C (4PM to midnight)	220	202	226	1351
10/27/2005	0	7	24	351	Tracking 100^{0}C till noon, 125^{0}C after	135	136	138	1351
10/28/2005	0	7	24	375	1350 A, tracking 125^{0}C	162	141	170	1351
10/29/2005	0	7	24	399	1350 A, 100^{0}C target	131	120	139	1355
10/30/2005	0	7	24	423	1350 A till 9PM, then 1025A	110	100	113	1375
10/31/2005	0	7	24	447	Constant current, 1025A	113	97	117	1035
11/1/2005	0	7	24	471	Constant T around 1000 C	126	109	130	1606
11/2/2005	0	7	24	495	1400 A tracking 190^{0}C	256	210	267	1402
11/3/2005	1	8	23	518	1400 A tracking 200^{0}C	247	215	255	1378
11/4/2005	0	8	24	542	Tracking T around 200^{0} C	233	208	242	1394
11/5/2005	0	8	24	566	T around 200^{0} C, very windy	234	205	235	1485
11/6/2005	1	9	22	588	1400 A tracking 190^{0}C	247	217	255	1400
11/7/2005	0	9	24	612	1400 A, 190^{0}C	242	208	256	1407
11/8/2005	0	9	24	636	1401 A, 190^{0}C	217	204	224	1423
11/9/2005	0	9	24	660	1350A, 190^{0}C, very windy, rain	241	211	252	1437
11/10/2005	0	9	24	684	1350 A, 190^{0}C	237	204	243	1454
11/11/2005	0	9	20	704	Constant T around 200^{0} C	257	220	268	1469
11/12/2005	0	9	24	728	Constant T around 200^{0} C	243	217	254	1486
11/13/2005	0	9	24	752	1400A, 200^{0}C	244	219	251	1502
11/14/2005	0	9	24	776	Constant current, 1400A	224	215	229	1525
11/15/2005	0	9	24	800	T, 200^{0} C	247	225	260	1543
11/16/2005	1	10	17	817	Current, 1550 A, storms, windy	251	221	259	1555
11/17/2005	0	10	24	841	Constant T, 200^{0}C, sunny, T rise	241	229	251	1566
11/18/2005	0	10	24	865	Constant T around 200^{0}C, sunny	275	223	293	1635
11/19/2005	0	10	24	889	Constant T around 200^{0} C	243	221	257	1688
11/20/2005	0	10	8	897	Constant T around 200^{0} C	217	214	225	1702
11/26/2005	1	11	8	905	Constant T, 200^{0} C	216	202	223	1718
11/27/2005	0	11	24	929	Constant T, 200^{0} C	249	225	263	1779
11/28/2005	1	12	21	950	T, 2000 C, rain 8-11AM, 3000 C spike	305	210	317	1843
11/29/2005	1	13	14	964	T around 200^{0} C, Rain 9:30 AM	260	217	267	1897
11/30/2005	0	13	24	988	T around 200^{0} C	261	227	272	2292

4- Measured and Predicted Line Tension and Sag:

The most commonly used method to compute both line tension and sag is the one developed by AFL and known as Sag 10; it is also referred to as the graphic method. It uses mechanical properties (Modulus, tensile strength, elongation and creep) measured in the laboratory. It assumes a Catenary shape for sagged conductor and takes into consideration environmental conditions (wind load and ice accumulation). A second method used in this report is called STESS, a model developed by Barrett and Associates, and is similar to the Sag 10 but varies in details where it allows to compute creep versus time. It uses a compressive stress values ranging from 0 to -2.45 Ksi to fit the data. The CAT-1 system measured tension on both the tree and road- sides of the line as a function of conductor temperature. Results are shown in figures 14 to 17. The STESS model shows good agreement at both high and low temperatures for the tree side when using -2.5 Ksi residual compressive stress. In the temperature range 60 to 120^0C agreement is not as good and may be due to processing variations in the residual stress of various Al strands. In general the model fits the high temperature data better, Figures 16 and 17.

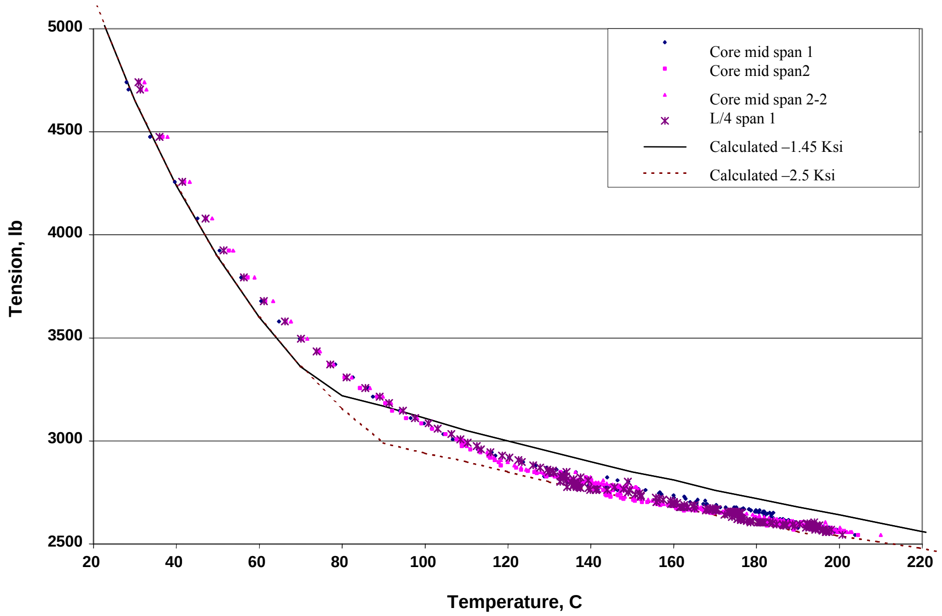


Figure 14. Tree side tension VS temperature on September 14, 2005.
Model agrees with measured data at high temperature

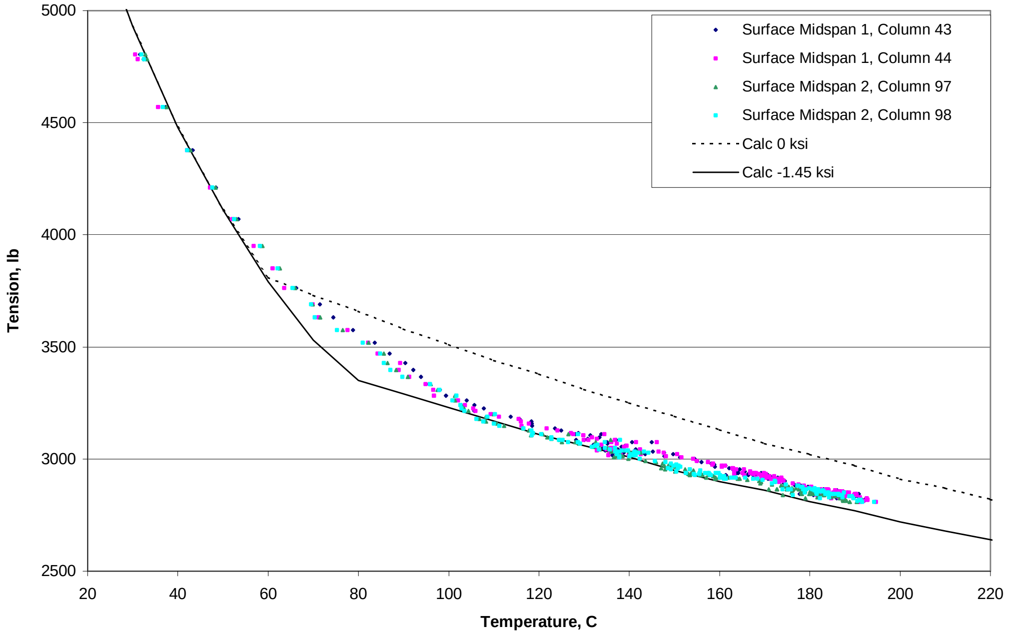


Figure 15- Road- side tension VS conductor surface temperature, September 14, 2005. Model fits data very well using a compressive stress of –1.45 Ksi particularly above 100^0 C

Similar results were obtained by analyzing the ORNL data for November 6, 2005.

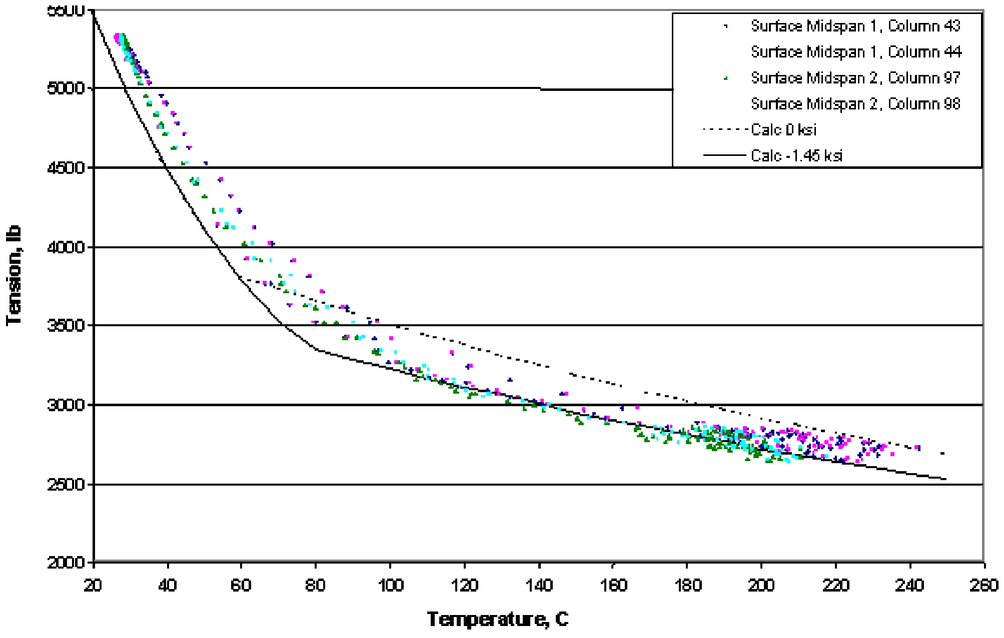


Figure 16- Road- side tension VS temperature, November 2005. Model agrees with measured data above 1000C using a compressive stress of –1.45 Ksi

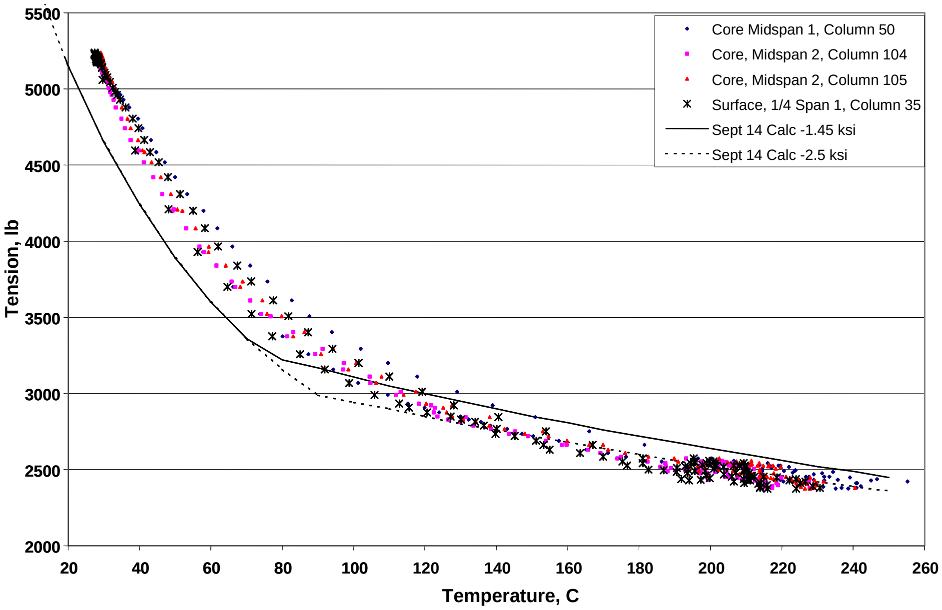


Figure 17. Tree side tension VS temperature, November 6, 2005. Model agrees with measured data at high temperature using Al compressive stress of –2.5 Ksi .

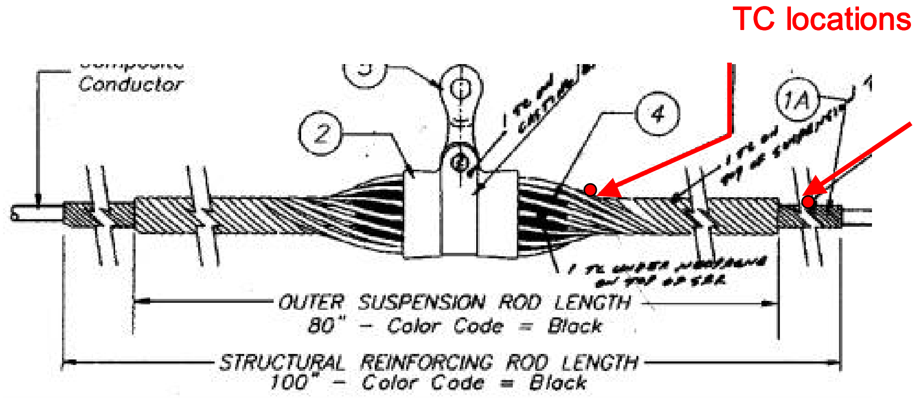
The STESS model agrees well with measured values at high temperature. Residual stress in Al may be traced back to the manufacturing process and it could be the cause of the absence of a well- defined knee- point for the conductor at the tree side. Laser measured conductor clearance above ground shows wide scatter; it could be due to changing wind conditions and because the measurement was done at a single location along the conductor surface.

5- Accessories Response at High Temperature:

Both Preformed Line Product and American Fujikura Ltd, AFL (Previously known as Alcoa Fujikura) accessories were used for installation of the line. They performed well and ran much cooler than the conductor during exposure to temperatures above 200^0 C.

5-1 PLP Accessories:

Temperature profiles of suspension, dead end and splice were measured. The thermocouples were mounted on both the outer and inner- stiffening rods as illustrated schematically in figure 19. The inner rods temperature was several degrees higher than that of the outer rods because of thermocouples proximity to the conductor strands and core- see figure 21.



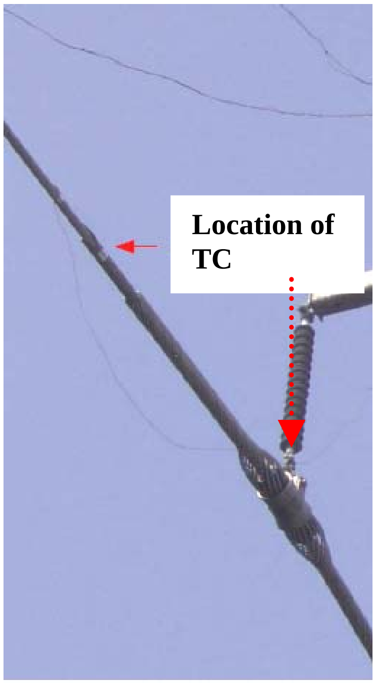
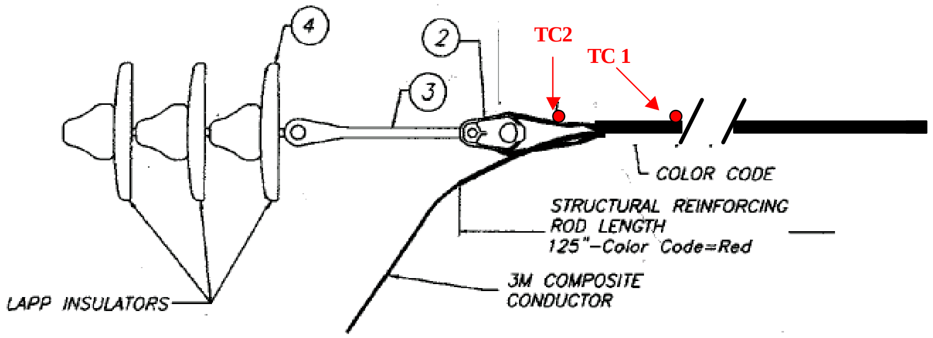
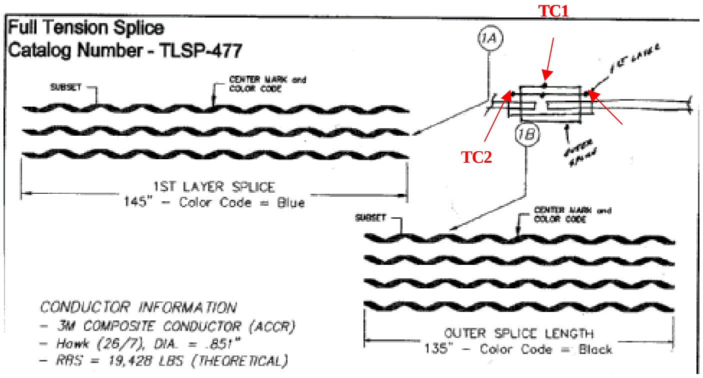


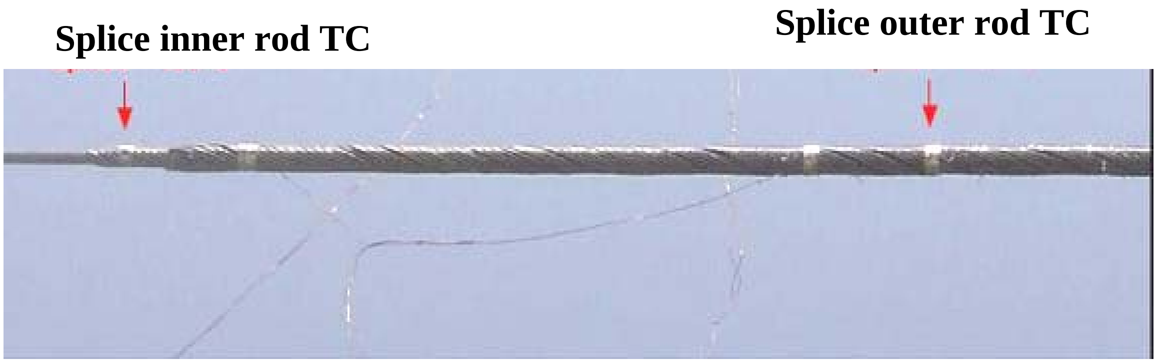
Figure 18 - Suspension System schematics showing thermocouples (TC) locations. The inner rod TC location is shown in the image very close to conductor



19- a PLP dead end Thermocouple, TC, Locations



19- b PLP Splice TC Locations



19-c actual location of thermocouples on the PLP splice

Figure 19- Schematics of thermocouples location on PLP THERMOLIGN^{TM} DEAD END and SPLICE and an image showing actual location of the two thermocouples.

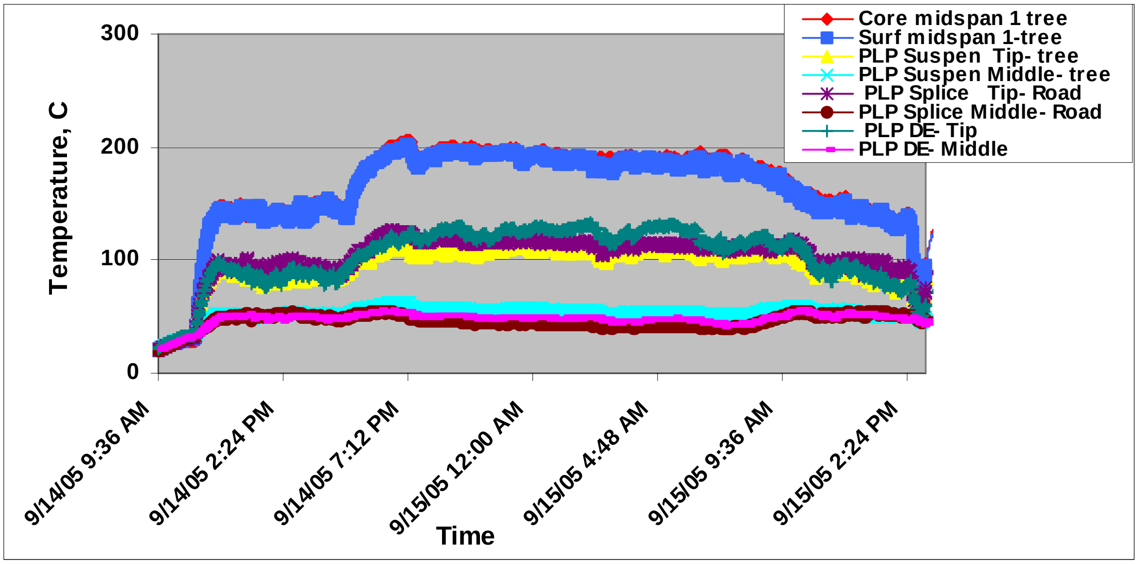
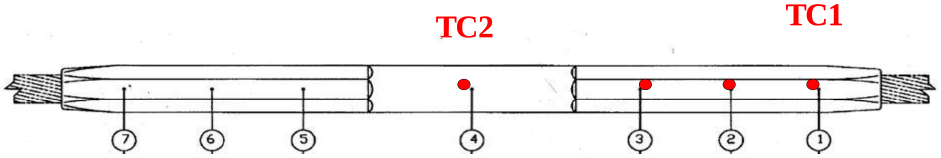


Figure 20- shows an example of PLP THERMOLIGN^{TM} SUSPENSION, SPLICE and DEAD END temperature profiles during conductor cycling at 150^{0}C and 200^{0}C. PLP accessories ran cool, below 120^{0}C at conductor temperature of 200^{0}C

5-2 Alcoa Accessories:

Both compression splice and dead ends temperatures were below 105^0 C during conductor exposure to temperatures above 200^0 C- see Figure 22. They show no problem during continued thermal cycling. Thermocouples were designated TC1 at the accessory mouth (hot- closer to conductor) and TC2 on the surface as illustrated schematically in figure 21.



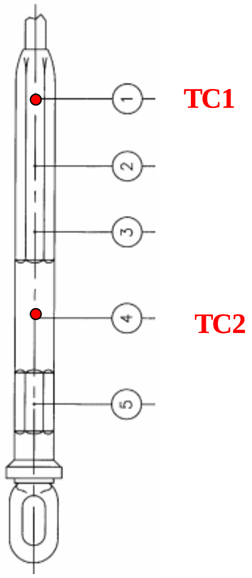


Figure 21- Thermocouples location on both the AFL compression dead end and splice.

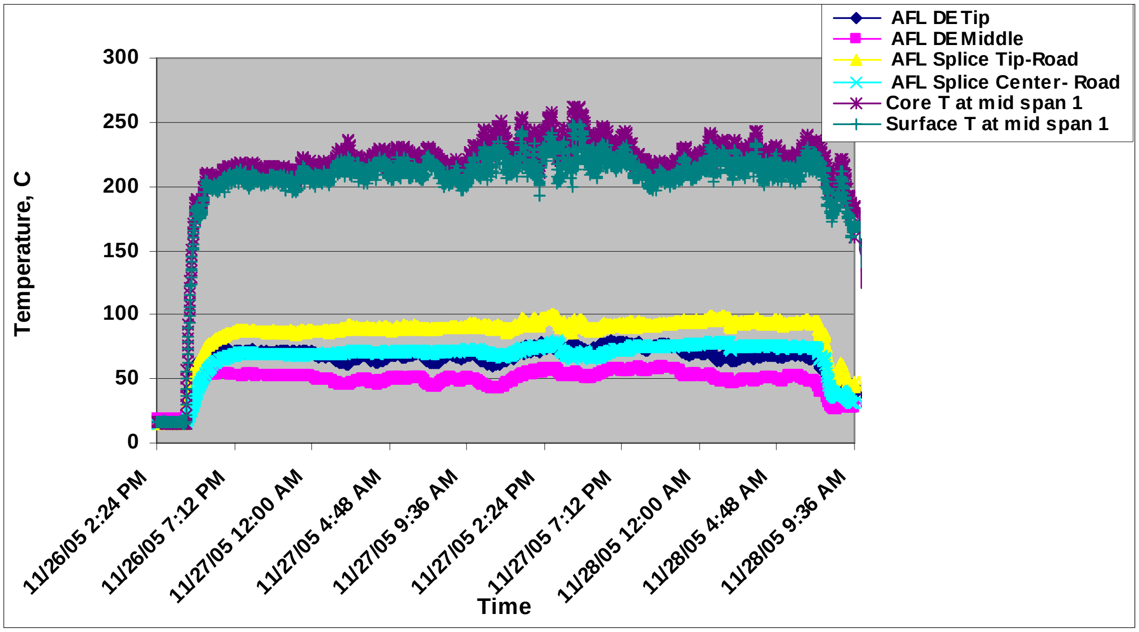


Figure 22- Alcoa compression splice and dead end temperature during one cycle; both ran very cool when conductor was at or above 200^0 C

All installed accessories ran cool when conductor was at or above 200^0C. Further Examination of conductor, accessories and their interfaces will be done after line is taken down to check for any changes as a result of thermal cycling.

6- Ampacity and Thermal Rating of Conductor:

6-1 Ampacity Prediction using IEEE Model

The IEEE Standard 738-1993-was used to predict conductor temperature during thermal cycling. Weather conditions for constant current and wind were used in the model; Figure 24 shows an example of steady state, high temperature cycle data used in the model. Figure 24 plots measured current VS predicted one (using both IEEE and CIGRE models) at conductor temperatures around 200^0 C; agreement is good. Conductor emissivity, ε =0.347, measured at ORNL in 2003, was used in the model calculations. ACCR 795. Conductor emissivity is not expected to change due to the low KV of the line (400 V). Conductor is rated at 1653 amps for continuous operation at 210^0 C and 1778 amps for emergency loading at 240^0 C. The data shows the conductor was sometimes exposed to temperatures higher than 240^0C and current above 2200 amps.

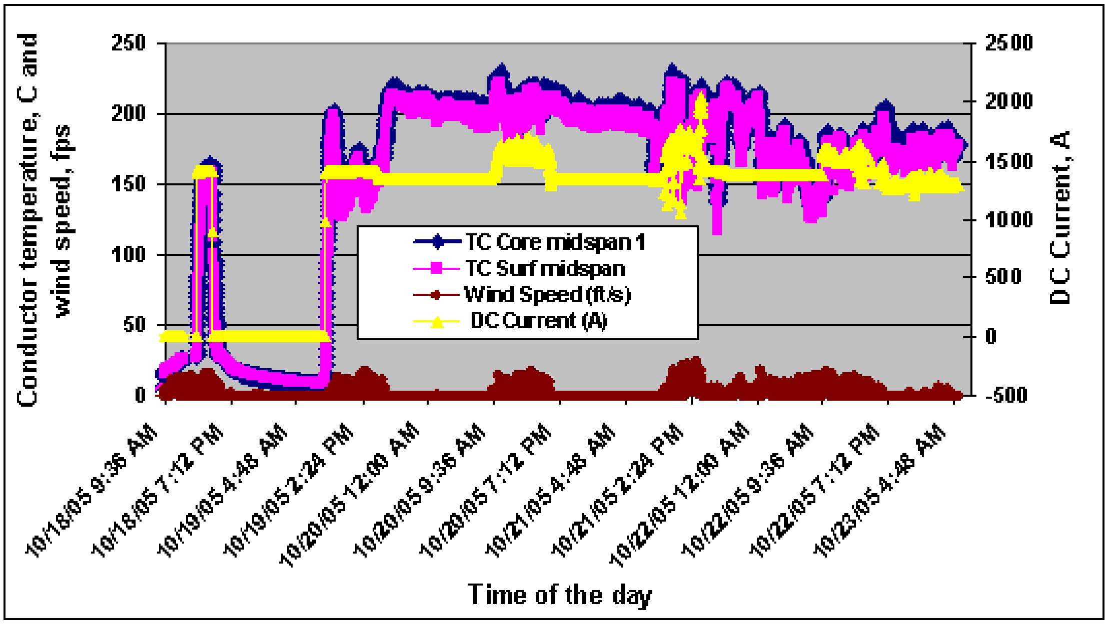


Figure 23 shows an example of constant current thermal cycles data used in the model prediction in October 2005

6-2 IEEE VS CIGRE' Ampacity Model:

The CIGRE' 1997 model was used to compute current to compare with the IEEE Std 736, both programs were provided by the Valley Group Rate kit software. There were small differences between the two models in agreement with literature data. Predicted current values agree well with measured current as plotted in figure 25..

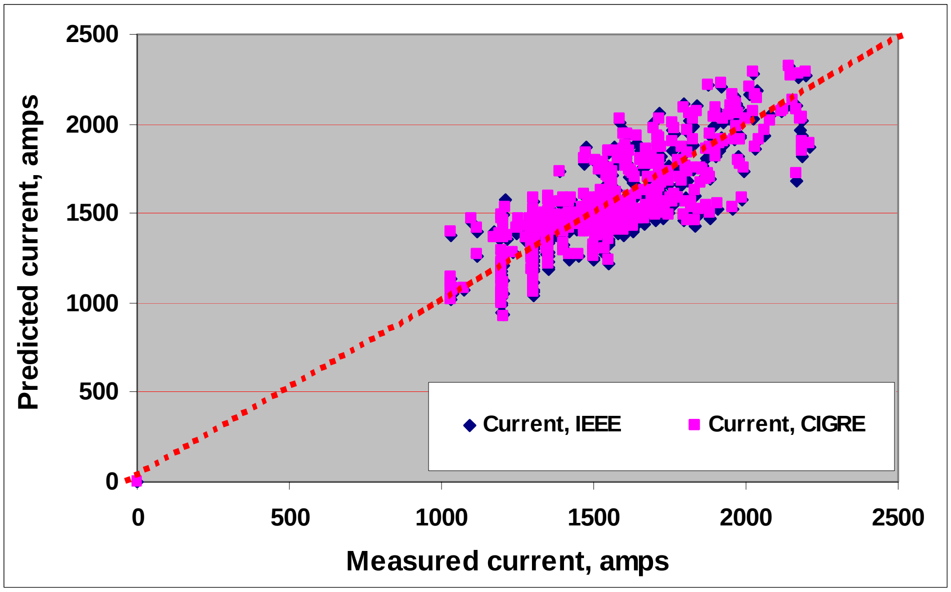


Figure 24- Comparison of both the IEEE and CIGRE predictive models with measured current data- Agreement is good

7- Summary:

ACCR 795 conductor was successfully installed and tested at ORNL. It was thermally cycled from ambient to over 200^0 C for several hundred hours, using a DC power supply. Measured temperature difference between conductor core and its surface was as low as 5^0C and as high as 20^0C degrees and depended on both wind speed and core temperatures at and above 200^0 C. Wind speeds above 0 fps produced larger temperature gradient from surface to core.

Data analysis shows that the measured conductor current agrees well with the IEEE thermal rating model predicted values. The conductor is rated at 1653 A current for continuous operation at 210^0 C and at 1778 A emergency current at 240^0C. The CIGRE' model agrees with the IEEE 736 model.

Conductor tension was stable during and after thermal cycling. Measured line tension versus temperature agrees well with values computed using the strain summation method, STESS.

Both PLP and AFL accessories ran cool, below 120^0 C at conductor's temperature exceeding 200^0 C. The conductor and accessories were exposed for up to 1000 hours at high temperature and show no visual damage. Conductor will be de-installed in early 2006 and shipped to NEETRAC for inspection and mechanical testing (residual strength). The results will be included in a follow up report.

8- Appendix

8-1 Conductor Specs

Designation		795-T16
Stranding		26/19
Diameter		
individual Core	in	0.082
individual Al	in	0.175
Core	in	0.41
Total Diameter	in	1.11
Area		
Al	in^2	0.624
Total Area	in^2	0.724
Weight	lbs/linear ft	0.896
Breaking Strength		
Core	lbs	18,556
Aluminum	lbs	12,828
Complete Cable	000's lbs	31,384
Final Modulus		
Core	msi	35.0
Aluminum	msi	8.6
Complete Cable	msi	12.3
Thermal Elongation		
Core	10^-6/C	6.3
Aluminum	10^-6/C	23.0
Complete Cable	10^-6/C	16.5
Heat Capacity		
Core	W-sec/ft-C	22
Aluminum	W-sec/ft-C	324
Resistance		
DC @ 20C	ohms/mile	0.1100
AC @ 25C	ohms/mile	0.1126
AC @ 50C	ohms/mile	0.1237
AC @ 75C	ohms/mile	0.1349
AC @ 100C	ohms/mile	0.1460
AC @ 210C	ohms/mile	0.1951

AC @ 240C	ohms/mile	0.2084
Geometric Mean Radius	ft	0.0375
Reactance (1 ft Spacing, 60hz)		
Inductive Xa	ohms/mile	0.399
Capacitive X'a	ohms/mile	0.0912