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Duration Test Report for the Ventera VT10 Wind Turbine

J. Smith, A. Huskey, D. Jager, and J. Hur
National Renewable Energy Laboratory

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Technical Report
NREL/TP-5000-57142
June 2013

Contract No. DE-AC36-08GO28308

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Prepared under Task No. WE11.0308

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Duration Test Report

for the

Ventera VT10 Wind Turbine

at the National Wind Technology Center
in Boulder, Colorado

Conducted for

Wind Power Program
DOE/NREL

Conducted by

National Wind Technology Center
National Renewable Energy Laboratory
15013 Denver West Parkway
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Joe Smith, Arlinda Huskey, Dave Jager, Jerry Hur

25 October 2012

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1. Background

This test was conducted as part of the U.S. Department of Energy's (DOE) Independent Testing project. This project was established to help reduce the barriers of wind energy expansion by providing independent testing results for small wind turbines. Five turbines were tested at the National Wind Technology Center (NWTC) at the National Renewable Energy Laboratory (NREL) as a part of round one of this project. Duration testing is one of up to five tests that may be performed on the turbines, including power performance, safety and function, noise, and power quality. Test results will provide manufacturers with reports that can be used to fulfill part of the requirements for small wind turbine certification.

The test equipment included a grid-connected Ventera Energy Corporation VT10 wind turbine mounted on an 18.3-m (60-ft) self-supporting lattice tower manufactured by Rohn.

2. Test Objective and Requirements

The objective of this test was to assess the following aspects of the Ventera VT10 in accordance with Clause 9.4 of the International Electrotechnical Commission's (IEC) standard, *Wind turbines - Part 2: Design requirements for small wind turbines*, IEC 61400-2 Ed. 2.0:2006-03 (referred to as the "Standard" throughout this report):

- Structural integrity and material degradation
- Quality of environmental protection
- Dynamic behavior.

The wind turbine will pass the duration test when it has achieved reliable operation for:

- Six months
- Two thousand and five hundred hours of power production in winds of any velocity
- Two hundred and fifty hours of power production in winds of $1.2*V_{ave}$ (10.2 m/s) and above
- Twenty-five hours of power production in winds of $1.8*V_{ave}$ (15.3 m/s) and above.

Reliable operation means:

- Operational time fraction of at least 90%
- No major failure of the turbine or components in the turbine system
- No significant wear, corrosion, or damage to turbine components
- No significant degradation of produced power at comparable wind speeds.

Based on the parameters defined in the Standard for small wind turbine classes, Ventera Energy Corporation identified the VT10 as a class III turbine. This corresponds to a V_{ave} of 7.5 m/s.

In addition, this test was conducted in accordance with NREL quality system procedures, so that this report meets the full requirements of the NREL accreditation by A2LA. NREL's quality system requires that this report meet all applicable requirements specified by A2LA and ISO/IEC 17025 and to note any exceptions in the test report.

3. Description of Test Turbine

The test turbine was a Ventera VT10 wind turbine. Manufactured by Ventera Energy Corporation, the VT10 is a downwind, three-blade, passive yaw, permanent magnet, horizontal-axis wind turbine and has an advertised rated power of 10 kW. The test turbine used a Diversified Technology, Inc. GALE-12 inverter to deliver electrical energy to the 60-Hz grid. To control rotor speed, besides the inverter loading the generator, each blade has a tip that begins to pitch at rated rotor speed.

Table 1 lists the configuration of the VT10 that was tested at the NWTC. Figure 1 is a picture of the VT10 at the NWTC.

Figure 1. Ventera VT10 test turbine at the NWTC

Source: NREL 22251

The system was installed in March 2010 and had several months of commissioning/shake-down, during which the original inverter was replaced. Additional delays in testing were from NREL personnel incorrectly wiring a filter for the inverter and birds nesting in the lattice tower. Testing began on 19 July 2010.

The following components were considered part of the test turbine system:

- Generator and blades
- Tower and foundation designed for installation at the NWTC test site 3.3c
- Wind brake[1]
- All wiring between the generator and the utility disconnect (in the data shed)
- Inverter
- Kilowatt-hour meter.

Table 1. VT10 Test Turbine Configuration and Operational Data

Turbine Manufacturer and Address	Ventera Energy Corporation 1302 W. 5th St Duluth, MN 55806
Model name	VT10
Production date	October 2009
Generator serial number	100993
Design nominal voltage at terminals (Vac)	240 Vac
Maximum current at terminals (A)	60 A
Design frequency at terminals (Hz)	60
Small wind turbine (SWT) class	III
V_{ave} as defined by SWT class (m/s)	7.5
Design 50-year extreme wind speed, Ve50 (m/s)	55
Rotor diameter (m)	6.7
Hub height (vertical center of rotor) (m)	21.7
Tower type	18.3-m (60-ft) Rohn SSV series, three-legged, self-supporting tower hinged on two legs; plus 3-m (10-ft) extension tube for a total height of 21.3 m (70 ft)
Rated electrical power (kW)	10
Rated wind speed (m/s) (lowest wind speed at which turbine produces rated power)	13
Rated rotor speed (rpm) (lowest rotor speed at which turbine produces rated power)	260
Rotor speed range (rpm)	100–280 (governing from 260–280)
Cut-out wind speed	None
Fixed or variable pitch	Fixed, but uses mechanically pitching tips to govern rotor speed
Number of blades	3
Blade tip pitch angle (deg)	4.5 (30° pitching range during governing)
Blade make, type, serial number	Injection-molded glass fiber plastic w/ nonlinear and optimized taper and twisted airfoil FX63-137; set numbered 1408
Description of inverter	Diversified Technology, Inc.'s GALE-12 model: AMFA00100000000027AH Serial Number: 57583

[1] The "wind brake" is a required component supplied with the turbine. It shorts the generator's three phases, thereby creating an electromagnetic force in opposition to the generator's rotation.

The VT10 turbine tested at the NWTC was in the standard configuration sold by Ventera Energy Corporation at that time.

Figure 2 shows the general electrical arrangement of the test. The wire run from the base of the tower to the meteorological (met) tower junction box was approximately 15 meters of #6 American Wire Gauge (AWG) wire. The wire run from the met tower junction box and wind brake to the data shed was approximately 75 meters of #6 AWG wire. The data shed housed the inverter, instrumentation, the disconnect switch, and a breaker panel. The transformer was located outside and adjacent to the data shed, which first stepped the voltage up to 480 volts (V) and then to 13.2 kilovolts (kV) for the NREL grid.

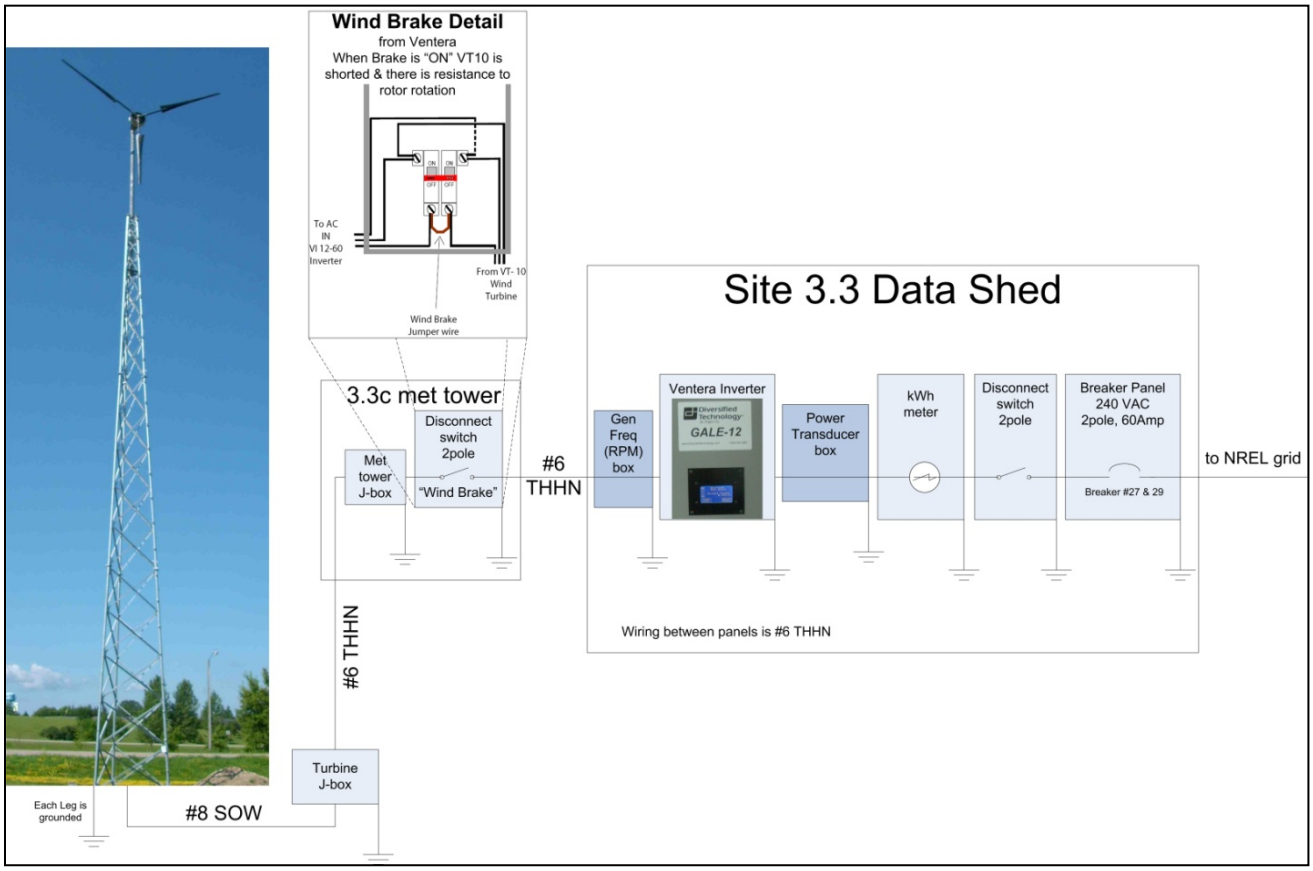


Figure 2. Electrical single-line drawing of Ventera VT10 installation

Source: NREL, 2012

4. Description of Test Site

The test turbine was located at site 3.3c at the NWTC, which is approximately 8 km south of Boulder, Colorado. The terrain consists of mostly flat terrain with short vegetation. The site has prevailing winds bearing approximately 290° relative to true north. Figure 3 shows the turbine and met tower locations as well as nearby obstructions and topographical features of the site.

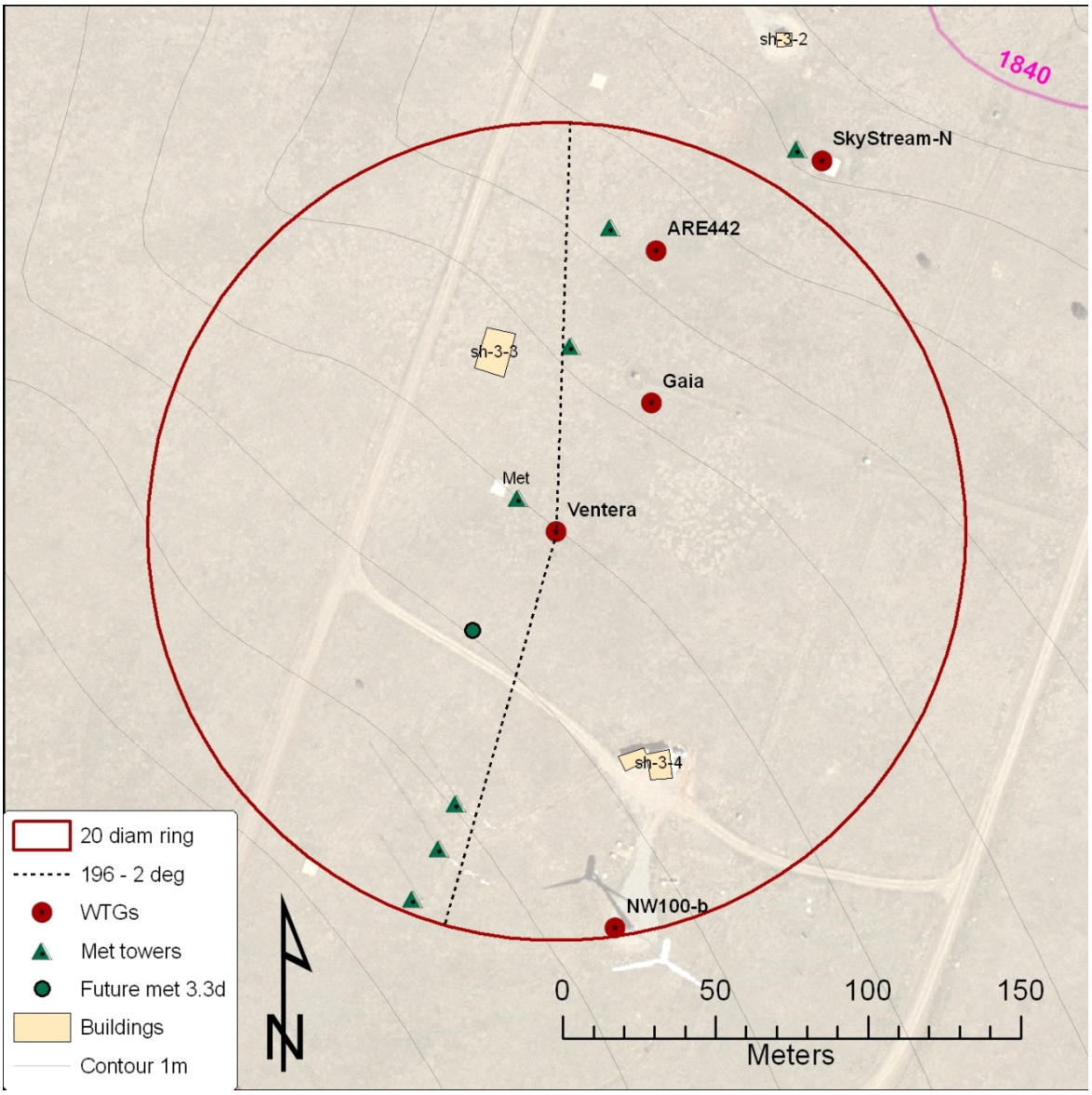


Figure 3. Map of the test site

Source: NREL, 2012

5. Description of Instrumentation

Test instrumentation was installed in accordance with IEC 61400-12-1 for measuring wind speed, wind direction, turbine power, air temperature, and air pressure. Figure 4 provides the location of the met tower instruments and provides an equipment list and the specifications for each of the instruments used. For duration testing, there were additional signals to monitor the rotor speed and the inverter's connection to the electrical grid.

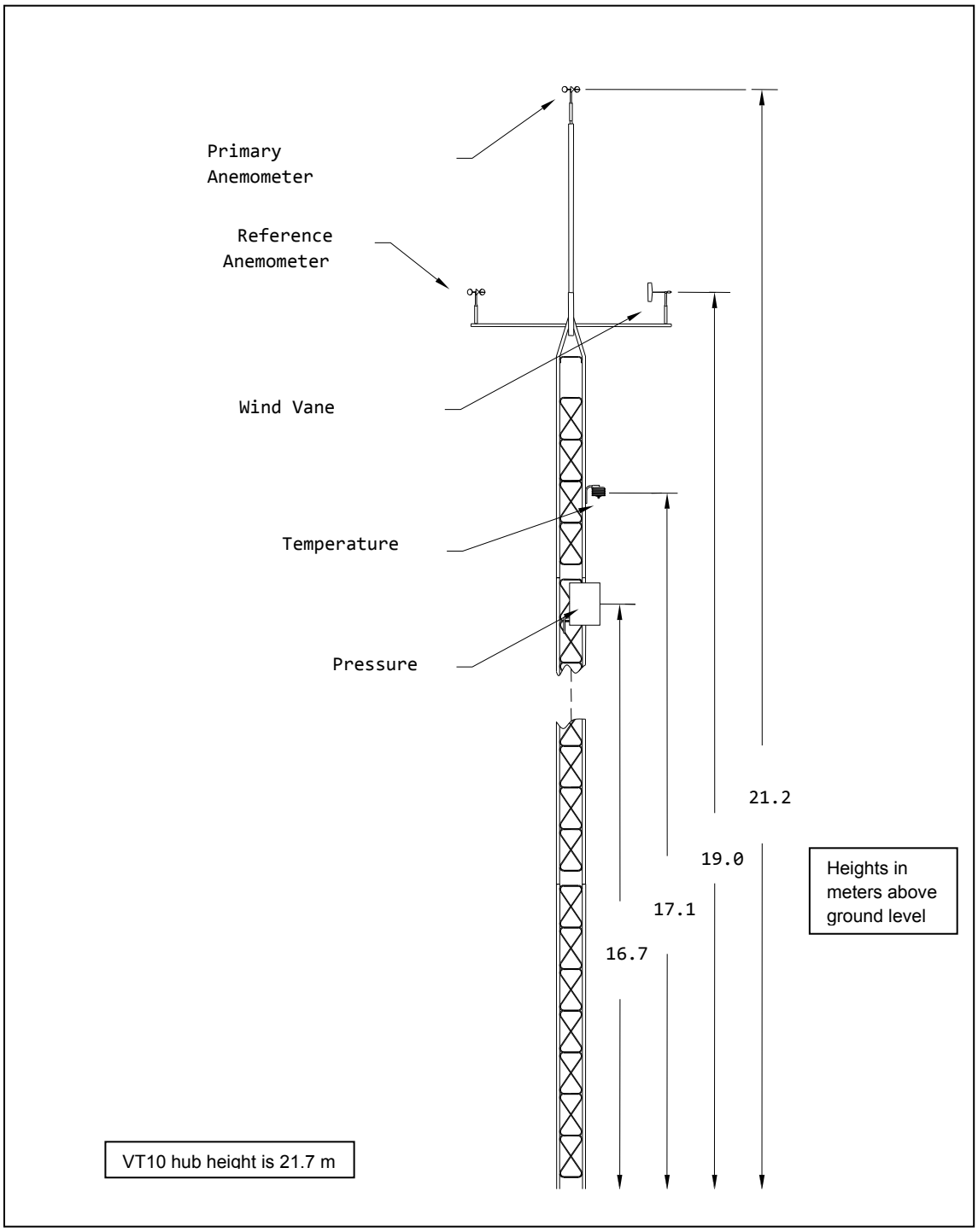


Figure 4. Meteorological tower and instruments

Source: NREL, 2012

Table 2. Equipment List for Duration Test

Instrument	Make and Model	Serial Number	Calibration Due Date
Power transducer	Second Wind Phaser-5-4A 20	02061	28 September 2011
Current transformers	Ohio Semitronics, 12974	001293046 001078333	Calibrated with power transducer
Primary anemometer	Thies, First Class	0609009	21 January 2011, with post-test calibration on 17 July 2011
Reference anemometer	Met One 020	T2351	n/a
Wind vane	Met One, 020C with Aluminum Vane	G4707	18 January 2011; with in situ comparisons
Pressure sensor (replaced during test)	Vaisala, PTB101B	C1040014	10 August 2011
Temperature sensor	Met One, T200	0603-1	13 August 2011
Precipitation sensor	Campbell Scientific, 237	None	In situ
Data acquisition system (DAS)	Compact DAQ w/LabView		
	cDAQ backplane (9172)	12B5EBE	n/a
	NI 9229	13DEC38	22 February 2011
	NI 9217	13FAE1C	22 February 2011
	NI 9205	13E3D05	22 February 2011

The power transducers were not compliant with class 0.5 (or better) specifications of the IEC 60688, but they exceeded the minimum accuracy required by the Standard. This should have no effect on results or uncertainty. The power transducer that was used matches the performance required by the IEC Standard, but it is not IEC certified. Therefore, the power transducer was an exception to the Standard.

The current transformers were not compliant with class 0.5 (or better) specifications of the IEC 60044-1, but they exceeded the minimum accuracy required by the Standard. This should have no effect on results or uncertainty. The current transformers that were used match the performance required by the IEC Standard, but are not IEC certified. Therefore, the current transformers were an exception to the Standard.

The wind vane was slightly damaged during high winds during the final days of October 2010, but it was repaired on 1 November 2010. Comparisons with other wind vanes at the NWTC showed that the vane's performance was consistent before and after these events. Additional comparisons showed that the repaired vane was consistent with a neighboring test site's measurements until the end of the test. However, wind direction does not factor into the duration test results; hence, detailed analysis was omitted from this report.

The vane calibration due date passed during the testing phase. In lieu of a recalibration or a post-test calibration on the vane, the aforementioned in situ comparisons were used to show that the vane's performance was consistent throughout the test.

In addition, the data acquisition modules were used beyond their calibration dates. A post-test calibration confirmed that the modules were still operating within their design tolerances. The post-test calibrations can be found in Appendix A.

6. Results

6.1 Period of Testing

The testing phase for the VT10 was from 19 July 2010 to 24 May 2011.

6.2 Months of Operation

The duration test was conducted over a period of approximately 10 months. This exceeded the 6-month minimum required by the Standard.

6.3 Hours of Power Production

Hours of power production are divided into three categories. They include:

- Any wind speeds: 3,206.4 hours (2,500 hours required)
- Above 1.2*V_{ave} (9 m/s): 808.8 hours (250 hours required)
- Above 1.8*V_{ave} (13.5 m/s): 262.4 hours (25 hours required).

Thus, the turbine met the requirements for hours of power production during the test. Table 3 shows the overall and month-by-month results of the duration test.

Table 3. Monthly and Overall Results of the VT10 Duration Test

	Hours of power production			Environmental conditions			Operational time fraction					
Month	0 m/s	1.2*Vavg	1.8*Vavg	max gust	TI @ 15 m/s	# points	T_T	T_G	T_U	T_E	T_N	O [%]
Totals	***3206.4***	***808.8***	***262.4***	***41.9***	***18.7***	***269***	***7539.0***	***6422.6***	***855.8***	***193.3***	***67.3***	***99.0***
Minimum Met?	Yes	Yes	Yes				Yes					Yes
Jul 2010	92	4.8	0	18.3		0	422	291.5	9.4	120.7	0	100
Aug	272.7	23.5	2.8	27.6	17.1	4	744	676.7	57.3	10	0	100
Sep	157.3	17	2.5	27.7	14.5	2	720	321.2	390.5	8.3	0	100
Oct	292.5	77.3	31.2	38.2	20.6	31	744	645.5	84.2	14.3	0	100
Nov	283	62.3	19.8	41.9	19.1	19	720	715.5	2.6	2	0	100
Dec	298.8	66.2	29.3	35.3	17.7	25	744	715.7	18.7	9.5	0	100
Jan 2011	424.8	187.2	67.3	40.9	19.3	75	744	676.8	64.1	3.2	0	100
Feb	258.8	85.2	30	32.4	17.4	41	672	478.5	186.9	6.7	0	100
Mar	398.5	101	39	40.9	19.7	34	744	637.3	38	1.3	67.3	90.4
Apr	448.5	155	37.5	40.5	17.3	34	720	699.7	3.9	16.3	0	100
May	279.5	29.3	3	30.5	20.8	4	565	564.2	0.2	1	0	100

6.4 Operational Time Fraction

The operational time fraction is defined as follows:

$$O = \frac{T_T - T_N - T_U - T_E}{T_T - T_U - T_E} \times 100\%$$

where:

T_T = total time period under consideration
T_N = time during which the turbine is known to be non-operational
T_U = time during which the turbine status is unknown
T_E = time that is excluded in the analysis.

The overall operational time fraction of the combined wind turbine system during the total testing period was 99.0%. The final column of Table 3 shows the operational time fraction per month.

The total test time (T_T) was 3,206.4 hours. The total environmental exposure from the beginning of the test to completion was over 7,539 hours.

The VT10 turbine system experienced one period of non-operational time, or downtime (T_N), in March 2011, which was due to a bad electrical connection in the up-tower slip-ring housing. On 21 March 2011, it was discovered that the turbine was not working properly. On 24 March 2011, inspections found that a wire nut had burned. See Figure 5 for details.

Figure 5. Burned wire nut in generator slip-ring assembly

Source: NREL 22250

The main reasons for excluding time (T_E) in the duration test included:

- Time during power outages that prevented the turbine from running
- Noise or safety and function testing that required the turbine to be shut down
- NWTC-initiated inspections of the VT10.

If no reliable measurements were available, the time was classified as unknown time (T_U) because the turbine's status was unknown. These downtimes occurred primarily when the data acquisition system (DAS) was off (during maintenance or a power outage), or if both of the anemometers were iced.

6.5 Environmental Conditions

During the test period, the highest instantaneous wind speed was 42 m/s during November 2010. The average turbulence intensity at 15 m/s during the test was 18.8%.

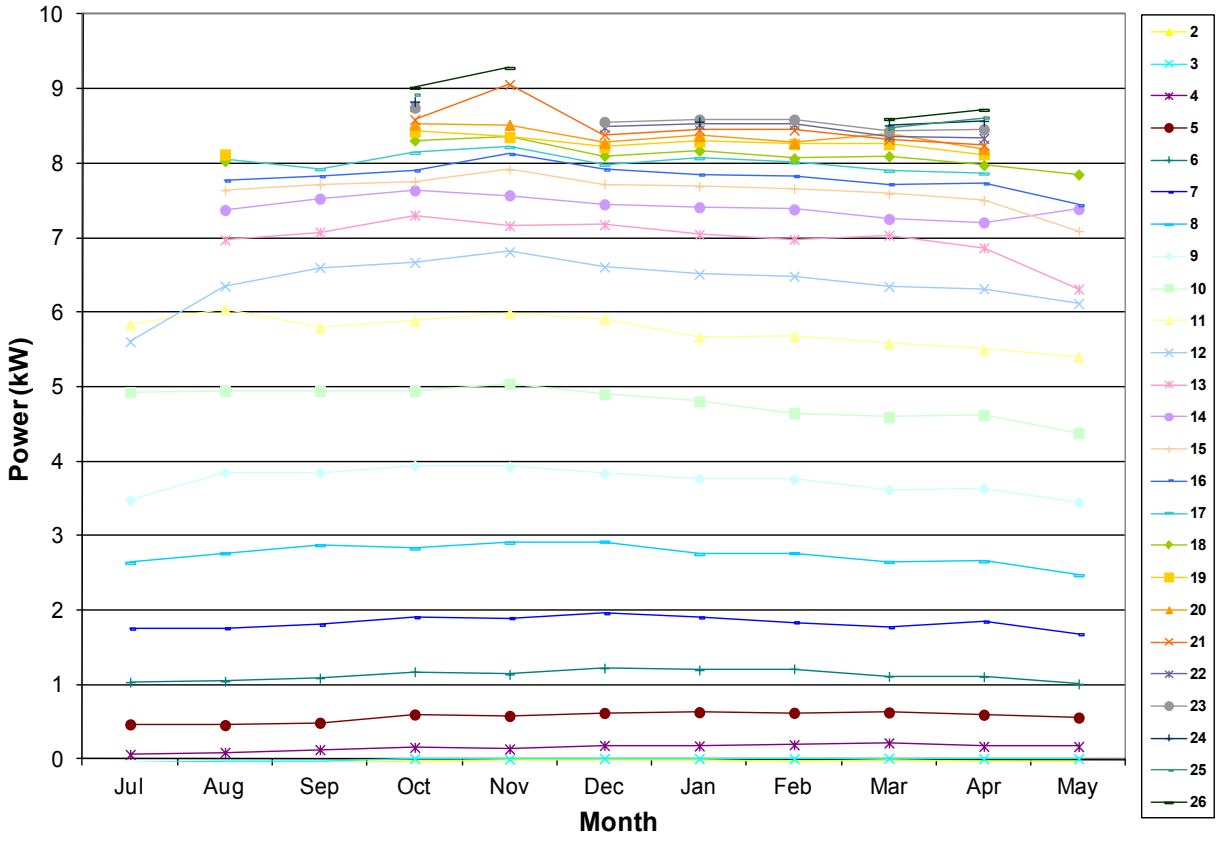


Figure 6. Power in each wind speed bin (m/s) versus time

For the power degradation analysis, the average power level for each wind speed bin was plotted as a function of time over the whole test period. This plot was analyzed for any noticeable trends in power production (shown in Figure 6). There is a slight increase in several bins during the winter months, which corresponds to increased air density. After accounting for seasonal density changes, there did not appear to be a trend of decreased power at any given wind speeds over time.

6.6 Dynamic Behavior

The turbine operation was observed by NWTC personnel for at least 5 minutes at wind speeds of approximately 5 m/s, 10 m/s, 15 m/s, and 20 m/s, for a total observation time of at least 1 hour.

The VT10 requires winds between 5 and 6 m/s to get the rotor spinning, but winds as low as 3 m/s can keep a spinning rotor moving. The turbine at NWTC, when not spinning, could exhibit significant yaw error in winds below 4 m/s, but in winds above 4 m/s, it would orient itself properly in the downwind orientation. It was never observed to operate in the upwind position.

In winds around 10 m/s, the turbine tracked the wind well when compared to the wind vane on the nearby met tower. Some tower vibration was observed, but it was not excessive (accelerations on the VT10 were not measured).

In winds above 13 m/s, the rotor tips would start to pitch. This would dramatically increase the noise, but the turbine continued to track the wind well. There were noticeable vibrations in the tower, especially at the joint between the lattice tower and the 3-m extension tube, where the generator was mounted. These were not deemed excessive.

6.7 Post-Test Inspection

The test was completed on 24 May 2011. The turbine was decommissioned on 13 June 2011. Post-test inspections took place at decommissioning and a more thorough inspection was performed on 16 June 2011. The following post-test inspection observations were made:

- There was no significant accumulation of wear during the test. However, neither the generator nor the blades were disassembled, as their disassembly could be dangerous (strong magnets in the generator and springs with potential energy in the blades), and without proper reassembly, the VT10 would be unusable for a future installation.
- During installation very minor cracks were noticed in the generator's housing, which was a resin cast around the stator coils. These cracks did not appear to expand at all during the test.
- The exterior of the yaw bearings were rusting, but this would not affect performance in any way.
- The nut and bolt positions were marked before the test, and all were still in the same positions at the end of the test.

Figure 7. Rust on the outside of the yaw bearing (circled)

Source: NREL 22254

7. Uncertainty

The uncertainty was estimated for the following parameters:

- Hours of power production
- Operational time fraction
- Environmental conditions.

No uncertainty analysis was done for the power degradation results. These results were used only to find relative trends that might indicate deterioration of the turbine's performance.

7.1 Hours of Power Production

It is assumed that the turbine is producing power for the entire 10-minute period whenever the average power for that period is positive. This method overestimates time for power production in low average wind speed, when the VT10 might only produce for a fraction of the 10-minute period. At higher wind speeds, this method would produce less of an overestimate. If the VT10 was only producing power 25% of the time in average wind speeds below 5 m/s, the total time of power production would be 2,550 hours, which is still in excess of the minimum required by the Standard.

For the hours of power production above 9 m/s and 13.5 m/s, the uncertainty in the wind speed is assumed to be the dominant factor. Assuming an uncertainty in wind speed of 0.3 m/s, the hours of power production reduced to 804.3 (above 9.3 m/s) and 260.8 (above 13.8 m/s), which is still well in excess of the 250 and 25 hours, respectively, that are required.

The analysis tool used at the NWTC does not accurately account for switching from standard to daylight savings time, even though the time stamp on the data does reflect this switch. It is assumed that the net effect on results is negligible, even though its influence can be seen in the values of T_U for November and March.

7.2 Operational Time Fraction

If there was a failure at any time during a 10-minute period, the entire 10-minute period was classified as downtime (T_N). This means that the 99.0% is the lower bound of the operational time fraction.

7.3 Environmental Conditions

The maximum deviation in wind speed measurements for the calibration range was 0.028 m/s, which resulted in a standard uncertainty of 0.02 m/s. The calibration range was only to 16 m/s, and thus an extrapolation to 44 m/s could be unreliable. However, it was assumed that the standard uncertainty of calibration was consistent at 0.02 m/s. Combining the calibration uncertainty with operational characteristics (0.052 m/s + 0.52%), mounting effects (1%), and terrain effects (2%), while assuming that the DAS uncertainty was negligible (for the maximum instantaneous gust of 42 m/s) the uncertainty was 1 m/s.

Standard deviation of wind speed was used for the turbulence intensity (TI) calculation. Average wind speed at 15 m/s has an uncertainty of 0.4 m/s, resulting in a TI estimate of between 18.3% and 19.3%.

8. Deviations and Exceptions

8.1 Deviations from the Standard

As explained in Section 5, Description of Instrumentation:

- The power transducer was not compliant with IEC 60688, but exceeded the minimum accuracy required by the Standard. This should have no effect on results or uncertainty.
- The current transformers were not IEC 60044-1, but exceeded the minimum accuracy required by the Standard. This should have no effect on results or uncertainty.

8.2 Deviations from Quality Assurance

The primary anemometer was used beyond its calibration due date. The anemometer was post-test calibrated and found to have held its calibrations for the test period. Appendix A includes the post-test calibration sheets.

The wind vane was damaged and repaired during the test. It was also used beyond its calibration due date. In situ comparisons with other NWTC test sites showed that the vane held its performance throughout the test.

The DAS modules were used beyond the calibration due date. They were post-test calibrated and found to be in compliance with the specifications. Appendix A includes the post-test calibration sheets.

A. Appendix - Equipment Calibration Sheets

A.1. Primary anemometer pre-test calibration sheet; installed on 21 January 2010, and used until the end of the test

A.2. Primary anemometer post-test calibration sheet

A.3. Primary anemometer pre- and post-test calibration comparison; the difference was less than 0.1 m/s for the range of 6 m/s to 12 m/s

A.4. Power transducer calibration sheet; installed 28 September 2010, and used until the end of the test

A.5. Wind vane calibration sheet; installed 18 February 2010 and used for the entire test

A.6. RTD probe calibration sheet; installed 17 August 2010 and used until the end of the test

A.7. Pressure transducer calibration sheet; installed 17 August 2010 and used until the end of the test

A.8. NI 9229 data acquisition module calibration; installed 26 July 2010 and used until the end of the test

A.9. NI 9229 data acquisition module post-test calibration; in tolerance

A.10. NI 9217 data acquisition module calibration; installed 26 July 2010 and used until the end of the test

A.11. NI 9217 data acquisition module post-test calibration; in tolerance

A.12. NI 9205 data acquisition module calibration; installed 26 July 2010 and used until the end of the test

A.13. NI 9205 data acquisition module post-test calibration; in tolerance

Svend Ole Hansen ApS
SCT. JORGENS ALLÉ 7 · DK-1615 KOBENHAVN V · DENMARK
TEL: (+45) 33 25 38 38 · FAX: (+45) 33 25 38 39 · WWW.SOHANSEN.DK
WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 09.02.3147 **Date of issue:** June 15, 2009

Type: Thies 4.3351.10.000 **Serial number:** 0609009

Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany

Client: Sky Power Int'l LLC, 250 Sawdust Road, 29657-8521 Liberty SC, USA

Anemometer received: June 11, 2009 **Anemometer calibrated:** June 12, 2009

Calibrated by: mh **Calibration procedure:** IEC 61400-12-1, MEASNET

Certificate prepared and approved by: Calibration engineer, soh

Calibration equation obtained: v [m/s] = 0.04636 · f [Hz] + 0.22372

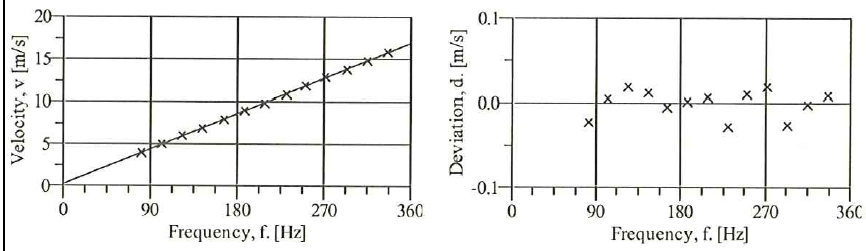
Standard uncertainty, slope: 0.00127 **Standard uncertainty, offset:** 0.05862

Covariance: -0.0000007 (m/s)²/Hz **Coefficient of correlation:** ρ = 0.999991

Absolute maximum deviation: -0.028 m/s at 10.883 m/s

Barometric pressure: 1004.2 hPa **Relative humidity:** 24.1%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.07	32.0	23.8	3.986	81.6316	-0.022	0.029
4	13.93	31.9	23.7	4.939	101.6035	0.004	0.033
6	20.26	31.8	23.7	5.955	123.2072	0.020	0.038
8	27.48	31.7	23.7	6.935	144.5096	0.012	0.044
10	35.79	31.6	23.7	7.914	165.9949	-0.006	0.049
12	45.23	31.5	23.7	8.895	187.0034	0.002	0.055
13-last	56.18	31.5	23.7	9.913	208.8310	0.007	0.061
11	67.70	31.5	23.7	10.883	230.5182	-0.028	0.067
9	80.29	31.6	23.7	11.853	250.5970	0.011	0.073
7	94.49	31.7	23.7	12.860	272.1574	0.019	0.080
5	109.40	31.8	23.7	13.840	294.2530	-0.026	0.086
3	125.69	31.9	23.8	14.838	315.2489	-0.001	0.092
1-first	143.07	32.2	23.8	15.838	336.5955	0.009	0.099



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CAL Reg.nr. 452
Accreditation to ISO 17025

Page 1 of 2

Figure A.1. Primary anemometer pre-test calibration sheet; installed on 21 January 2010 and used until the end of the test

Svend Ole Hansen ApS
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WIND ENGINEERING FLUID DYNAMICS

CERTIFICATE FOR CALIBRATION OF CUP ANEMOMETER

Certificate number: 11.02.4877 **Date of issue:** July 18, 2011

Type: Thies 4.3351.10.000 **Serial number:** 0609009

Manufacturer: ADOLF THIES GmbH & Co.KG, Hauptstrasse 76, 37083 Göttingen, Germany

Client: National Renewable Energy Lab, 1617 Cole Boulevard, Golden, Colorado 80401-3393, USA

Anemometer received: June 30, 2011 **Anemometer calibrated:** July 17, 2011

Calibrated by: cn **Calibration procedure:** IEC 61400-12-1, MEASNET

Certificate prepared by: jsa **Approved by:** Calibration engineer, soh

Calibration equation obtained: v [m/s] = 0.04670 · f [Hz] + 0.15965

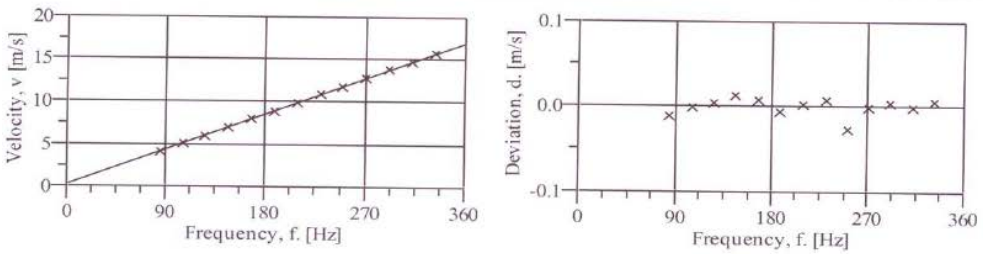
Standard uncertainty, slope: 0.00081 **Standard uncertainty, offset:** 0.05257

Covariance: -0.0000003 (m/s)²/Hz **Coefficient of correlation:** $\rho = 0.999996$

Absolute maximum deviation: -0.026 m/s at 11.811 m/s

Barometric pressure: 998.7 hPa **Relative humidity:** 32.0%

Succession	Velocity pressure, q. [Pa]	Temperature in wind tunnel [°C]	Temperature in control room [°C]	Wind velocity, v. [m/s]	Frequency, f. [Hz]	Deviation, d. [m/s]	Uncertainty u_c (k=2) [m/s]
2	9.49	34.2	26.7	4.108	84.7680	-0.011	0.028
4	14.54	34.1	26.6	5.086	105.4851	-0.001	0.032
6	20.53	34.0	26.6	6.041	125.8334	0.005	0.037
8	27.57	33.9	26.6	6.999	146.1792	0.012	0.042
10	35.85	33.8	26.6	7.981	167.2917	0.008	0.047
12	45.14	33.8	26.6	8.954	188.4300	-0.006	0.053
13-last	55.37	33.7	26.6	9.917	208.8464	0.003	0.058
11	67.02	33.8	26.6	10.911	230.0220	0.008	0.064
9	78.51	33.9	26.6	11.811	250.0281	-0.026	0.069
7	92.42	34.0	26.6	12.816	271.0172	-0.001	0.075
5	106.62	34.0	26.6	13.768	291.2600	0.005	0.080
3	122.30	34.1	26.7	14.748	312.3682	-0.001	0.086
1-first	138.51	34.3	26.7	15.698	332.5736	0.006	0.092



ilac-MRA DANAK CAL Reg.nr. 452 Accreditation to ISO 17025 measnet

CHECKED

Figure A.2. Primary anemometer post-test calibration sheet

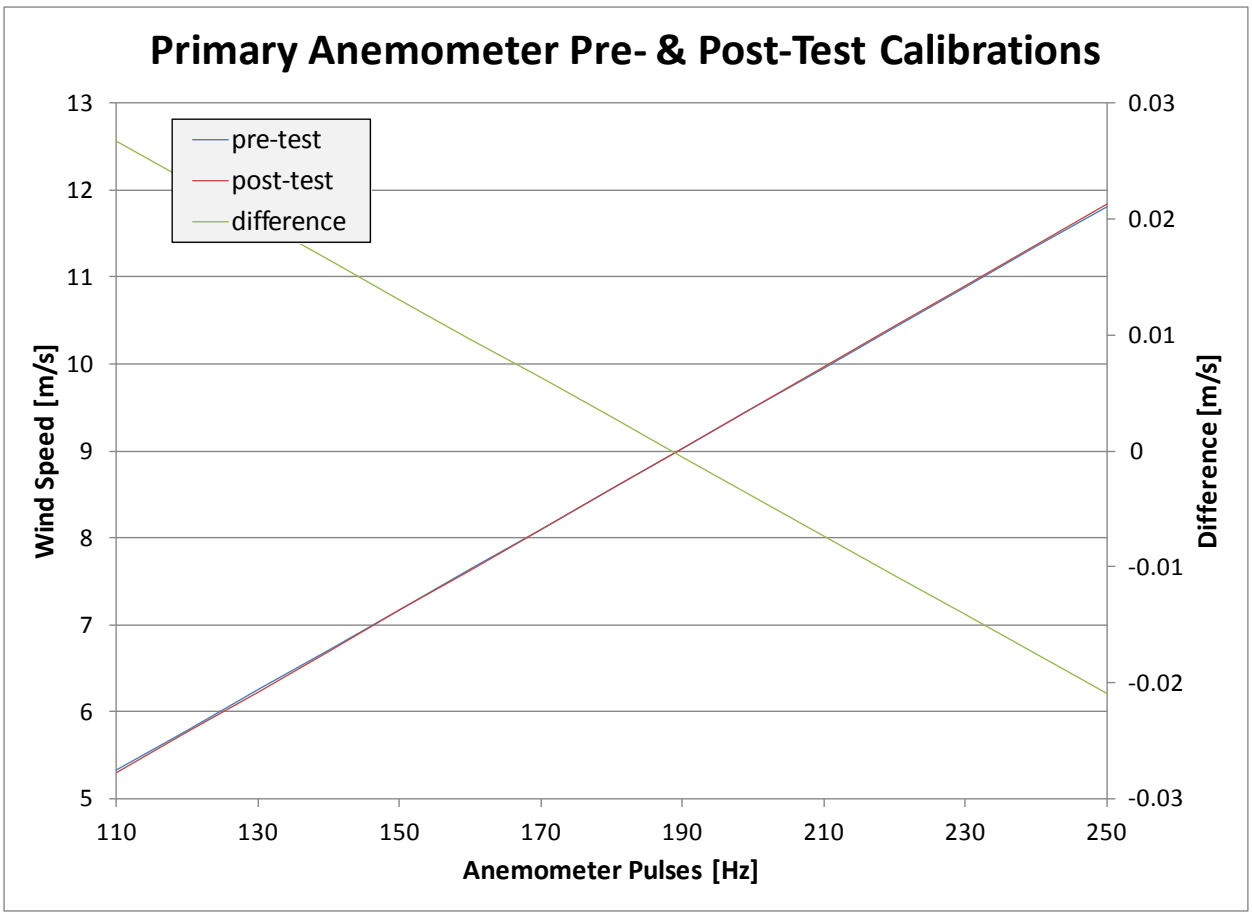


Figure A.3. Primary anemometer pre- and post-test calibration comparison; the difference was less than 0.1 m/s for the range of 6 m/s to 12 m/s

Branch #: 5000

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Phaser Power Transducer & 2-CTs DOE #: 02825C

Model # : Phaser-5-4A 20 S/N : 02061

Calibration Date: 09/22/2010 Due Date: 09/22/2012

A. Set-Up for Total Real Power Calibration:
A.1. Voltage is applied between phases A&B and N = 120 V @ 60 Hz.
A.2. Current is applied to n = 2 TURNS through the two current transformer that are connected to phases A&B. Please note that the number of turns are not included in calculating the input power.
A.3. Analog Output-1 is measured across precision resistor = 250 Ω.
A.4. Phaser Full Scale setting = -18 KW to 18 KW.

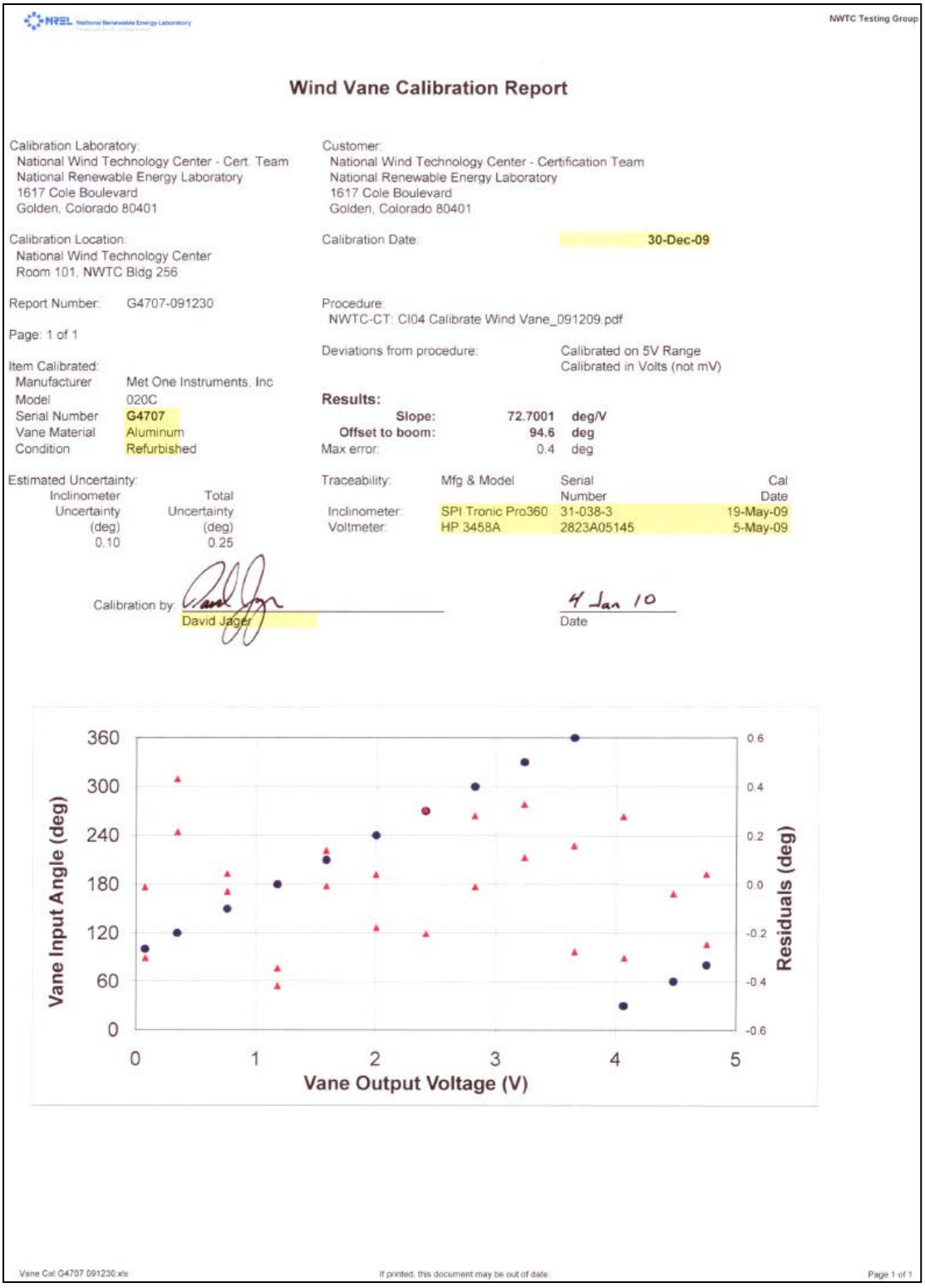
Input Current (AAC)	Input Power (KW)	Analog Output-1 (VDC)
75	18	4.991
50	12	4.325
25	6	3.658
0	0	2.996
-25	-6	2.331
-50	-12	1.667
-75	-18	1.002

B. Set-Up for Power Factor Calibration:
B.1. Voltage & Current are applied as A.1 & A.2.
B.2. Analog Output-2 is measured across precision resistor = 250 Ω.

Power (KW)	Power Factor	Analog Output-2 (VDC)
18	1.0	4.988
"	0.8	4.172
"	0.6	3.370
"	0.4	2.567

Page 1 of 2

Figure A.4. Power transducer calibration sheet; installed 28 September 2010 and used until the end of the test



NWTC Testing Group

Wind Vane Calibration Report

Calibration Laboratory:
National Wind Technology Center - Cert. Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Customer:
National Wind Technology Center - Certification Team
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Calibration Location:
National Wind Technology Center
Room 101, NWTC Bldg 256

Calibration Date: 30-Dec-09

Report Number: G4707-091230

Procedure:
NWTC-CT: CI04 Calibrate Wind Vane_091209.pdf

Page: 1 of 1

Deviations from procedure:
Calibrated on 5V Range
Calibrated in Volts (not mV)

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	020C
Serial Number	G4707
Vane Material	Aluminum
Condition	Refurbished

Results:

Slope:	**72.7001**	**deg/V**
Offset to boom:	**94.6**	**deg**
Max error:	0.4	deg

Estimated Uncertainty:

Inclinometer Uncertainty (deg)	Total Uncertainty (deg)
0.10	0.25

Traceability:

	Mfg & Model	Serial Number	Cal Date
Inclinometer:	SPI Tronic Pro360	31-038-3	19-May-09
Voltmeter:	HP 3458A	2823A05145	5-May-09

Calibration by: David Jager

Date: 4 Jan 10

Vane Cal G4707 091230.xls

If printed, this document may be out of date

Page 1 of 1

Figure A.5. Wind vane calibration sheet; installed 18 February 2010 and used for the entire test

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD DOE #: 03465C

Model # : T200A S/N : 0603-1

Calibration Date: 08/13/2010 Due Date: 08/13/2011

No	Function Tested	Nominal Value (°C)	Measured Values (Ω)		( )Mfr. Specs. OR (X)Data only
			AS Found	AS Left	
*	Temperature:	-10	96.113	Same	
		0	100.035	"	
		10	103.938	"	
		20	107.840	"	
		30	111.721	"	
	Notes: - Calibration was performed using instruments that are traceable to NIST. DOE#s 124272, 108603, and 108604. - Calibration was performed at temperature = 24 °C, and relative humidity = 40%. - Uncertainty of nominal values = ± 0.03 °C with k = 2.				

Tested By: P. Morse Q.A by: Bev

Date : 08/13/2010 Date : 08/13/2011

Figure A.6. RTD probe calibration sheet; installed 17 August 2010 and used until the end of the test

Branch #: 5000 sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Pressure Transmitter DOE #: 03510C

Model # : PTB101B S/N : C1040014

Calibration Date: 08/10/2010 Due Date: 08/10/2011

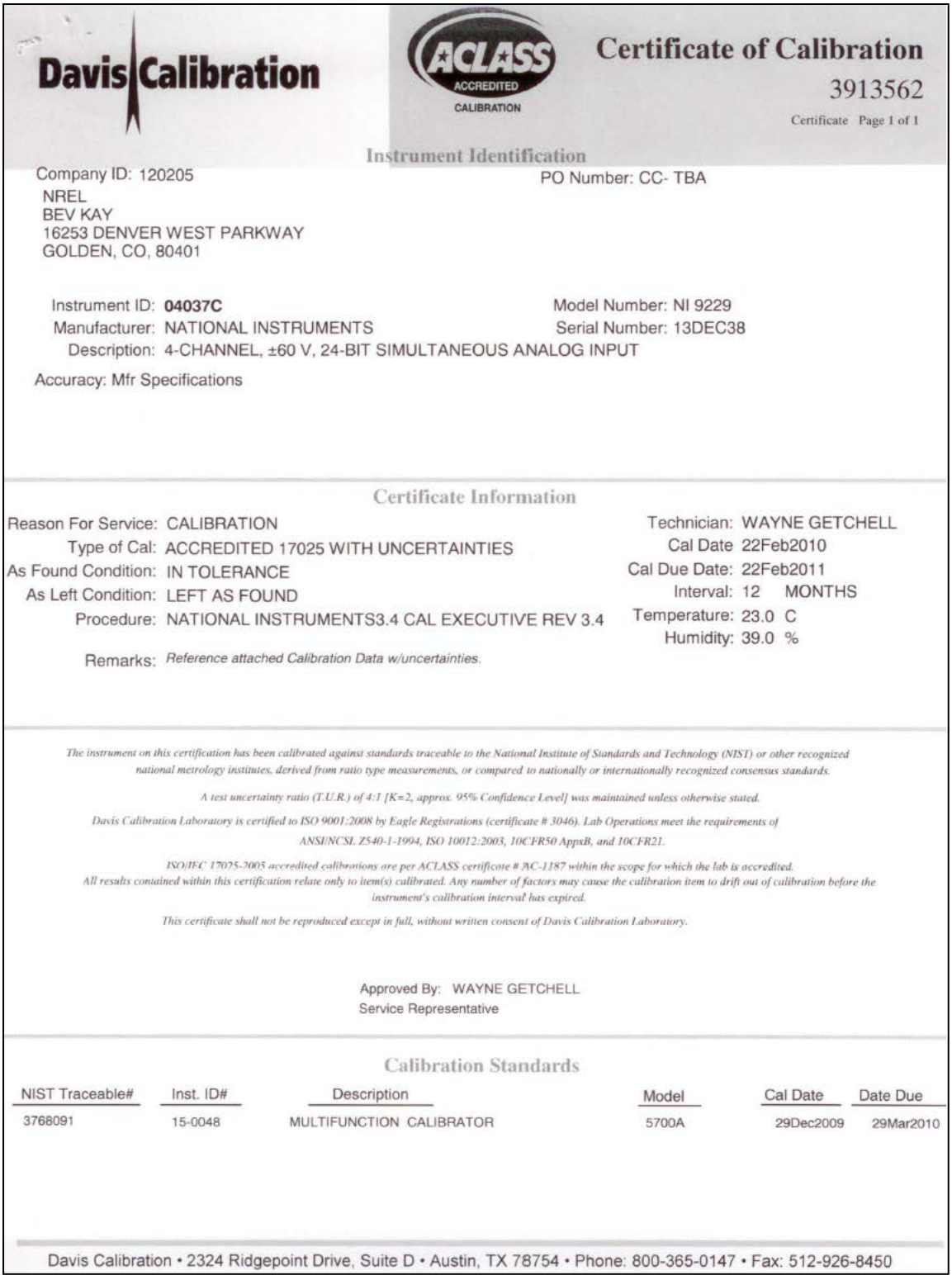
No	Function Tested	Nominal Value (kPa)	Measured Output Voltage (VDC)		( )Mfr. Specs. OR (X)Data only (mb)
			As Found	As Left	
*	Absolute Pressure				
		65	0.270		
		70	0.543		
		75	0.815		
		80	1.087		
		85	1.358		
		90	1.629		
		95	1.901		
		100	2.173		

Notes:
1. Expanded Uncertainty of the nominal value is ± 0.2 kPa, with k = 2.
2. Calibration was performed at 23°C and 40% RH.
3. Calibration was performed using standards that are traceable to NIST. DOE Numbers: 128120, 108685, and 02301C.

Calibrated By: P. Morse
Date: 08/10/2010

QA By: Bev
Date: 08/10/2010

Figure A.7. Pressure transducer calibration sheet; installed 17 August 2010 and used until the end of the test



Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3913562

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NREL
BEV KAY
16253 DENVER WEST PARKWAY
GOLDEN, CO, 80401

PO Number: CC- TBA

Instrument ID: **04037C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT

Model Number: NI 9229
Serial Number: 13DEC38

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS3.4 CAL EXECUTIVE REV 3.4
Remarks: *Reference attached Calibration Data w/uncertainties.*

Technician: WAYNE GETCHELL
Cal Date 22Feb2010
Cal Due Date: 22Feb2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 9001:2008 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited. All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.

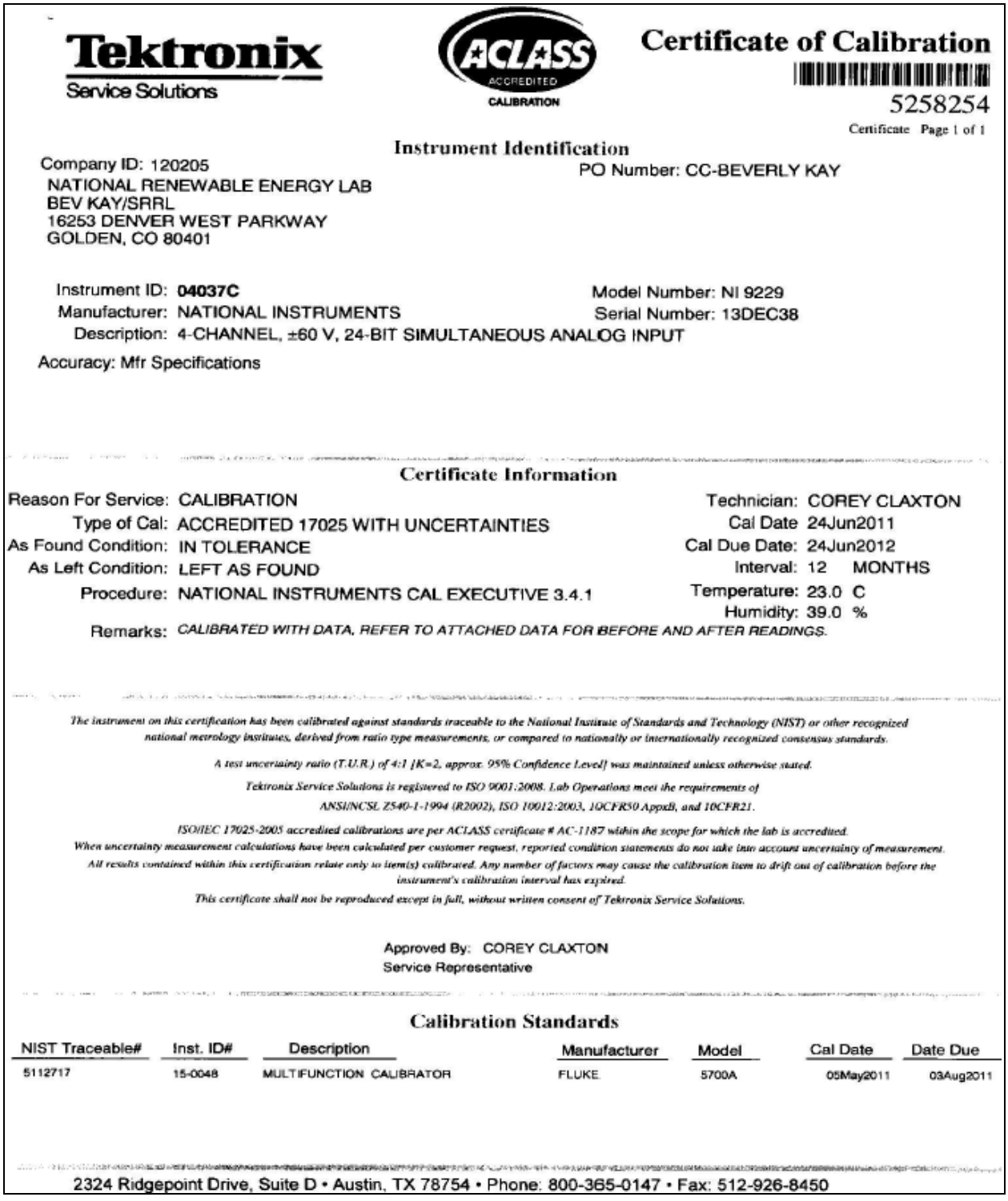
Approved By: WAYNE GETCHELL
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3768091	15-0048	MULTIFUNCTION CALIBRATOR	5700A	29Dec2009	29Mar2010

Davis Calibration • 2324 Ridgepoint Drive, Suite D • Austin, TX 78754 • Phone: 800-365-0147 • Fax: 512-926-8450

Figure A.8. NI 9229 data acquisition module calibration; installed 26 July 2010 and used until the end of the test



Tektronix
Service Solutions

ACCREDITED CALIBRATION

Certificate of Calibration

5258254

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NATIONAL RENEWABLE ENERGY LAB
BEV KAY/SRRL
16253 DENVER WEST PARKWAY
GOLDEN, CO 80401

PO Number: CC-BEVERLY KAY

Instrument ID: **04037C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CHANNEL, ±60 V, 24-BIT SIMULTANEOUS ANALOG INPUT
Model Number: NI 9229
Serial Number: 13DEC38
Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE 3.4.1
Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

Technician: COREY CLAXTON
Cal Date 24Jun2011
Cal Due Date: 24Jun2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 AppB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

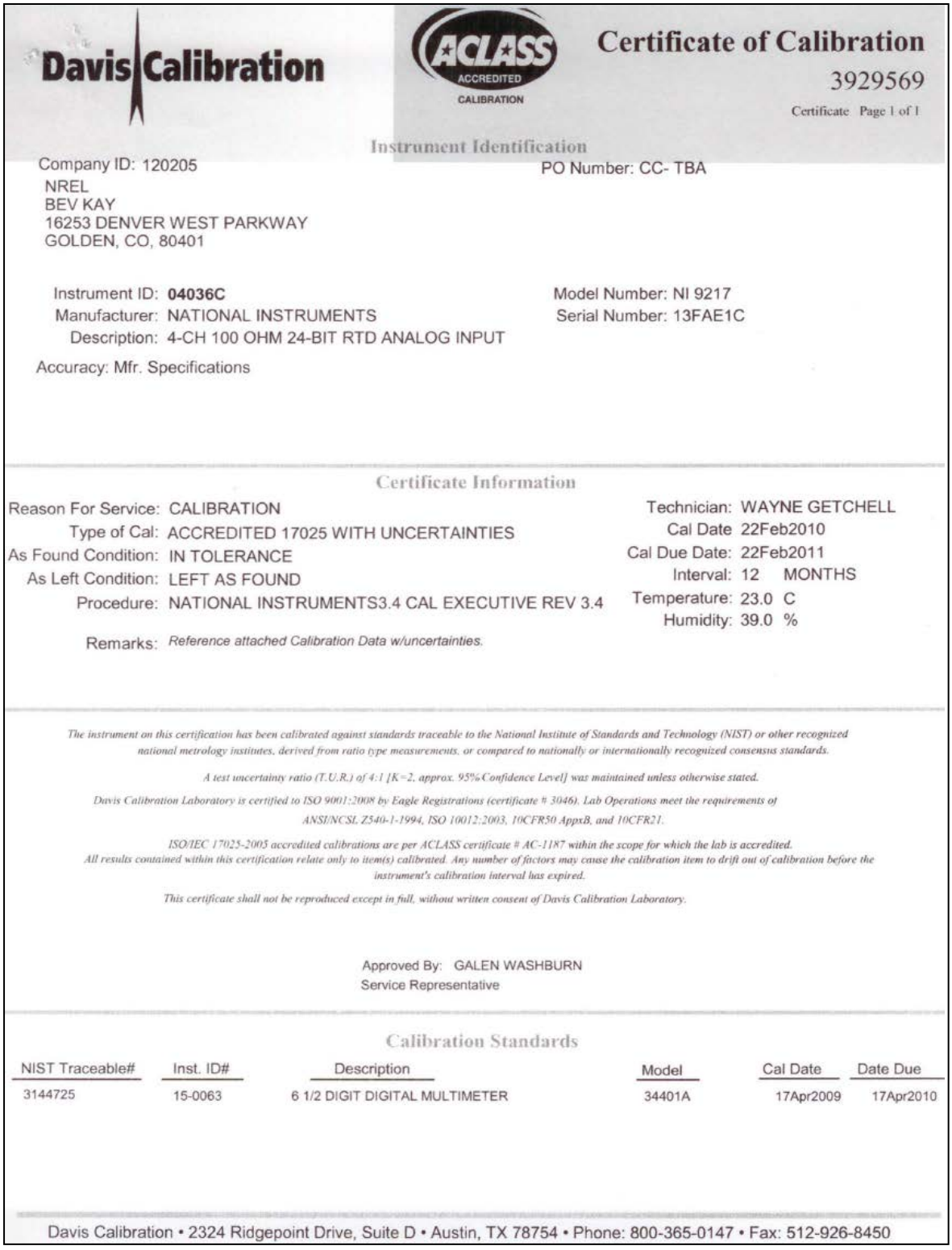
Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Manufacturer	Model	Cal Date	Date Due
5112717	15-0048	MULTIFUNCTION CALIBRATOR	FLUKE	5700A	05May2011	03Aug2011

2324 Ridgepoint Drive, Suite D • Austin, TX 78754 • Phone: 800-365-0147 • Fax: 512-926-8450

Figure A.9. NI 9229 data acquisition module post-test calibration; in tolerance



Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3929569

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NREL
BEV KAY
16253 DENVER WEST PARKWAY
GOLDEN, CO, 80401

PO Number: CC- TBA

Instrument ID: **04036C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT

Model Number: NI 9217
Serial Number: 13FAE1C

Accuracy: Mfr. Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS3.4 CAL EXECUTIVE REV 3.4

Technician: WAYNE GETCHELL
Cal Date 22Feb2010
Cal Due Date: 22Feb2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

Remarks: *Reference attached Calibration Data w/uncertainties.*

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 9001:2008 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited. All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.

Approved By: GALEN WASHBURN
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3144725	15-0063	6 1/2 DIGIT DIGITAL MULTIMETER	34401A	17Apr2009	17Apr2010

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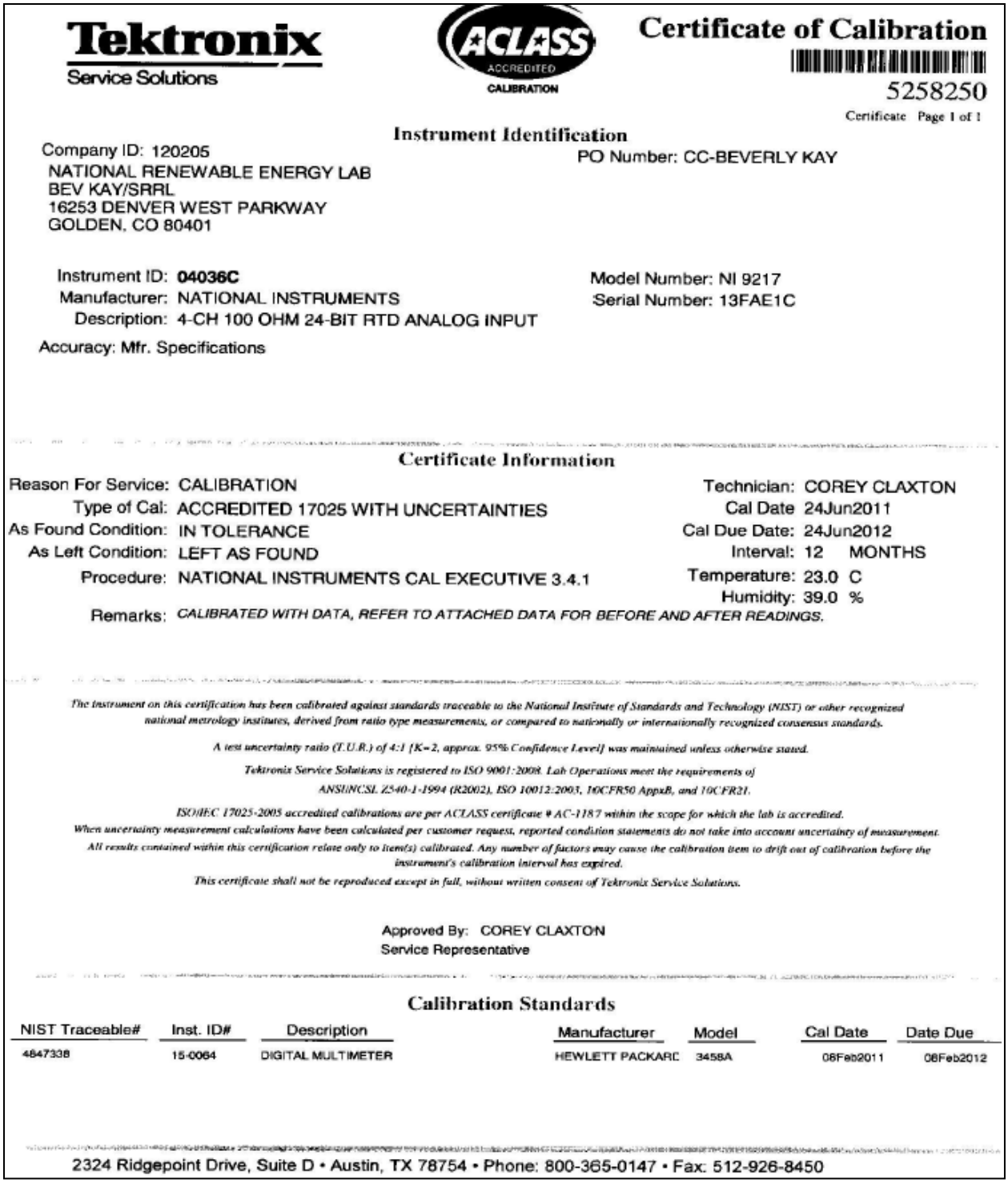
Figure A.10. NI 9217 data acquisition module calibration; installed 26 July 2010 and used until the end of the test



Tektronix
Service Solutions

ACCLASS ACCREDITED CALIBRATION

Certificate of Calibration

5258250

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NATIONAL RENEWABLE ENERGY LAB
BEV KAY/SRRL
16253 DENVER WEST PARKWAY
GOLDEN, CO 80401

PO Number: CC-BEVERLY KAY

Instrument ID: **04036C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 4-CH 100 OHM 24-BIT RTD ANALOG INPUT
Accuracy: Mfr. Specifications

Model Number: NI 9217
Serial Number: 13FAE1C

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE 3.4.1
Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

Technician: COREY CLAXTON
Cal Date 24Jun2011
Cal Due Date: 24Jun2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.
When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.
All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.
This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

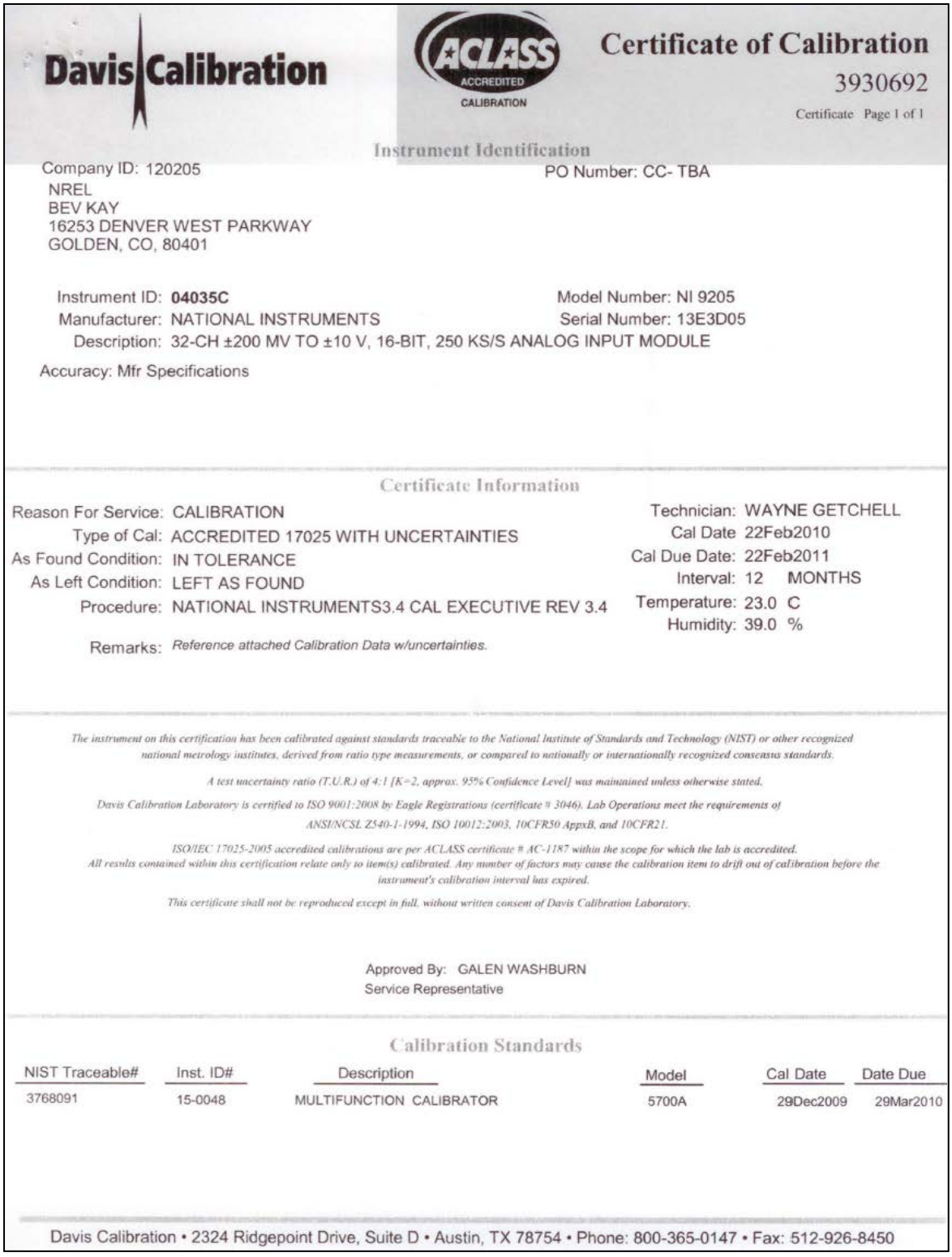
Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Manufacturer	Model	Cal Date	Date Due
4847338	15-0064	DIGITAL MULTIMETER	HEWLETT PACKARD	3458A	08Feb2011	08Feb2012

2324 Ridgepoint Drive, Suite D • Austin, TX 78754 • Phone: 800-365-0147 • Fax: 512-926-8450

Figure A.11. NI 9217 data acquisition module post-test calibration; in tolerance



Davis Calibration

ACCREDITED CALIBRATION

Certificate of Calibration

3930692

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NREL
BEV KAY
16253 DENVER WEST PARKWAY
GOLDEN, CO, 80401

PO Number: CC- TBA

Instrument ID: **04035C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE

Model Number: NI 9205
Serial Number: 13E3D05

Accuracy: Mfr Specifications

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS3.4 CAL EXECUTIVE REV 3.4

Remarks: *Reference attached Calibration Data w/uncertainties.*

Technician: WAYNE GETCHELL
Cal Date 22Feb2010
Cal Due Date: 22Feb2011
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Davis Calibration Laboratory is certified to ISO 9001:2008 by Eagle Registrations (certificate # 3046). Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994, ISO 10012:2003, 10CFR50 AppxB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited. All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Davis Calibration Laboratory.

Approved By: GALEN WASHBURN
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Model	Cal Date	Date Due
3768091	15-0048	MULTIFUNCTION CALIBRATOR	5700A	29Dec2009	29Mar2010

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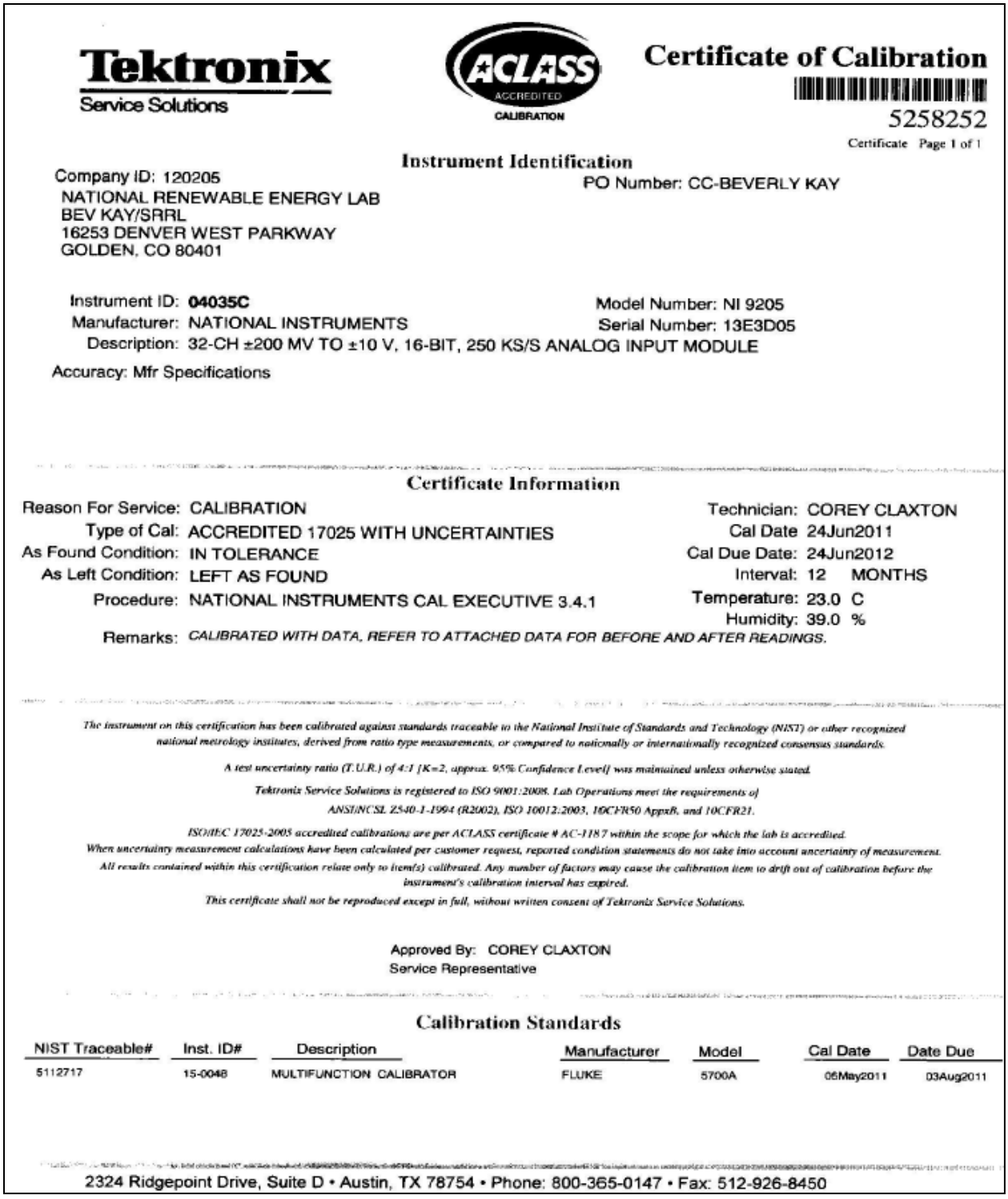
Figure A.12. NI 9205 data acquisition module calibration; installed 26 July 2010 and used until the end of the test



Tektronix
Service Solutions

ACCREDITED
CALIBRATION

Certificate of Calibration

5258252

Certificate Page 1 of 1

Instrument Identification

Company ID: 120205
NATIONAL RENEWABLE ENERGY LAB
BEV KAY/SRRL
16253 DENVER WEST PARKWAY
GOLDEN, CO 80401

PO Number: CC-BEVERLY KAY

Instrument ID: **04035C**
Manufacturer: NATIONAL INSTRUMENTS
Description: 32-CH ±200 MV TO ±10 V, 16-BIT, 250 KS/S ANALOG INPUT MODULE
Accuracy: Mfr Specifications

Model Number: NI 9205
Serial Number: 13E3D05

Certificate Information

Reason For Service: CALIBRATION
Type of Cal: ACCREDITED 17025 WITH UNCERTAINTIES
As Found Condition: IN TOLERANCE
As Left Condition: LEFT AS FOUND
Procedure: NATIONAL INSTRUMENTS CAL EXECUTIVE 3.4.1

Technician: COREY CLAXTON
Cal Date 24Jun2011
Cal Due Date: 24Jun2012
Interval: 12 MONTHS
Temperature: 23.0 C
Humidity: 39.0 %

Remarks: *CALIBRATED WITH DATA, REFER TO ATTACHED DATA FOR BEFORE AND AFTER READINGS.*

The instrument on this certification has been calibrated against standards traceable to the National Institute of Standards and Technology (NIST) or other recognized national metrology institutes, derived from ratio type measurements, or compared to nationally or internationally recognized consensus standards.

A test uncertainty ratio (T.U.R.) of 4:1 [K=2, approx. 95% Confidence Level] was maintained unless otherwise stated.

Tektronix Service Solutions is registered to ISO 9001:2008. Lab Operations meet the requirements of ANSI/NCSL Z540-1-1994 (R2002), ISO 10012:2003, 10CFR50 AppB, and 10CFR21.

ISO/IEC 17025-2005 accredited calibrations are per ACLASS certificate # AC-1187 within the scope for which the lab is accredited.

When uncertainty measurement calculations have been calculated per customer request, reported condition statements do not take into account uncertainty of measurement.

All results contained within this certification relate only to item(s) calibrated. Any number of factors may cause the calibration item to drift out of calibration before the instrument's calibration interval has expired.

This certificate shall not be reproduced except in full, without written consent of Tektronix Service Solutions.

Approved By: COREY CLAXTON
Service Representative

Calibration Standards

NIST Traceable#	Inst. ID#	Description	Manufacturer	Model	Cal Date	Date Due
5112717	15-0048	MULTIFUNCTION CALIBRATOR	FLUKE	5700A	05May2011	03Aug2011

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Figure A.13. NI 9205 data acquisition module post-test calibration; in tolerance