June 2003 NREL/EL-500-34017

Wind Turbine Generator System

Duration Test Report

for the

Atlantic Orient 15/50 Wind Turbine

by

National Wind Technology Center
National Renewable Energy Laboratory
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April 14, 2003

Approval By: 19 may 2003
Jeroen van Dam, NREL Test Engineer Date

Approval By: Hal Link 19/May 2003
Hal Link, NREL Certification Test Manager Date

Approval By: 5/28/03
Sandy Butterfield, NREL Certification QA manager Date

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5.0 Test Objective

The objective of this test is to investigate:

- Structural integrity and material degradation (e.g., cracks, deformations, wear)
- Quality of environmental protection of the Atlantic Orient Corporation (AOC) 15/50 wind turbine (e.g., corrosion, failure of paint or seals).

The wind turbine will have passed the duration test when it has achieved:

- Reliable operation during the test period
- 1,500 hours of power production in winds of any velocity
- 250 hours of power production in winds of 1.2 V_{ave}[1] (10.2 m/s) and above
- 25 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 found during periodic inspections or the final turbine inspection
- No significant degradation in time of produced power at comparable wind speeds.

6.0 Background

This test is being conducted as part of the U.S. DOE's Small Wind Turbine Field Verification Program (FVP). The primary purpose of this program is to provide consumers, manufacturers, and host site organizations with an independent assessment of the performance and reliability of small U.S. wind turbines.

The Atlantic Orient Corporation developed the AOC 15/50 with assistance from the U.S. DOE and NREL. The test turbine, located at the National Wind Technology Center (NWTC), is owned by NREL and serves several functions, including:

- Developing NREL's certification testing capabilities
- Participating in an international round-robin testing program
- Testing wind/diesel hybrid test systems
- Developing improvements to the design of the AOC 15/50 model
- Demonstrating modern wind turbine technology.

The test plan for the duration test is included as Appendix C to this report. In the test plan, more information can be found on:

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[1] Note that V_{ave} is determined by the wind turbine class as specified by IEC 61400-2 2nd edition. The AOC 15/50 is a Class II turbine; Class II has a V_{ave} of 8.5m/s.

- The test turbine
- The test site
- The test equipment
- The analysis method.

7.0 Deviations from Test Plan

The following deviation was made from the test plan:

o The turbine was re-instrumented in the period between December 2000 and February 2001 because the calibration on most instruments expired. A list with instruments present in May 2001 is given below in Table 1. Calibration sheets of these instruments (other than the data logger, serial number 3100) are in Appendix A.

Table 1: List of Equipment Present at the End of Duration Test

Power Transducer and CTs	
Make/Model:	OSI, DWV-008EY01
Serial Number (Transducer/CTs):	00121762/8012365
Range with CTs:	-120 to 120 kW
Calibration Due Date:	13 February 2002
Primary Anemometer (North)	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	U2644
Calibration Due Date:	13 February 2002
Met Tower Location:	Height AGL: 25.0 m (100% of hub height)
Primary Wind Direction Sensor (South)	
Make/Model:	Met One, 020C with Aluminum Vane
Serial Number:	W1496
Calibration Due Date:	20 February 2002
Met Tower Location:	Height AGL: 22.6 m (90.4% of hub height)
Data Logger	
Make/Model:	Campbell Scientific CR23X
Serial Number:	3100
Calibration Due Date:	30 August 2001

8.0 Results

The duration test began on November 22, 1999, and was completed on 20 May 2001; thus the total test period is longer then 6 months.

From 25 May to 10 July, the data acquisition software was set to output 1-second data. The data during this period were not analyzed. In the period between 14 November 2000 and 20 February 2001, the turbine was re-instrumented because most instruments were out of their calibration period. No data are available from this period. This time is classified as Tu ($T_{unknown}$) for the operational time fraction.

In Table 2, the overall results of the duration test are given and the results broken down for each calendar month.

Hours of power production
The hours of power production at any wind speeds: 1550 hours (1500 hours required)
The hours of power production above 1.2*V_{ave} (10.2 m/s): 383 hours (250 hours required)
The hours of power production above 1.8*V_{ave} (15.3 m/s): 97 hours (25 hours required)

In August 2000 and February 2001, the power transducer malfunctioned; thus no hours of power production could be determined.

Table 2: Monthly and Overall Results of the AOC 15/50 Duration Test

AOC 15/50 Duration test	Hours of power production in wind speed above:			Environmental conditions			Operational time fraction [hrs]					Expected energy		
Month	0 m/s	10 m/s	15 m/s	max gust	TI @ 15 m/s	# data points	Tt	Tu	Tn	Te	O [%]	$P_{measured}$	$P_{expected}$	P_{meas}/P_{expect} [%]
Overall	*1550.33*	*382.67*	*97.33*	*43.3*	*17.67*	*240*	*13043*	*3717.0*	*775.3*	*1180.0*	*90.48*	*25455.1*	*25473.8*	99.93
November 1999	27.00	18.67	9.00	0.0	21.48	18	176	0.0	40.8	1.3	76.56	898.1	908.1	98.90
December 1999	166.17	67.67	25.33	0.0	18.18	43	744	0.0	83.3	10.8	88.63	4506.4	3955.6	113.93
January 2000	124.17	42.83	7.17	22.5	18.34	30	744	38.5	232.7	6.8	66.70	2806.9	2573.7	109.06
February 2000	174.00	57.50	13.33	30.5	16.58	39	696	0.0	11.8	107.8	97.99	3734.9	3675.8	101.61
March 2000	105.33	24.17	6.33	36.9	20.55	8	744	0.0	1.8	459.0	99.36	1643.2	2056.3	79.91
April 2000	118.33	30.83	11.17	28.9	17.23	11	720	0.2	10.8	382.7	96.79	1804.8	2158.2	83.63
May 2000	130.67	27.33	7.17	35.9	15.75	15	744	157.8	1.2	0.0	99.80	1774.0	1820.2	97.46
June 2000							720	720.0	0.0	0.0				
July 2000	74.50	3.33	0.50	21.4	21.15	1	744	232.8	26.8	0.5	94.75	545.6	577.6	94.45
August 2000				21.0	17.86	6	744	0.0	0.0	0.2	100.00	0.0	0.0	
September 2000	62.50	12.67	0.33	25.7	16.05	11	720	0.0	3.5	0.3	99.51	1017.6	971.1	104.79
October 2000	112.33	13.17	0.00	18.2			744	0.0	339.8	18.5	53.16	1066.9	963.6	110.72
November 2000	78.33	14.67	2.83	18.6	17.02	14	720	397.8	0.0	3.7	100.00	1144.3	996.7	114.82
December 2000							744	744.0	0.0	0.0				
January 2001							744	744.0	0.0	0.0				
February 2001				20.6			672	522.7	0.2	68.7	99.79	0.0	0.0	
March 2001	129.17	33.33	7.17	32.3	16.20	27	744	145.0	5.7	13.3	99.03	1808.0	1697.5	106.51
April 2001	157.50	23.50	4.33	43.3	18.73	12	720	0.0	12.3	60.0	98.13	1710.1	2043.6	83.68
May 2001	90.33	13.00	2.67	30.3	16.19	5	459	14.2	4.5	46.3	98.87	994.2	1075.9	92.41

Operational time fraction

The operational time fraction was calculated by using the formula in Appendix B:

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

The overall operational time fraction in the total test period was 90.5%. In Figure 1 the operational time fraction is given per month.

Guidance on how to classify data points in the duration test is given in Appendix B. Some details on how time was classified for the AOC is given in the test plan (Appendix A) and below.

The main reasons for turbine downtime (T_N) during the test period were:

- Short circuit in a tip rectifier causing additional short circuits in the rest of the turbine (mainly caused by the lack of fuses, which were not installed in NREL's test turbine but which are installed in the currently sold turbines)
- Short circuit in March 2000
- Broken bolts on the yaw bearing in October 2000.

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

- Problems with slip rings. These were installed by NREL for measurement of rotor signals, and are thus an NREL modification. All downtime related with this modification was counted as $T_{E.}$
- Problems caused by connecting the turbine to the Hybrid Power Test Bed. This was counted as T_E for similar reasons (loss of grid is seen as an external cause of the downtime).
- In case acoustic measurements were taken at a neighboring turbine and the AOC was shut down
- Maintenance of data acquisition hardware
- Starting and stopping the turbine for performing other measurements on the AOC (power quality or loads).

If no reliable measurements were available, the time was classified as T_U. The main causes of T_U were explained at the beginning of this chapter.

The AOC 15/50 is considered as available during non-operating time due to the brake cooling cycle and wind speeds above cut-out wind speed. This is considered normal behavior.

Environmental conditions

As an indication of the environmental conditions during the duration test, the standard asks for reporting of the maximum 3-sec gust and the average turbulence intensity at 15 [m/s]. The 3-sec gust channel was added to the data logger program on January 14, 2000; thus the recorded gust may not be the highest experienced by the turbine during the test. The maximum recorded 3-sec gust was 43.3 m/s at 2:20 AM on April 7, 2001.

The average turbulence intensity at 15 m/s during the duration test was 17.7%.

Power degradation checks

Two different analysis methods were used to find any hidden degradation or faults of the turbine that would be reflected in the power performance.

- **Expected energy:** In this analysis, the measured produced energy is compared to the expected energy for each month. The expected energy is calculated by looking at the measured wind speed and using a power curve to determine the power level that could be expected at that wind speed. For each month, the ratio of the two summed power levels is calculated.
- **Power performance degradation:** A power curve is made for each month. For certain wind speed bins, the average power level in that wind speed bin is plotted as a function of time over the whole test period. All parts of the power curve can be looked at separately, which is an advantage over the expected energy analysis, in which an integration of the whole power curve is performed.

The expected energy calculation results are given in Figure 2. The variations are caused by air density variations and partial upwind operation of the turbine. Because there is no clear trend visible, no hidden defects are expected.

Figure 3 gives the power performance degradation plot, which gives the power level in certain wind speed bins for each month. Variations in the power levels between the months are again caused by air density variations and occasional upwind operation. From these plots, it was concluded that the power production does not show a clearly increasing or decreasing trend in time. Thus there is no reason to expect a hidden fault in the turbine.

The post-test inspection report is included as Appendix B.

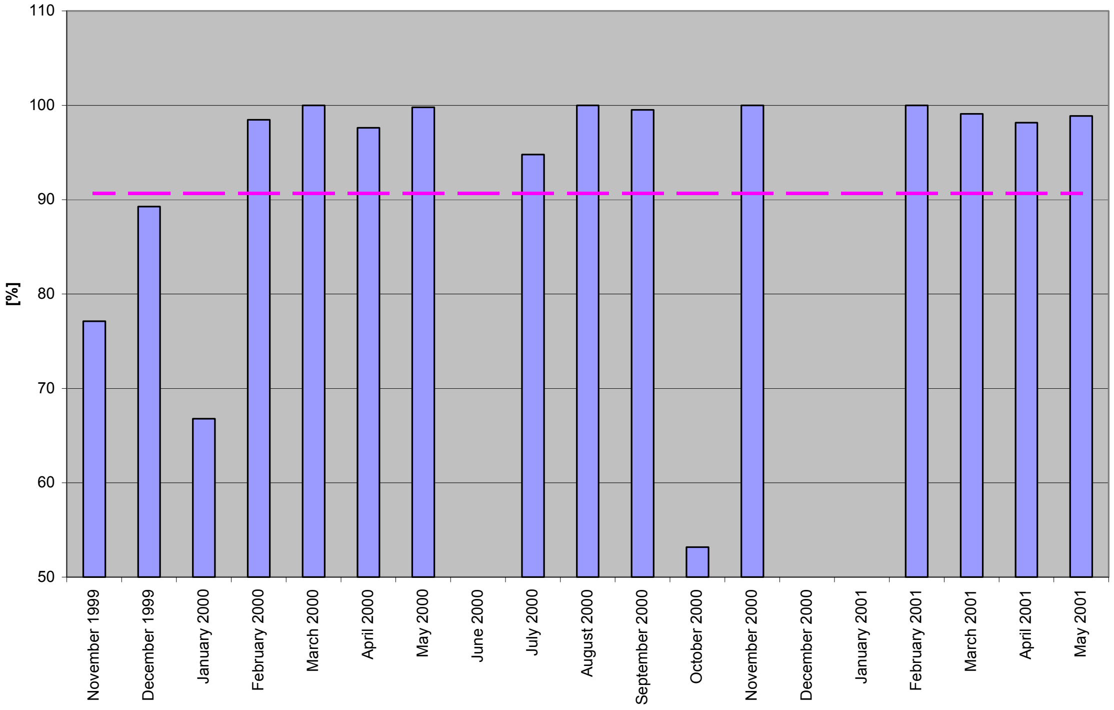


Figure 1: Operational time fraction for each month.

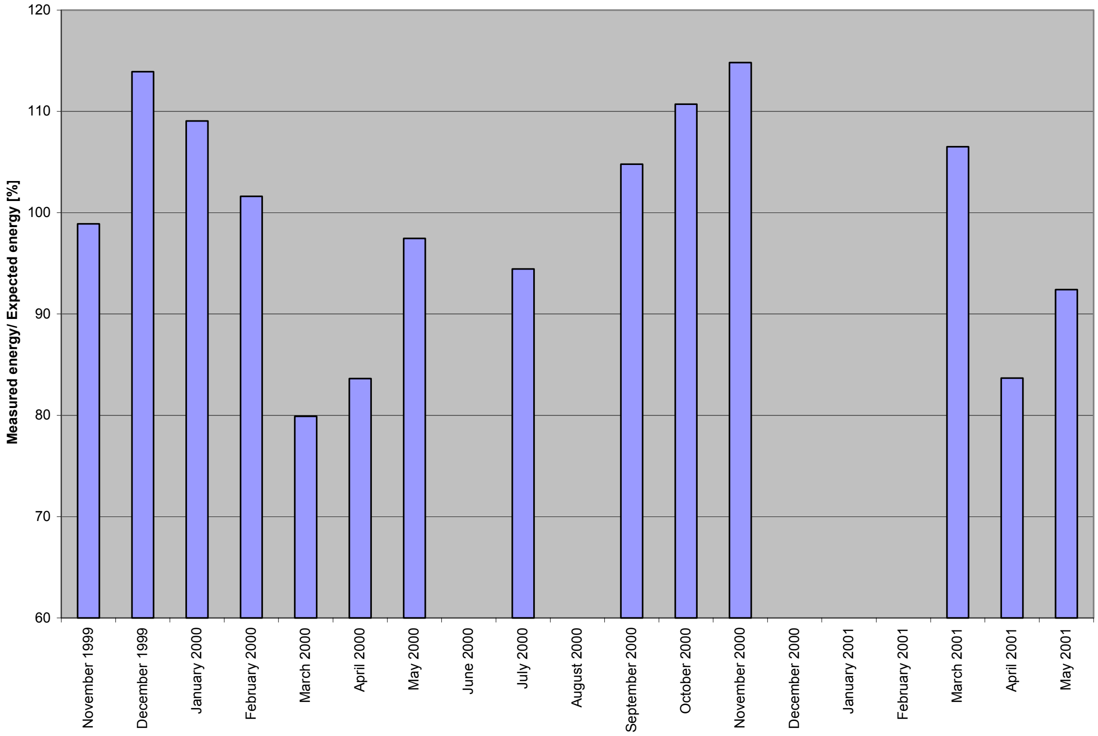


Figure 2: Measured kWh-production as a percentage of the expected power production per month.

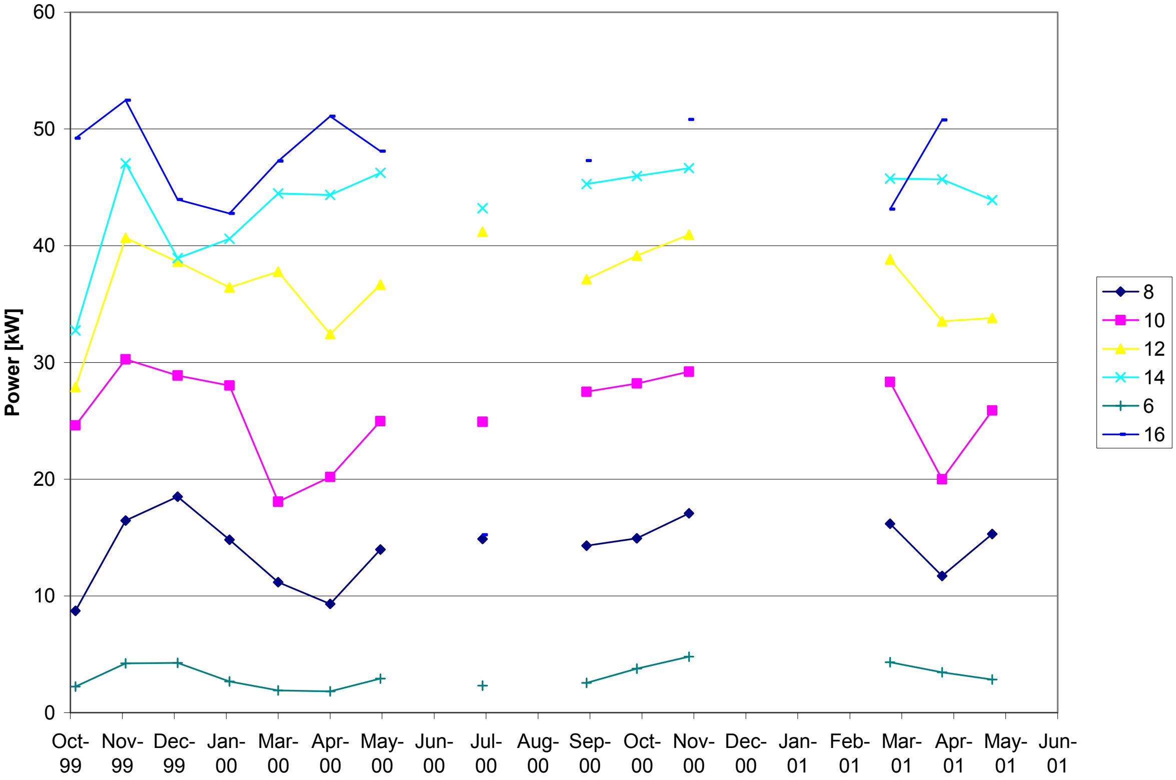


Figure 3: Power level in several wind speed bins as a function of time.

9.0 Uncertainty

The uncertainty is estimated for the following parameters:

- Operational time fraction
- Hours of power production
- 3-sec gust.

No uncertainty analysis was preformed for the expected energy and power degradation results. These results were used only to find relative trends, which might indicate hidden faults in the turbine.

Operational time fraction:
Any data points in which the turbine was unavailable for more then 1% of the 10-minute period were counted against the turbine T_N. This analysis method tends to underestimate operational time fraction. However, the assumption that 5% of the hours classified as T_E and T_N were classified wrong leads to an uncertainty of 0.5%-1% in the operational time fraction.

Hours of power production:
The power signal had a slight negative offset of –0.3 kW. Hours of power production were only counted if the power signal was larger then 0. This takes care of part of the uncertainty in the power signal.

There were 3717 hours of $T_{U.}$ The turbine was likely to be running during some of this time. Because the Tu was spread over the year and thus over the wind season, it is reasonable to assume that the wind was distributed similarly in the unknown time as in the whole test period. This leads to the estimation that during the unknown periods, the AOC produced power at any wind speed during an additional 617 hours—161 hours above 10.2 m/s and 42 hours above 15.3 m/s.

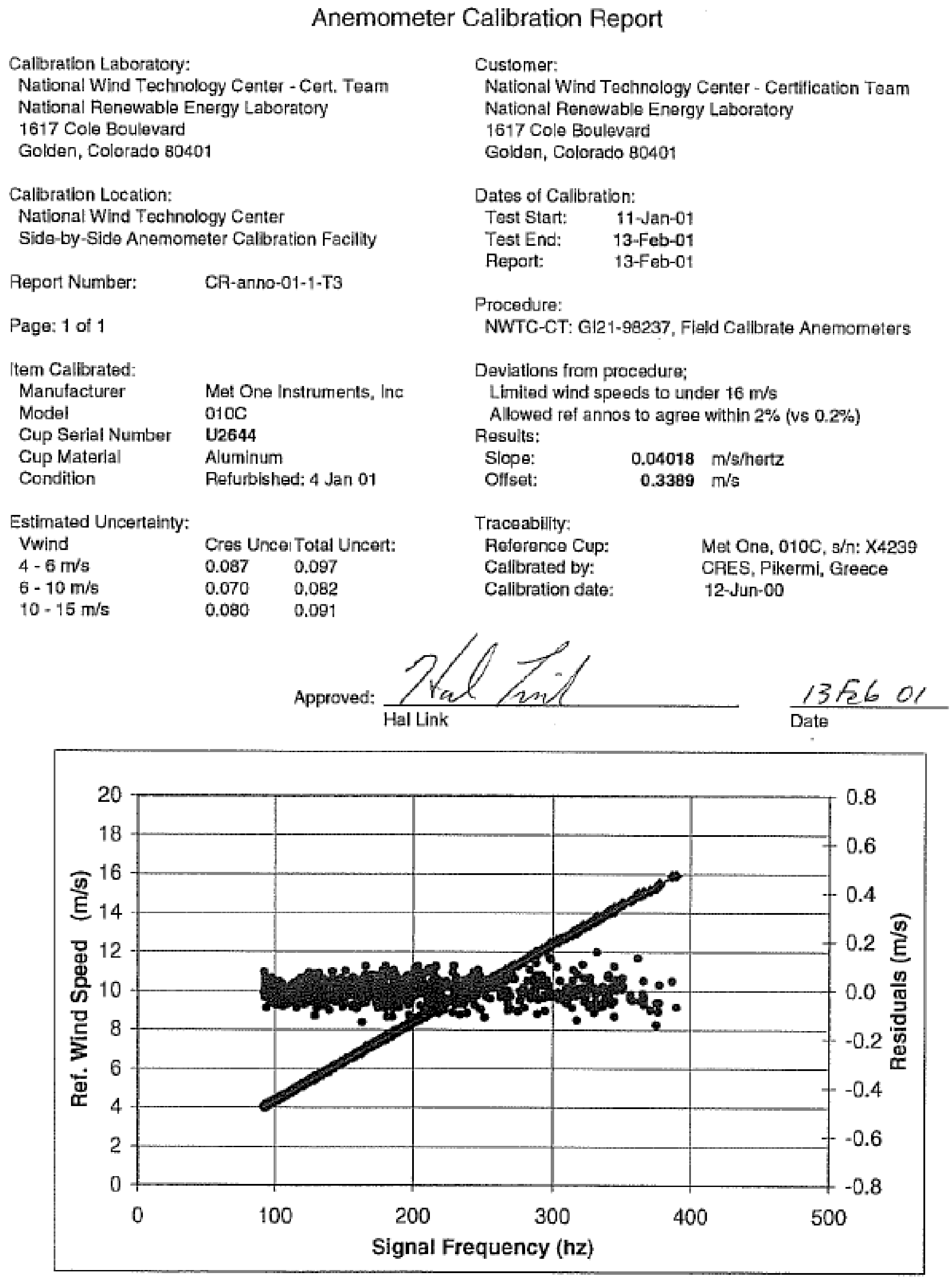
The measurement of operating time in wind above 10.2 and 15.3 m/s is also affected by the possibility that the anemometer was in the wake of the turbine when winds are from the east. Under these conditions, the anemometer will read lower than the free wind speed and may result in the operating time not being counted. However, east winds at the NWTC tend to be of low velocity, and the wake effect lowers measured wind speed by only a few meters per second. Therefore this effect should not have caused an undercount of operating hours of more than one or two hours for each condition.

Finally, site calibration corrections were not applied. In winds from some directions, this effect would lead to measured winds being 1%-2% lower than what the turbine really feels. These effects combine to undercount the hours of power production in winds over 10.2 and 15.3 m/s by as much as 180 and 55 hours, respectively.

3-sec gust:
The uncertainties in the wind speed measurements are 0.2 m/s calibration uncertainty, 2% operational characteristics, 0.5% mounting effects, and 3% terrain effects. For the peak recorded 3-sec gust of 43.3 m/s, the uncertainty is 1.6 m/s.

Appendix A: Calibration Sheets

Anemometer U2644



Anemometer 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
Side-by-Side Anemometer Calibration Facility

Dates of Calibration:
Test Start: 11-Jan-01
Test End: 13-Feb-01
Report: 13-Feb-01

Report Number: CR-anno-01-1-T3

Procedure:
NWTC-CT: GI21-98237, Field Calibrate Anemometers

Page: 1 of 1

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**U2644**
Cup Material	Aluminum
Condition	Refurbished: 4 Jan 01

Deviations from procedure;
Limited wind speeds to under 16 m/s
Allowed ref annos to agree within 2% (vs 0.2%)

Results:
Slope: **0.04018** m/s/hertz
Offset: **0.3389** m/s

Estimated Uncertainty:

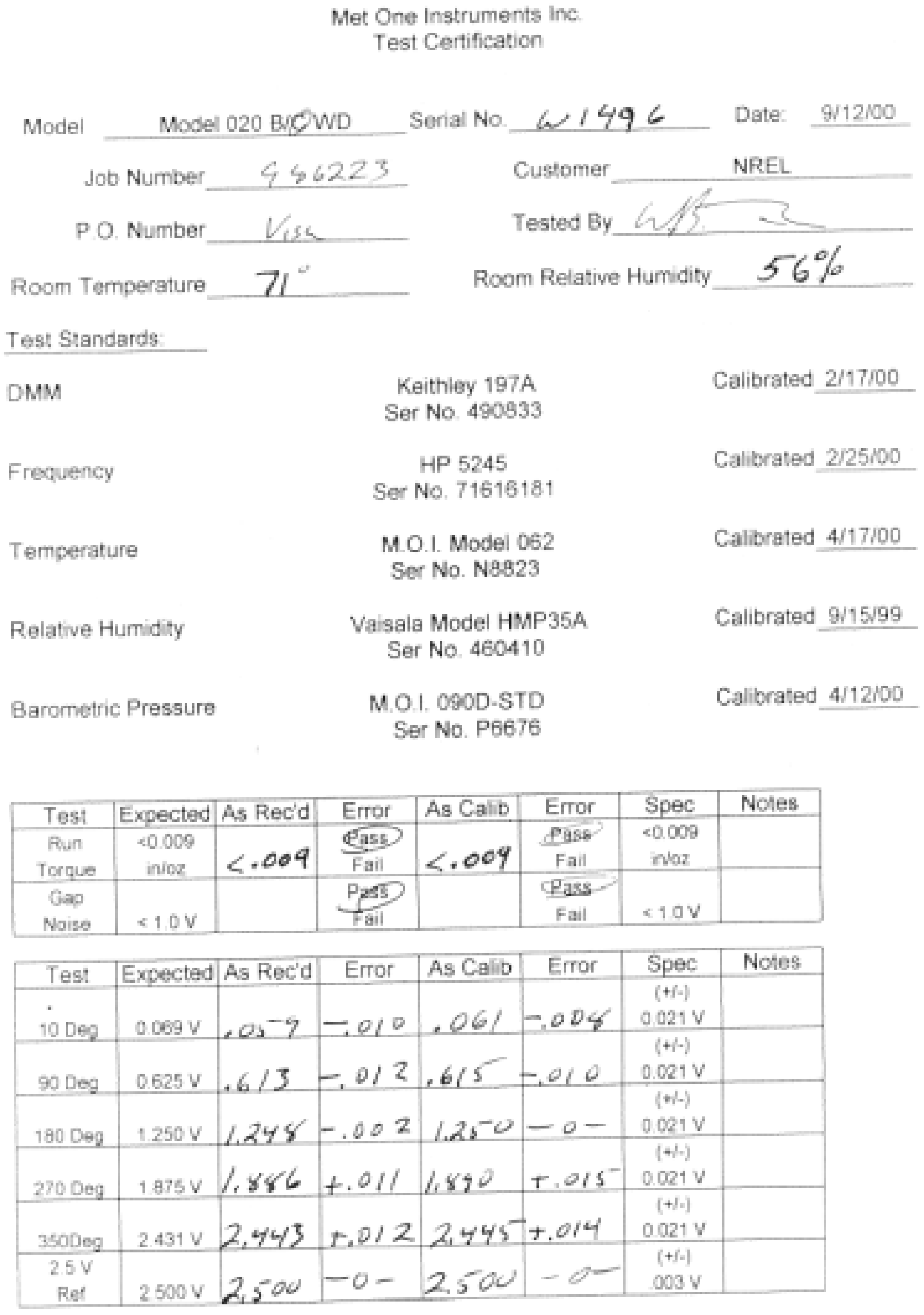
Vwind	Cres Uncei	Total Uncert:
4 - 6 m/s	0.087	0.097
6 - 10 m/s	0.070	0.082
10 - 15 m/s	0.080	0.091

Traceability:
Reference Cup: Met One, 010C, s/n: X4239
Calibrated by: CRES, Pikermi, Greece
Calibration date: 12-Jun-00

Approved: Hal Link
Hal Link

13 Feb 01
Date

Wind Vane W1496



Met One Instruments Inc.
Test Certification

Model Model 020 B/C WD Serial No. W1496 Date: 9/12/00

Job Number 946223 Customer NREL

P.O. Number Visa Tested By

Room Temperature 71° Room Relative Humidity 56%

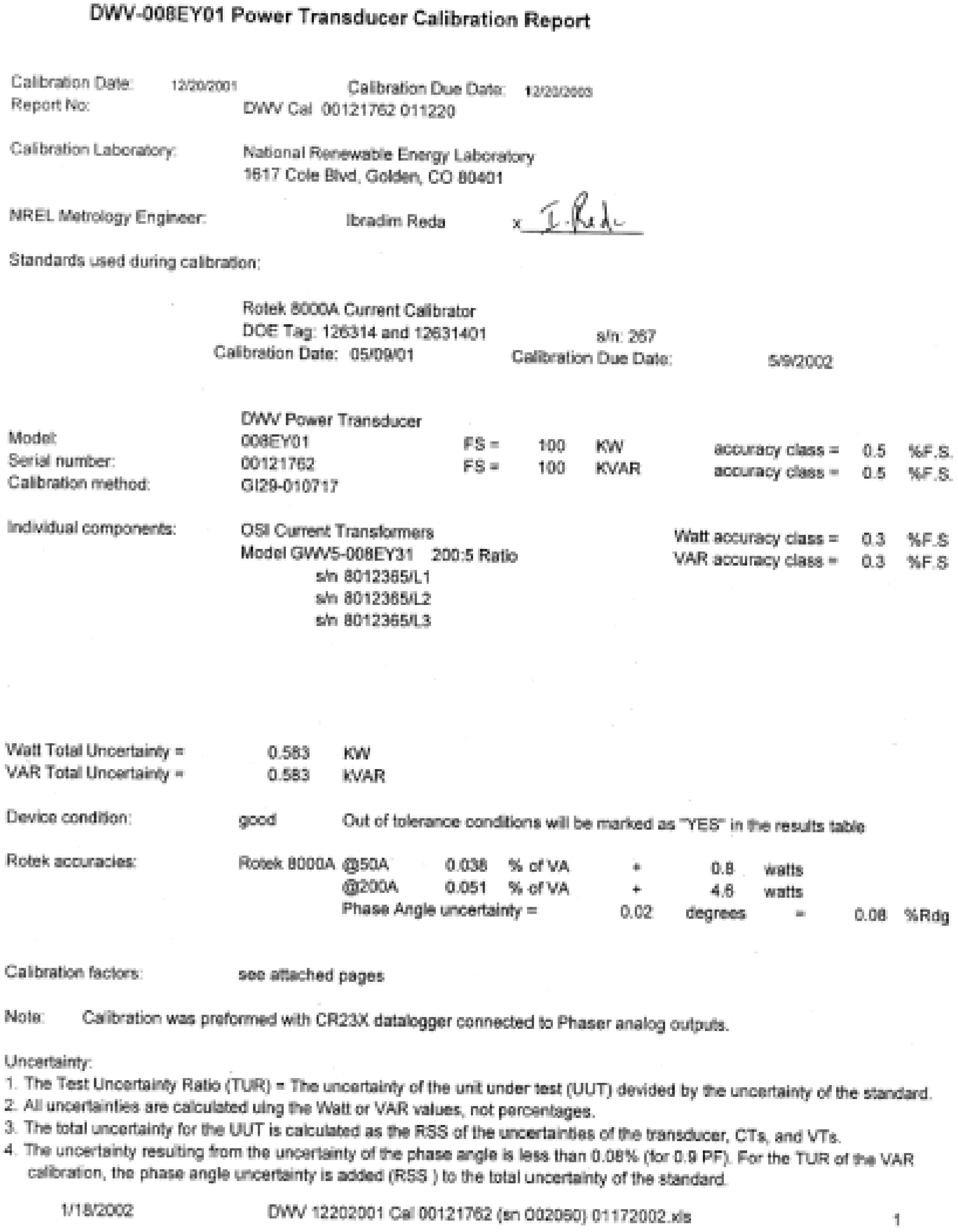
Test Standards:

DMM	Keithley 197A Ser No. 490833	Calibrated 2/17/00
Frequency	HP 5245 Ser No. 71616181	Calibrated 2/25/00
Temperature	M.O.I. Model 062 Ser No. N8823	Calibrated 4/17/00
Relative Humidity	Vaisala Model HMP35A Ser No. 460410	Calibrated 9/15/99
Barometric Pressure	M.O.I. 090D-STD Ser No. P6676	Calibrated 4/12/00

Test	Expected	As Rec'd	Error	As Calib	Error	Spec	Notes
Run Torque	<0.009 in/oz	<.009	[✓ Pass] Fail	<.009	[✓ Pass] Fail	<0.009 in/oz	
Gap Noise	< 1.0 V		[✓ Pass] Fail		[✓ Pass] Fail	< 1.0 V	

Test	Expected	As Rec'd	Error	As Calib	Error	Spec	Notes
10 Deg	0.069 V	.059	-.010	.061	-.004	(+/-) 0.021 V	
90 Deg	0.625 V	.613	-.012	.615	-.010	(+/-) 0.021 V	
180 Deg	1.250 V	1.248	-.002	1.250	-0-	(+/-) 0.021 V	
270 Deg	1.875 V	1.886	+.011	1.890	+.015	(+/-) 0.021 V	
350Deg	2.431 V	2.443	+.012	2.445	+.014	(+/-) 0.021 V	
2.5 V Ref	2.500 V	2.500	-0-	2.500	-0-	(+/-) .003 V	

Power Transducer 00121762



DWV-008EY01 Power Transducer Calibration Report

Calibration Date: 12/20/2001 Calibration Due Date: 12/20/2003
Report No: DWV Cal 00121762 011220

Calibration Laboratory: National Renewable Energy Laboratory
1617 Cole Blvd, Golden, CO 80401

NREL Metrology Engineer: Ibradim Reda x I. Reda

Standards used during calibration:

Rotek 8000A Current Calibrator
DOE Tag: 126314 and 12631401 s/n: 267
Calibration Date: 05/09/01 Calibration Due Date: 5/9/2002

	DWV Power Transducer						
Model:	008EY01	FS =	100	KW	accuracy class =	0.5	%F.S.
Serial number:	00121762	FS =	100	KVAR	accuracy class =	0.5	%F.S.
Calibration method:	GI29-010717						

Individual components: OSI Current Transformers
Model GWV5-008EY31 200:5 Ratio
s/n 8012365/L1
s/n 8012365/L2
s/n 8012365/L3

Watt accuracy class = 0.3 %F.S
VAR accuracy class = 0.3 %F.S

Watt Total Uncertainty = 0.583 KW
VAR Total Uncertainty = 0.583 kVAR

Device condition: good Out of tolerance conditions will be marked as "YES" in the results table

Rotek accuracies: Rotek 8000A @50A 0.038 % of VA + 0.8 watts
@200A 0.051 % of VA + 4.6 watts
Phase Angle uncertainty = 0.02 degrees = 0.08 %Rdg

Calibration factors: see attached pages

Note: Calibration was preformed with CR23X datalogger connected to Phaser analog outputs.

Uncertainty:

1. The Test Uncertainty Ratio (TUR) = The uncertainty of the unit under test (UUT) devided by the uncertainty of the standard.
2. All uncertainties are calculated uing the Watt or VAR values, not percentages.
3. The total uncertainty for the UUT is calculated as the RSS of the uncertainties of the transducer, CTs, and VTs.
4. The uncertainty resulting from the uncertainty of the phase angle is less than 0.08% (for 0.9 PF). For the TUR of the VAR calibration, the phase angle uncertainty is added (RSS) to the total uncertainty of the standard.

1/18/2002 DWV 12202001 Cal 00121762 (sn 002050) 01172002.xls 1

Appendix B: Post-Test Inspection Report

Component Wear and Durability Assessment
Atlantic Orient Corporation's AOC 15/50

Introduction

The NREL team disassembled and assessed the AOC 15/50 wind turbine in September 2001 as part of the Turbine Field Verification Program's (FVP's) duration test. The turbine, which had been operating at NREL since October 1994 (except for one 18-month period), was due for a detailed 5-year inspection.

The FVP duration test calls for a post-test inspection to determine whether any component exhibits wear or other degradation that might suggest failure before completing 20 years of operation or being replaced in accordance with the turbine's Operation and Maintenance Manual. The assessment includes an evaluation of yaw bearings, gearbox, and blades (to verify that there are no cracks); circuit boards (to verify that there are no thermal or electrical signs of fatigue); and the generator, parking brake, and tower.

This assessment began September 9, 2001. The following people from NREL participated: Scott Wilde, Eric Jacobson, Joe Derrick, Jerry Bianchi, Walt Musial, Jason Cotrell, and Hal Link. Bruce Johnson from AOC also participated.

Findings

Nacelle

Metal shavings left over from a machining process were found in nacelle areas that are difficult to reach. These particles appear to have been formed during the manufacturing process, not during operation.

Dirty oil was found on the tower top and nacelle underneath the generator-to-nacelle connection. The oil on the tower top was located primarily on the section under the generator at a yaw position correspondent with the primary wind direction.

Blades

The blades were inspected, and no major problems were found. The catch plates on the tip brakes are loose, and new grommets, screws, and washers have been ordered for reinstallation. A crack was found on one of the leading edges.

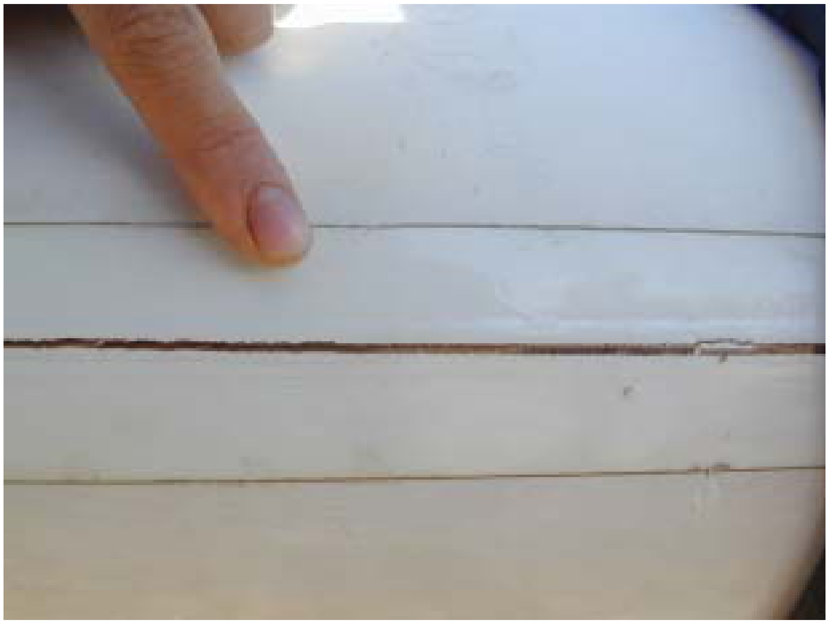


Figure B.1. Crack on the leading edge of one of the blades.

Gearbox

Normal wear was found on the ring gear, the high-speed carrier, and the planet gears.

The plate in the LS Carrier exhibited wear from the dislocation of the plate from its counter bore. This dislocation reduced the depth of the counter bore such that the plate could be sandwiched between the gear and carrier.

Figure B.2. The low-speed carrier.

Small metal pieces were found in the bottom of the nacelle casting. These were traced back to the wear from the LS Carrier and wear on the end of the LS planetary gears. Metal shavings were also removed from the main cavity of the nacelle; these shavings did not appear to originate from the wear on gears and plates.

Micropitting was evident on the faces of the low-speed planet gears.

Two oil samples were sent to Mobil Oil Corporation. Both were found to have a high metal content and a low viscosity.

Low-Speed Shaft

The low-speed shaft has two seals, a dust seal and an oil seal. The low-speed shaft showed signs of wear in the position where the two seals are located. There was discoloration on the shaft where the downwind seal was, but no significant groove. The upwind seal did make a groove and discolored the shaft. This groove was between 0.005 and 0.010 inch wide and less than 0.005 inch deep. There was no evidence that the seal was leaking oil, but some grease was found between the two seals.

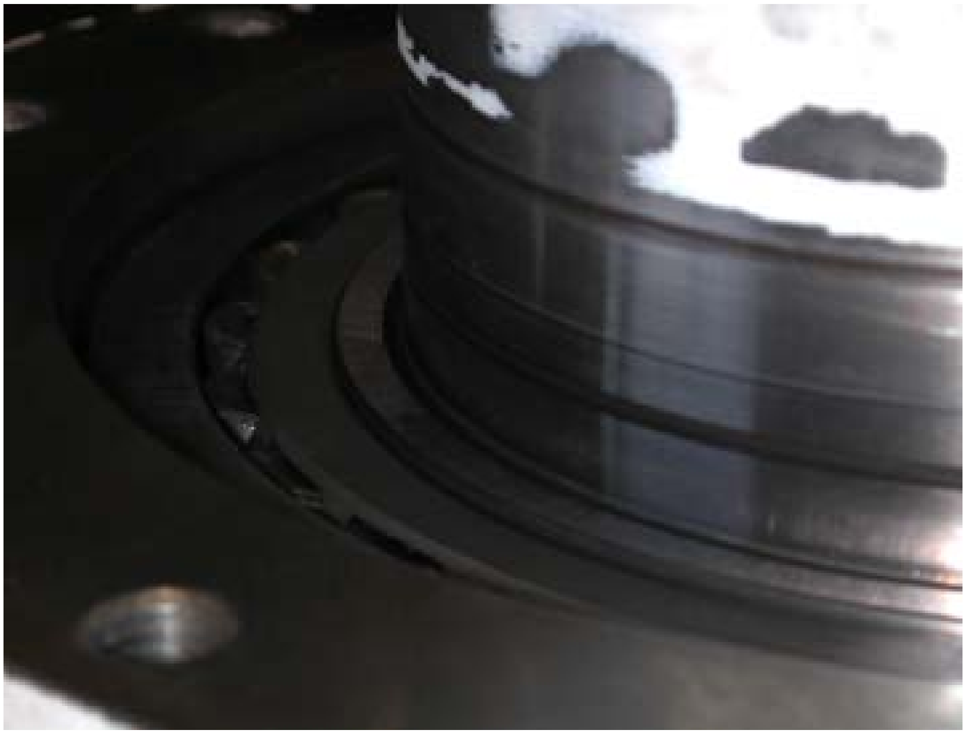


Figure B.3. Grooves on the low-speed shaft caused by the seals.

Generator

Two bad seals were found on the generator. The generator casing contained oil that had bypassed those seals. This oil appeared to be clean, but it was not sampled. MegaOhm resistance measurements were made between the generator windings and ground. Resistances were found to be between 10-15 MOhms on all three coils. There was a groove present on the input shaft from the drive train.

Yaw Bearing

The yaw bearing was removed from the turbine. It rotated smoothly.

The inner and outer rings were found to have intermittent marks on both ball paths with spacing that corresponds to the ball spacing. We speculate that these marks were caused by a single event such as an extreme load during installation or by a dithering load that may have occurred when shipping the turbine to the NWTC.

Figure B.4. The disassembled yaw bearing.

Figure B.5. Inner ring and intermittent marks.

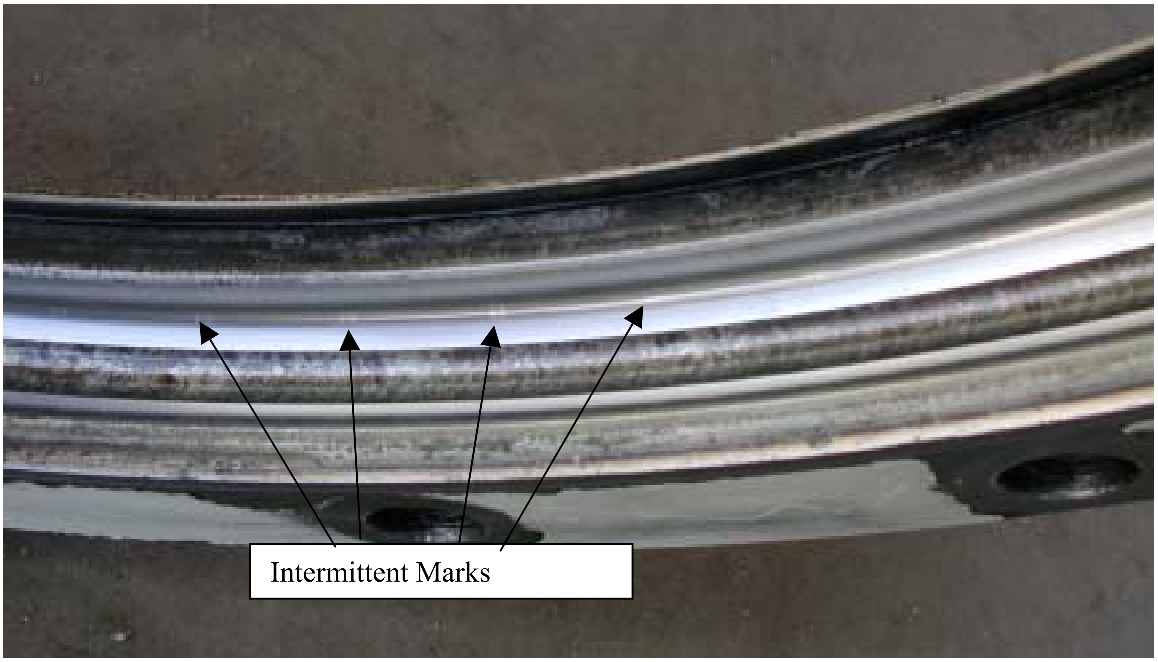


Figure B.6. Outer ring and intermittent marks.

Tower

The tower was inspected for cracks and loose or missing bolts. Some bolts had to be re-torqued.

Parking Brake

The parking brake appears to be working fine. Brake dust was found throughout the brake assembly. All three friction disks showed signs of wear. Each disk was observed to have lost approximately 2-3 thousands of material where the disks made contact with the stationary disk.

Appendix C: AOC 15/50 Duration Test Plan

Wind Turbine Generator System

Duration Test Plan

for the

Atlantic Orient 15/50 Wind Turbine

by

National Wind Technology Center
National Renewable Energy Laboratory
1617 Cole Boulevard
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for

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Approval By: ______________________ 14 May 2003
Jeroen van Dam, NREL Test Engineer Date

Approval By: Hal Link ______________________ 14 May 2003
Hal Link, NREL Certification Test Manager Date

Approval By: Trudy Forsyth ______________________ May 15, 2003
Trudy Forsyth, FVP Project Leader Date

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4 Test Objective and Requirements

The objective of this test is to investigate:

- Structural integrity and material degradation (e.g., cracks, deformations, wear)
- Quality of environmental protection of the Atlantic Orient Corporation (AOC) 15/50 wind turbine (e.g., corrosion, failure of paint or seals).

The wind turbine will have passed the duration test when it has achieved:

- Reliable operation during the test period
- 1,500 hours of power production in winds of any velocity
- 250 hours of power production in winds of 1.2 V_{ave}[1] (10.2 m/s) and above
- 25 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 found during periodic inspections or the final turbine inspection
- No significant degradation in time of produced power at comparable wind speeds.

IEC MT2, which is writing the second edition of the IEC61400-2, rewrote the duration test section. This new draft section was used when possible with the following exceptions:

- The assessment of dynamic behavior will not be part of this duration test.
- The number of hours of power production in winds of any velocity is 1,500 instead of 3,000.

A copy of the draft section can be found in Appendix B.

5 Background

This test is being conducted as part of the U.S. Department of Energy's (DOE's) Small Wind Turbine Field Verification Program. The primary purpose of this program is to provide consumers, manufacturers, and host site organizations with an independent assessment of the performance and reliability of small U.S. wind turbines.

AOC developed the AOC 15/50 with assistance from the DOE and the National Renewable Energy Laboratory (NREL). The test turbine, located at the National Wind Technology Center (NWTC), is owned by NREL and serves several functions, including:

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[1] Note that V_{ave} is determined by the wind turbine class as specified by IEC 61400-2 2nd edition. The AOC 15/50 is a class II turbine; class II has a V_{ave} of 8.5m/s.

- Developing NREL's certification testing capabilities
- Participating in a round-robin testing program under the International Energy Agency (IEA) R&D Wind Agreement for Cooperation in the Research and Development of Wind Turbine Systems
- Testing wind/diesel hybrid test systems
- Developing improvements to the design of the AOC 15/50 model
- Demonstrating modern wind turbine technology.

Currently NREL is testing three wind turbines as part of the DOE's Small Turbine Field Verification Program. As part of these tests, each turbine is subjected to a duration test. Duration testing is currently being defined as part of the IEC/ISO wind turbine certification process. This test plan will provide for testing in accordance with the preliminary definitions of a duration test as provided in IEC/ISO WT01 (ref 1) and the latest draft of IEC/ISO 61400-2, Ed 2 (ref 2). These standards are important parts of an international effort to certify wind turbines.

6 Test Turbine

The configuration of the AOC 15/50 wind turbine is shown in Figure 1 and Figure 2. The turbine is a three-bladed, downwind, free-yaw, constant-speed, stall-regulated machine. Rotational energy is converted to electrical power in the nacelle, which contains the gearbox, generator, and parking brake (Figure 2).

The blades were manufactured by AERPAC/Merrifield Roberts in the summer of 1996. They were designed by M. Zuteck and based on the NREL Thick series (modified) type airfoil. Composed of a wood/epoxy laminate, the blades are 7.2 m in length (from root to tip). The assembled rotor has a sweep area 15.0 meters in diameter. At the ends of the blades, electromagnetically controlled tip brakes are installed.

AOC specifies a blade pitch of 3.24^0 at the tip for the 1850 m elevation of the NWTC. This setting causes the power curve to peak at 65 kW. However, the blades were set to 0.9^0 for this test to correspond to the standard configuration for installations of the 50-Hz turbine at sea level sites. This setting causes the turbine's power curve to peak slightly over 50 kW.

The rotor is connected directly to the gearbox low-speed shaft, and the generator is connected to the gearbox high-speed shaft. The rotational speed of the rotor at rated power is 65 rpm. The transmission's gear ratio of 1:28.25 turns the generator at a nominal 1800 rpm. The generator is a three-phase, 60-Hz, 480-volt induction machine rated at 50 kW.

The tower is a 24.4-m, free-standing, three-legged lattice steel structure. The turbine uses three independent brake systems. Tip brakes mounted at the end of the blades provide aerodynamic braking. They use electromagnets to hold them in position. A capacitor/resistor network provides dynamic braking, and a mechanical brake is used for parking the rotor.

The machine is controlled by the Koyo DirectLogic 205 PLC controller, which is located in a small control shed at the base inside the turbine tower. The program used by the controller was originally developed in Canada for AOC. For this test, the program was modified by H. Link to increase safety and ease of operation. The program version used during the test is entitled Round Robin 86 (file name Rrobin86). Connection to the grid is via a 480VAC/13.2kVAC transformer located approximately 3 meters from the base of the tower. Table 1 lists configuration and operational data for the AOC 15/50 as tested.

The turbine was constructed in the summer of 1994 and first installed in September 1994. It was removed for site calibration tests and checkout tests of a 50-Hz turbine between April 29, 1996 and June 12, 1997. When reinstalled, the AERPAC blades were installed instead of the original Gougeon Brothers blades.

Figure 1. Overall configuration of the AOC 15/50 test turbine.

Figure 2. Nacelle configuration, AOC 15/50.

Table 1. Test Turbine Configuration and Operational Data

	Test Turbine
General Configuration:	
Make, Model, Serial Number	Atlantic Orient Corporation, AOC 15/50 S/N: none (this was the third AOC 15/50 turbine installed)
Rotation Axis	Horizontal
Orientation	Downwind
Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	15
Hub Height (m)	25
Performance:	
Rated Electrical Power (kW)	50
Rated Wind Speed (m/s)	12.0
Cut-In Wind Speed (m/s)	4.9
Cut-In Wind Speed Dead Band (m/s)	3.6
Cut-Out Wind Speed (m/s)	22.3
Extreme Wind Speed (m/s)	59.5 (peak survival)
Rotor:	
Swept Area (m^2)	177
Online Rotational Speed (rpm)	65
Coning Angle (deg)	6
Tilt Angle (deg)	0
Blade Pitch Angle (deg)	0.9^o toward feather
Direction of Rotation	CCW viewed from downwind
Power Regulation	stall regulation
Overspeed Control	centrifugal override of tip brake magnets
Drive Train:	
Gearbox Make, Type, Ratio	Fairfield/AOC, Planetary, 1:28.25
Generator: Make, Type, Speed, Voltage, Frequency	Magnatek, 3-phase induction, 1800 rpm, 480 VAC, 60 Hz
Braking System:	
Mechanical (Parking) Brake: Make, Type, Location	Sterns Series 81,000, on nacelle aft of generator
Aerodynamical Brake: Make, Type, Location	AOC, electromagnetic tip brakes, at the tips of all blades
Electrical Brake: Make, Type, Location	AOC, dynamic brake, connected to the tower droop cable at the base of turbine
Yaw System:	
Wind Direction Sensor	none
Yaw Control Method	free-yaw
Tower:	
Type	three-legged steel lattice
Height (m)	24.4

Control/Electrical System:	
Controller: Make, Type	Koyo, DirectLogic 205
Power Converter: Make, Type	none
Electrical Output: Voltage, Frequency, Number of Phases	480 VAC, 60 Hz, 3-phases

7 Test Site

The AOC 15/50 wind turbine under test is located at Site 1.1 of the National Wind Technology Center (hereafter referred to as the test site), approximately 8 km south of Boulder, Colorado. The site is located in somewhat complex terrain at an approximate elevation of 1850 m above sea level. Figure 3 shows the location of the test site relative to Boulder and the front range of the Rocky Mountains, as well as a plot plan of the test site including all obstructions for 20 rotor diameters (with topography lines listed in feet above sea level).

The meteorological tower is located 37.5 meters from the test turbine at a bearing of 292^o true. Figure 4 shows the test turbine from the direction of the prevailing winds.

The test site is relatively flat close to the turbine. However, some terrain variations and obstructions have the potential to influence winds at the meteorological tower and the turbine. NREL assessed the site and conducted a site calibration test to quantify terrain effects on wind speed measurement uncertainty. NREL found that an appropriate measurement sector for power performance testing includes westerly and northerly winds between $223\,^o$ and 66^o with respect to true north. Within this measurement sector, wind speed at the meteorological tower remains within 2% of wind speed at the position of the turbine’s hub. Duration test results that depend on wind speed measurements are obtained from data when winds are in this measurement sector.

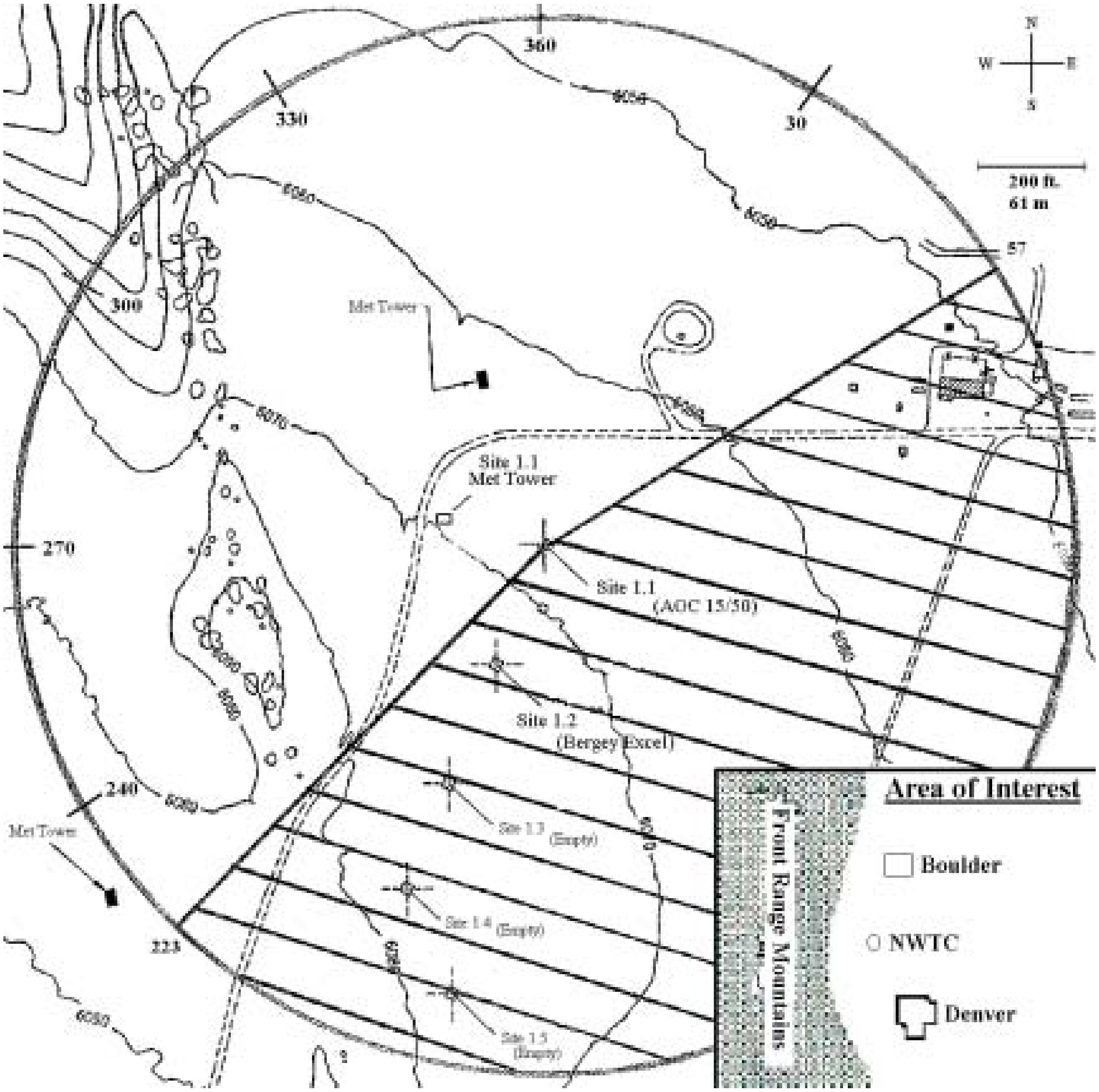


Figure 3. Location and plot plan of AOC 15/50 test site.

Figure 4. Test turbine through met tower from prevailing wind direction (292°).

8 Test Procedure

8.1 Test Equipment

Equipment used for duration testing differs only slightly from that used for power performance testing. Normal power performance requires measurements of wind speed, wind direction, turbine power, air temperature, air pressure, precipitation, and overall turbine system availability. For duration testing, NREL added signals for turbine availability and a small change to the data logger program to record the peak 3-second gust during the test period. The availability signals are further discussed in section 9.3

Table 2 is an equipment list that provides the requirements and specifications for each of the instruments used. Figure 5 shows the overall locations of the instrumentation. Figure 6 shows details of the instrument locations at the top of the met tower. Appendix A gives the calibration sheets of the instruments.

Table 2. Equipment List for Duration Tests

Power Transducer and CTs	
Make/Model:	OSI, GWV5-008EY05
Serial Number (Transducer/CTs):	8012365 / 8012365
Range with CTs:	-120 to 120 kW
Calibration Due Date:	November 6, 1999
Primary Anemometer (North)	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number:	T2346
Calibration Due Date:	October 29, 1999
Met Tower Location:	Height AGL: 25.0 m (100% of hub height)
Secondary Anemometer (South)	
Make/Model:	Met One, 010C with Aluminum Cups
Serial Number.	R1160
Calibration Due Date:	October 29, 1999
Met Tower Location:	Height AGL: 25.0 m (100% of hub height)
Primary Wind Direction Sensor (South)	
Make/Model:	Met One, 020C with Aluminum Vane
Serial Number:	U1475
Calibration Due Date:	December 18, 1999
Met Tower Location:	Height AGL: 22.6 m (90.4% of hub height)
Barometric Pressure Sensor	
Make/Model:	Vaisala, PTB101B
Serial Number:	R4230002
Calibration Due Date:	September 29, 1999
Met Tower Location:	Height AGL: 22 m (88.0% of hub height)
Atmospheric Temperature Sensor	
Make/Model:	Met One, T-200 RTD
Serial Number:	544114
Calibration Due Date:	December 18, 1999
Met Tower Location:	Height AGL: 22 m (88.0% of hub height)
Data Logger	
Make/Model:	Campbell Scientific CR23X
Serial Number:	1214
Calibration Due Date:	October 16, 2000

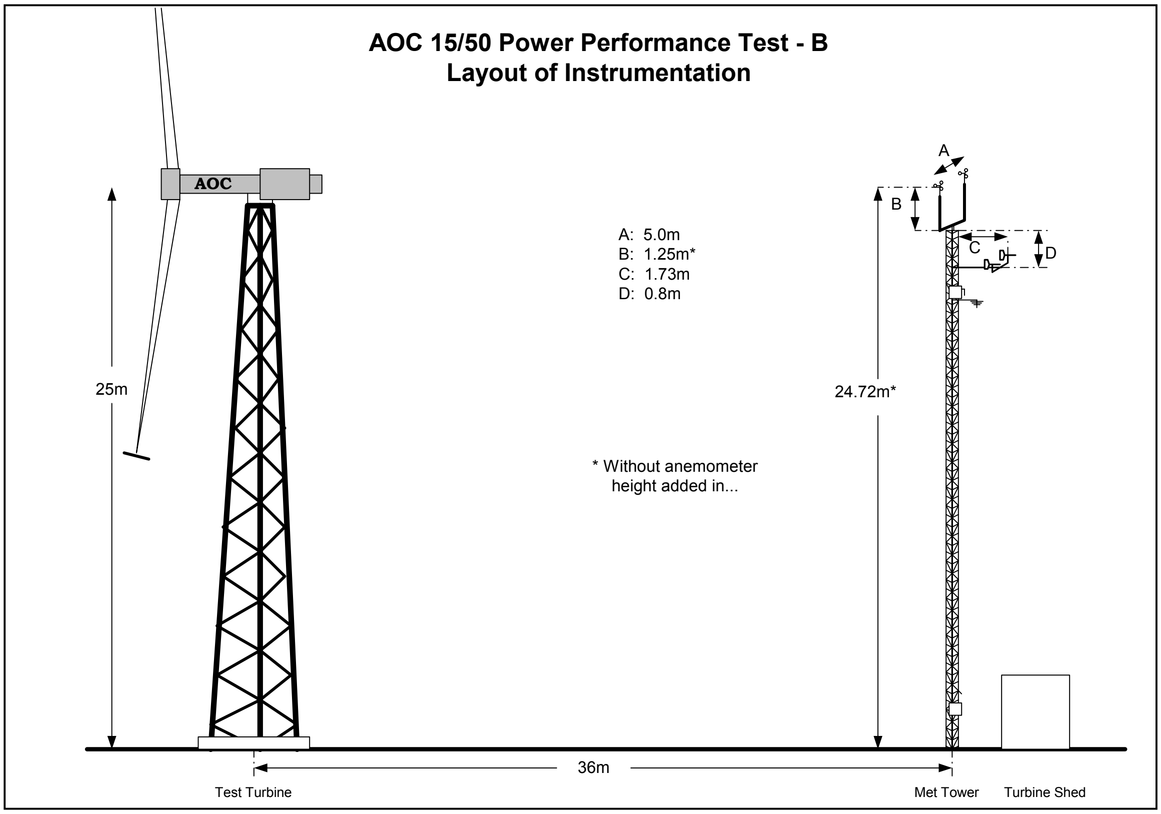


Figure 5. Layout of instrumentation.

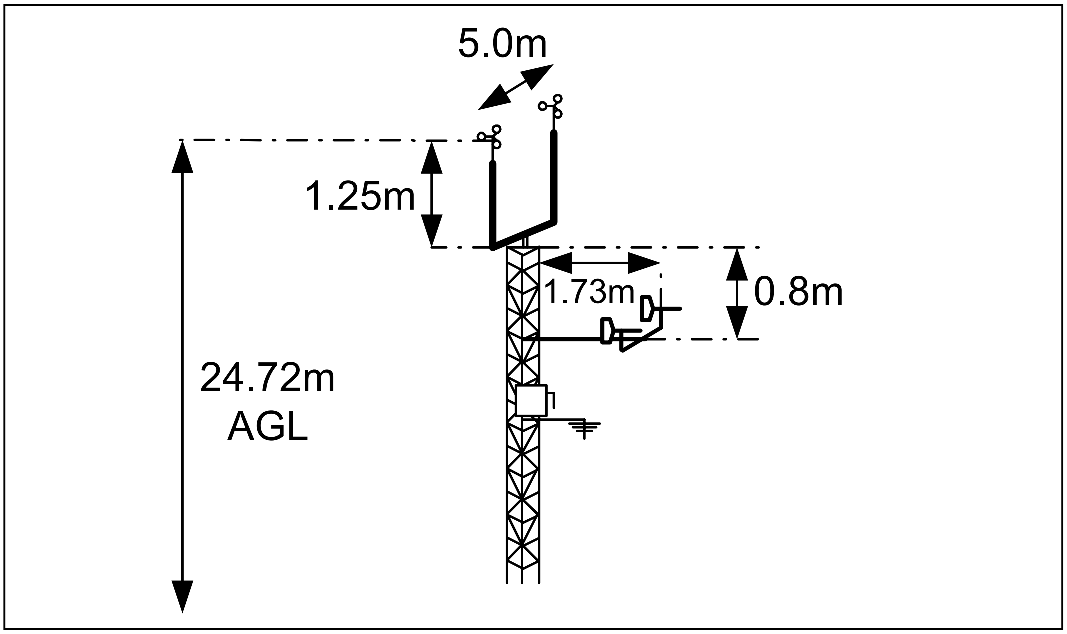


Figure 6. Detail of top of met tower.

8.2 Test Preparations

After the instruments have been mounted in the locations described in Section 8.1, the test technician tests their functionality and aligns the wind vane. Functionality tests are conducted in accordance with NREL's quality assurance system. They include comparing data acquisition measurements to independent readings whenever possible, comparing the two anemometer readings, and comparing measurements to theoretical models.

Once the wind direction sensor has been installed and confirmed to be functional, it is oriented so that its readings correspond to degrees from true north. At this site, the vane is first oriented such that it produces a zero-voltage output when pointed approximately east. This places the instrument's 6-degree dead band outside of the allowable measurement sector for power performance measurements.

Next the vane is pointed toward distant landmarks whose directions from the test turbine have been determined from topographical maps. The data logger readings are compared to the known directions, and a suitable calibration offset is determined. This offset is entered into the data logger program and confirmed.

After the in-field checks are completed, the data logger will be run for at least 6 hours. At the start of this time series, the battery charger will be connected to the 120 VAC ground line, and all instruments will measure and collect data normally. At the end of this time, the Test Analyst will examine the measurements of all instruments to ensure proper operation.

8.3 Measurement Procedures

All instruments will be sampled by the data logger at a rate of 1 Hz. The output data will be the 10-minute averages of the data with their standard deviations and minimum and maximum values for the 10 minutes also included. For status signals, the data logger records the percentage of time during each 10-minute period that the signal is high.

On a weekly basis, NREL will transfer data from the data logger to computers at NREL offices using a modem or laptop computer.

NREL personnel will, from ground level, check instruments located on the meteorological tower on a weekly basis. They will note whether there are any obvious failures such as broken or missing cups from the anemometers; bent, broken, or missing wind vane; misalignment of any sensors; and whether 120 VAC power is being provided to the data logger. NREL personnel will also record any unusual occurrences with the turbine or instrumentation in the appropriate logbook inside the turbine control shed.

NREL will analyze the data sets once per week. Using the procedures described in Section 9, the Test Analyst will note whether any problems have arisen. The test will be considered as suspended pending resolution of the problem. The Test Engineer will determine whether data obtained during the period when the problem was active can be used in the determination of power performance and note whether data are used in the test report.

If the test site or turbine changes during the test, the Test Engineer will determine whether it is appropriate to continue the test, restart the test, or cancel the test. All such actions will be documented in the test report. The test will continue until the turbine has passed the duration test. If the turbine experiences a major failure or if a significant improvement is desired, the test will be restarted.

If there is a major failure of the AOC 15/50, then the manufacturer may implement appropriate repairs and the test will be restarted. A major failure on the wind turbine system includes any failure of the system components, including blades, charge controller, alternator, yaw bearings, or inverter. A repair of a major failure sets the number of hours of turbine run time to zero (i.e., the test starts over).

8.4 Final Turbine Inspection

At the conclusion of the duration test, the turbine will undergo a detailed final inspection of the turbine system. The turbine will be inspected on the tower. Pictures of the turbine setup will be taken. Blades will be checked for cracks, turbine yaw will be checked, all turbine fasteners will be checked, the fuse will be checked, and the grounding for the turbine checked. Any deviations from normal in the final inspection checklist will be noted and included in the final report.

9 Analysis Methods

9.1 File Structure

NREL uses three Excel spreadsheets to analyze duration test data. Every week the Campbell data file is added to a "raw data" spreadsheet. This spreadsheet is used to ensure that the data files do not overlap and that there are no missing time stamps. Further, if the data file format has changed, the columns are put in those columns where the monthly spreadsheet expects them to be.

Every month, data are copied from the "raw data" file into a monthly analysis file. First a manual check of the signals is performed. After the data have been classified as valid or invalid, the automatic processing takes place. Finally, the logbook is used to check the correct availability classification.

The monthly results are linked to an "overall results" spreadsheet. Here the power degradation and expected energy plots are made, and the overall results for the whole test period are calculated.

9.2 Data Validity Checks

Flat spots, spikes, or clipping of data can be noticed by plotting time series of the average, standard deviation, minimum, and maximum of the signals. Scatter plots of power vs. wind speed, 3-sec gust vs. maximum wind speed, and rpm vs. wind speed are useful in spotting outliers that may indicate something wrong with either the turbine or the data acquisition system.

9.3 Data Processing

There are several parts of the analysis for which a data point can be used. Table 3 indicates how data are used in each part of the analysis and what channels should work properly. If a channel is used in a certain part of the analysis, the channel is first checked for proper functioning. This means checking for spikes, reliable values, clipping (max or min running out of scale) and comparison to other channels (e.g. comparing power vs. wind speed, max. wind speed vs. 3-sec gust, etc.) Based on the information in the logbook, manual changes were made to the spreadsheet.

Table 3. Conditions Under Which a Data Point Can Be Used for Parts of the Analysis

Criteria	Data Acquisition System Functional *	Power	Wind Speed	Turb. Avail	Sys avail.	WD in meas. sector	3-sec gust
Power production at any wind speed	Yes	>0		=1.0			
Power production above 10 m/s	Yes	>0	>10	=1.0			
Power production above 15 m/s	Yes	>0	>15	=1.0			
T_a (available)	Yes			=1.0	=1.0		
T_e (excluded)	Yes			=1.0	<1.0		
T_n (non-available)	Yes			<1.0			
T_u (unknown)							
Expected energy	Yes	Ok	Ok	=1.0		Yes	
Power degradation	Yes	Ok	Ok	=1.0		Yes	
Average TI at 15 m/s	Yes		14.5 > WS > 15.5			Yes	
Max 3-sec gust	Yes		Ok				Ok

* Data acquisition system functional means: Counts (the number of 1-second instrument readings) >595, -40°C<T_{air}<80°C and $V_{logger\ battery}$ > 11 V

Hours of power production

The spreadsheet calculates the amount of power production time based on a positive current flow to the utility grid. The spreadsheet accrues the total recording time, total turbine power production time, production time in winds at or above 1.2 V_{ave} (10.2 m/s), and production time in winds at or above 1.8 V_{ave} (15.3 m/s).

Power degradation and expected energy ratio

For the power degradation and expected energy ratio, two power curves are made. The monthly power curve is linked to the "overall results" spreadsheet, in which the power levels are plotted against time and an overall power curve for the whole test period is derived.

For the expected energy ratio, the overall power curve is used to determine an expected power level based on the measured wind speed. Once per month the measured power levels are integrated to calculate measured energy and the expected power levels are integrated to calculate expected energy. The ratio of measured energy over expected energy is the expected energy ratio.

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

In addition to the instruments listed in Table 2, the duration test requires signals to determine the operational time fraction. It is important to distinguish clearly between times when external conditions prevent the turbine from operating and when the turbine itself is faulted or otherwise not operating normally.

On the AOC turbine, the conditions listed in Table 4 are monitored by the controller. An “X” in the Turbine Availability and System Availability columns indicates when the PLC will set an output signal low. For example, if the controller senses a grid fault (and no other abnormal conditions), it will set the System Available output to a low voltage. It will leave the Turbine Available output at a high voltage. The data logger senses the PLC output through relays that convert the high-voltage signal from 120 VAC to 2.5 VDC.

Table 4. Turbine and System Availability Designations

Condition	Turbine Availability	System Availability
Grid fault		X
Motor over temperature	X	X
Generator over temperature	X	X
Overspeed	X	X
Overpower	X	X
Under speed	X	X
Coast up fault	X	X
Parking brake fault	X	X
Emergency stop	X	X
SCADA disable		X
Northern Power System disable		X
Wind diesel disable		X
Turbine off		X
Turbine in test mode		X

If the turbine is turned off to work on instrumentation, it will automatically show up as an external condition, which prevents the turbine from operating and will not count against turbine availability. This is appropriate. If the turbine is turned off to perform turbine maintenance, then the time should count against turbine availability. In this case, the turbine operator presses the emergency stop button before turning off the turbine and leaves it off until power has been restored. This will mark the data set with an internal fault and make it easy for the data analyst to attribute time against turbine availability. In addition, any action such as turning off power to the turbine or pressing the emergency stop button requires a log entry with the date, time, person performing the action, and an explanation of the situation. But use of the emergency stop button will help keep the times accurate.

In addition to the two status signals described above, the turbine’s PLC also provides an “online” signal indicating whether the turbine generator is connected to the utility (or wind/diesel system).

The system availability and turbine availability channels are used in the combination given in Figure 7. After the spreadsheet has automatically applied the criteria from Figure 7, the analyst uses the logbook to override the spreadsheet if needed.

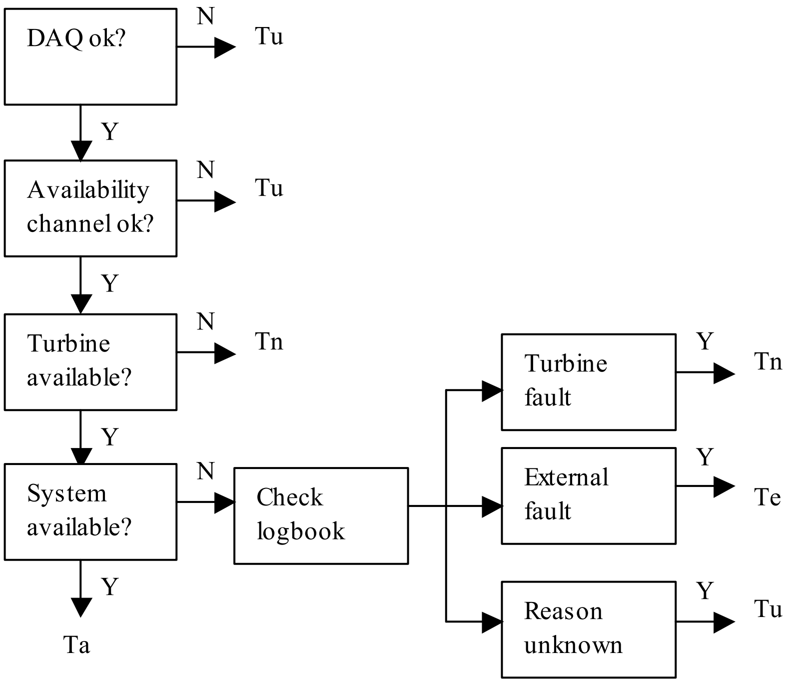


Figure 7. Classification of time for operational time fraction.

Table 5 specifies whether faults will be assigned to the turbine (external fault).

Table 5. Fault Condition Assignments

Condition	Turbine	External	No Fault
Grid fault		X	
Motor over temperature	X		
Generator over temperature	X		
Overspeed	X		
Overpower	X		
Under speed	X		
Coast up fault	X		
Parking brake fault	X		
Emergency stop	X		
SCADA disable*		X	
Northern Power System disable*		X	
Wind diesel disable*		X	
Turbine off*		X	
Turbine in test mode*		X	

Condition	Turbine	External	No Fault
Brake cooling cycle			X
Droop cable unwrap	X		
Inadvertent tip brake release	X		
Confusion of controller	X		

* This condition is considered an external fault unless the logbook entry indicates that this method was used to stop turbine operation due to a perceived problem with the turbine.

9.4 Uncertainty Analysis

Some uncertainty is expected in the measurement of the following parameters:

- turbine availability
- turbine operating time
- peak 3-sec gust
- expected energy ratios.

The major contribution to uncertainty in measured turbine availability is the amount of time during an outage that should be attributed to the turbine as opposed to external conditions. In most cases, this assignment should be straightforward. However, some occasions may arise in which the assignment is somewhat arbitrary and subject to the judgment of the test engineer. If as much as 24 hours of time fall into this category, then the final uncertainty will be on the order of 1%.

Turbine operating time will be accurately monitored by the data logger. If the logger is accurate to one-half second and the turbine experiences 750 on/off cycles during the test, the operating time in any winds will be measured within 0.1 hours. For 250 hours of operation in winds greater than or equal to 10 m/s, the turbine may see 125 on/off cycles, and the uncertainty will be about 1 minute. And the uncertainty for winds above 15 m/s will be about 0.1 minutes.

The peak 3-second gust will be driven by the uncertainty in wind speed measurements, including anemometer calibration, 0.2 m/s; operational characteristics, 2%; mounting affects, 0.5%; and terrain effects, 3%. If the peak 3-sec gust is 40 m/s, the uncertainty will be approximately 1.5 m/s.

The anticipated uncertainty in expected energy ratio accounts for the uncertainty in measuring wind speed and power, as well as the uncertainty associated with not accounting for air temperature and pressure. In the estimate of this uncertainty, NREL used power curve data recently obtained on the AOC 15/50 wind turbine to estimate Category A uncertainties for each wind speed bin. We also used the power curve data to determine the sensitivity factor that correlates wind speed uncertainty with power. And we used temperature and pressure measurements on the AOC 15/50 turbine to estimate the variations to expect due to air density changes. Finally, we used the wind speed distribution from these data to estimate an average wind speed for a Rayleigh wind speed distribution. We assumed Category A uncertainties would double due to the fewer number of data typically available in a month of testing.

The air density distribution contributes approximately 4% to the power variations. And the average wind speed for this site was found to be 5 m/s. Another consideration was that anemometer calibration, mounting, and site effects are unchanged from month-to-month so their contributions to uncertainty in expected energy production were zero. Overall, the uncertainty in expected energy ratio is estimated to be on the order of 8%. This figure will be revised using actual data for the final report on this test.

10 Reporting

10.1 Progress Reports

NREL will submit a progress report to NREL management periodically. This report will summarize:

- The status of the test (number of hours of data obtained, results so far)
- The anticipated completion date
- The status of resolutions to any problems.

10.2 Final Report

When the turbine has met the requirements of the duration test, NREL will produce a test report. This report will document:

- Total test time
- Turbine availability during the test
- Turbine operating time under any wind speed, in winds greater than 10 m/s, in winds greater than 15 m/s
- The peak 3-sec gust recorded during the test
- The cause and resolution of any significant downtime or failures
- Monthly expected energy ratios
- A summary of the post-test inspection
- This Test Plan as an Appendix
- Any changes to this Test Plan.

11 Exceptions to Standard Practice

The final turbine inspection will not include removal of the turbine from the tower and detailed inspection of all components.

12 Roles and Responsibilities

Table 6 lists the planned test team and identifies roles and responsibilities for each team member.

Table 6. Roles of Test Participants

Test Team Title	Name	Employer	Role(s)
NWTC-CT Manager	Hal Link	NREL	NREL approval of test plan.
Test Engineer and Analyst	Jeroen van Dam	NREL	Overall test management and responsibility. Customer contact person. Authorization for any deviations from planned test procedures. Supervision of test setup, checkout, and conduct. Analysis of test data. Identification of problems based on data analysis results. Review and report test results.
Test Technician	Eric Jacobson	NREL	Selection of instruments. Installation and checkout of test equipment. Implementation of corrective actions for problems. Download and store test data.
Site Manager	Hal Link	NREL	Supervision of operation and maintenance of test turbine. Responsible for ensuring safety of personnel and equipment at test site. Report any change in turbine configuration.

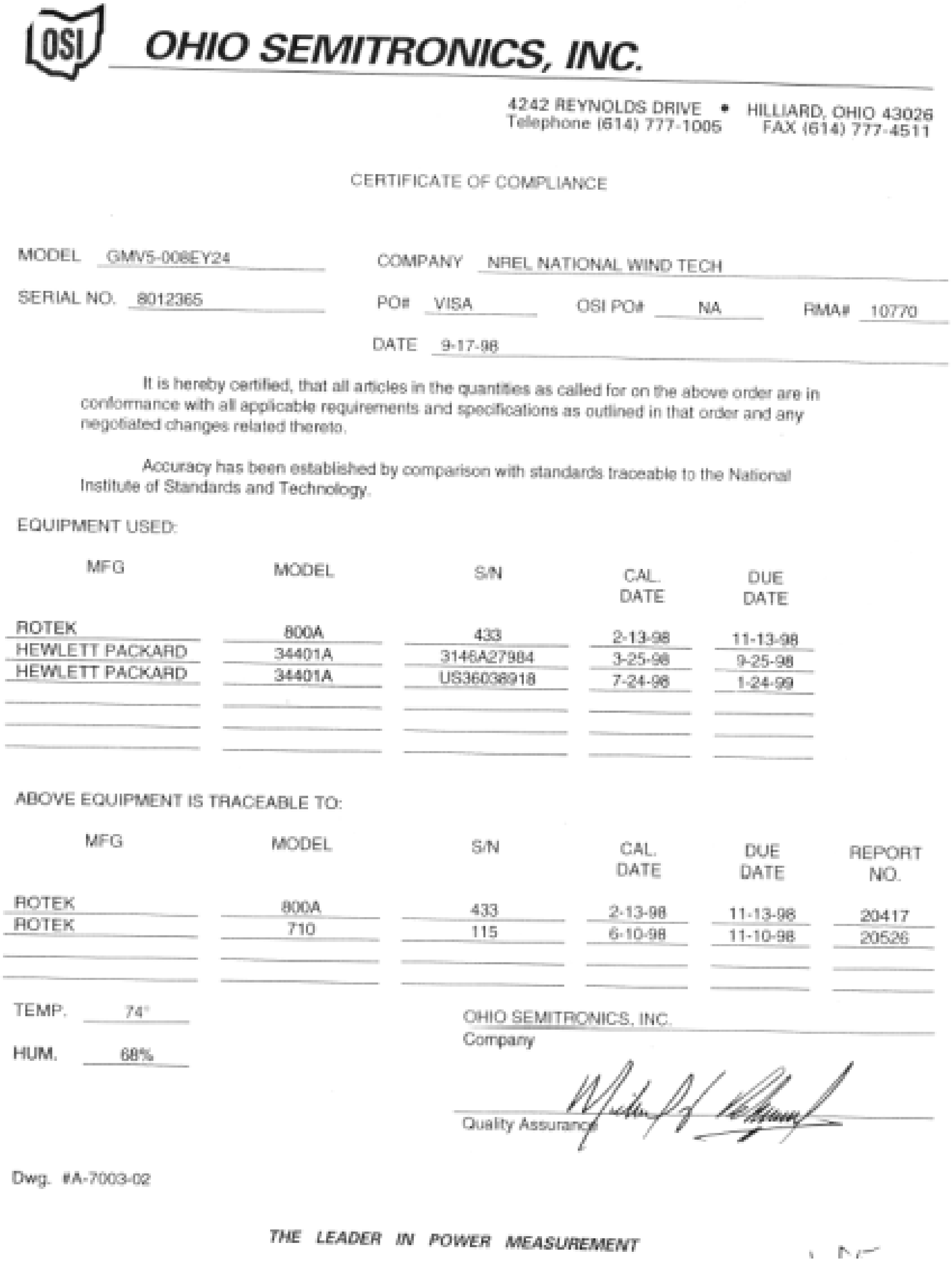
13 References

1. IEC WT01 (2001-04), International Electrotechnical Commission (IEC), IEC System for Conformity Testing and Certification of Wind Turbines - Rules and Procedures.
2. Draft IEC 61400-2 ed.2, International Electrotechnical Commission (IEC), Wind turbine generator systems - Part 2: Safety of small wind turbines.
3. Wind Turbine Generator System, Site Calibration Test Report for the AOC 15/50 Wind Turbine in Boulder, Colorado, Hal Link, Ryan Jacobson, Mark Meadors, 18 February 2000.
4. IEC 61400-12, International Electrotechnical Commission (IEC), Wind turbine generator systems – Part 12: Wind turbine power performance testing.

Appendix A: Calibration Sheets

Power transducer 8012365
Anemometer T2346
Anemometer R1160
Wind vane U1475
Pressure sensor R4230002
Temperature probe 544114
Data logger 1214

Power Transducer 8012365



OHIO SEMITRONICS, INC.

4242 REYNOLDS DRIVE • HILLIARD, OHIO 43026
Telephone (614) 777-1005 FAX (614) 777-4511

CERTIFICATE OF COMPLIANCE

MODEL GMV5-008EY24

COMPANY NREL NATIONAL WIND TECH

SERIAL NO. 8012365

PO# VISA OSI PO# NA RMA# 10770

DATE 9-17-98

It is hereby certified, that all articles in the quantities as called for on the above order are in conformance with all applicable requirements and specifications as outlined in that order and any negotiated changes related thereto.

Accuracy has been established by comparison with standards traceable to the National Institute of Standards and Technology.

EQUIPMENT USED:

MFG	MODEL	S/N	CAL. DATE	DUE DATE
ROTEK	800A	433	2-13-98	11-13-98
HEWLETT PACKARD	34401A	3146A27984	3-25-98	9-25-98
HEWLETT PACKARD	34401A	US36038918	7-24-98	1-24-99

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	800A	433	2-13-98	11-13-98	20417
ROTEK	710	115	6-10-98	11-10-98	20526

TEMP. 74°

HUM. 68%

OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Anemometer T2346

Annemometer Calibration Report

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

Calibration Location:
National Wind Technology Center
Side-by-Side Anemometer Calibration Facility

Report Number: CR-anno-98-4-T3

Page: 1 of 1

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**T2346**
Cup Material	Aluminum
Condition	Refurbished 15 Sep 98

Estimated Uncertainty:

Vwind	Cres Uncei	Total Uncert:
4 - 5 m/s	0.083	0.096
5 - 10 m/s	0.067	0.083
10 - 15 m/s	0.078	0.092

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

Dates of Calibration:
Test Start: 1-Oct-98
Test End: **28-Oct-98**
Report: 6-Nov-98

Procedure:
NWTC-CT: GI21-98237, Field Calibrate Anemometers

Deviations from procedure;
None

Results:

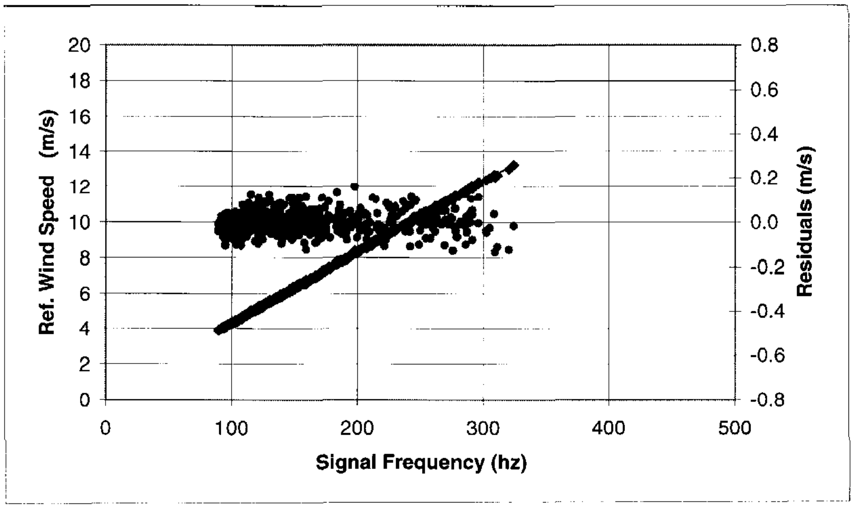
Slope:	**0.0399**	m/s/hertz
Offset:	**0.3247**	m/s

Traceability:

Reference Cup:	Met One, 010C, s/n: U2645
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	11-Mar-98

Approved: Hal Link
Hal Link

6Nov98
Date



Anemometer R 1160

Annemometer Calibration Report

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

Calibration Location:
National Wind Technology Center
Side-by-Side Anemometer Calibration Facility

Report Number: CR-anno-98-4-T4

Page: 1 of 1

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**R1160**
Cup Material	Plastic
Condition	Refurbished 15 Sep 98

Estimated Uncertainty:

Vwind	Cres Uncei	Total Uncert:
4 - 5 m/s	0.083	0.095
5 - 10 m/s	0.067	0.081
10 - 15 m/s	0.078	0.090

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

Dates of Calibration:

Test Start:	1-Oct-98
Test End:	**28-Oct-98**
Report:	6-Nov-98

Procedure:
NWTC-CT: GI21-98237, Field Calibrate Anemometers

Deviations from procedure;
None

Results:

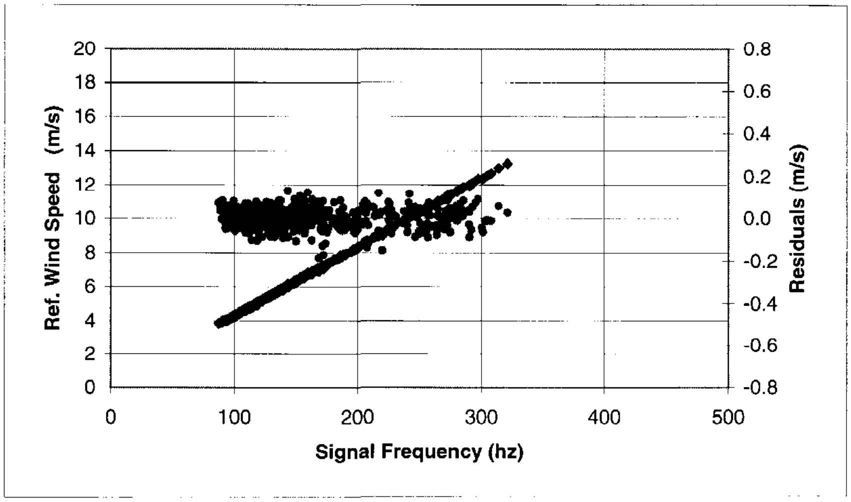
Slope:	**0.04036**	m/s/hertz
Offset:	**0.2650**	m/s

Traceability:

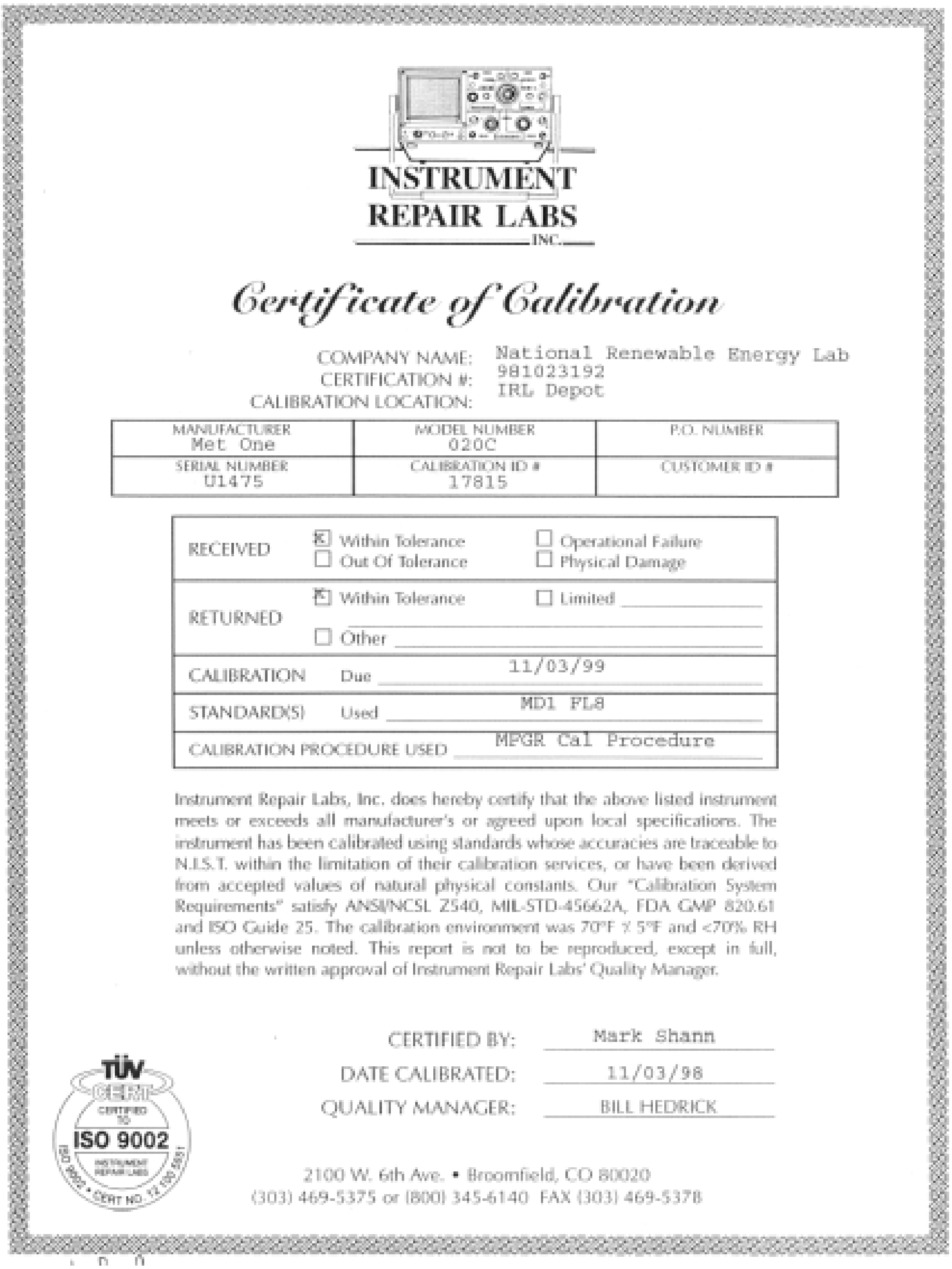
Reference Cup:	Met One, 010C, s/n: U2645
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	11-Mar-98

Approved: ______________________
Hal Link

6 Nov 98
Date



Wind Vane U 1475



INSTRUMENT REPAIR LABS
INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 981023192
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Met One	020C	
SERIAL NUMBER	CALIBRATION ID #	CUSTOMER ID #
U1475	17815	

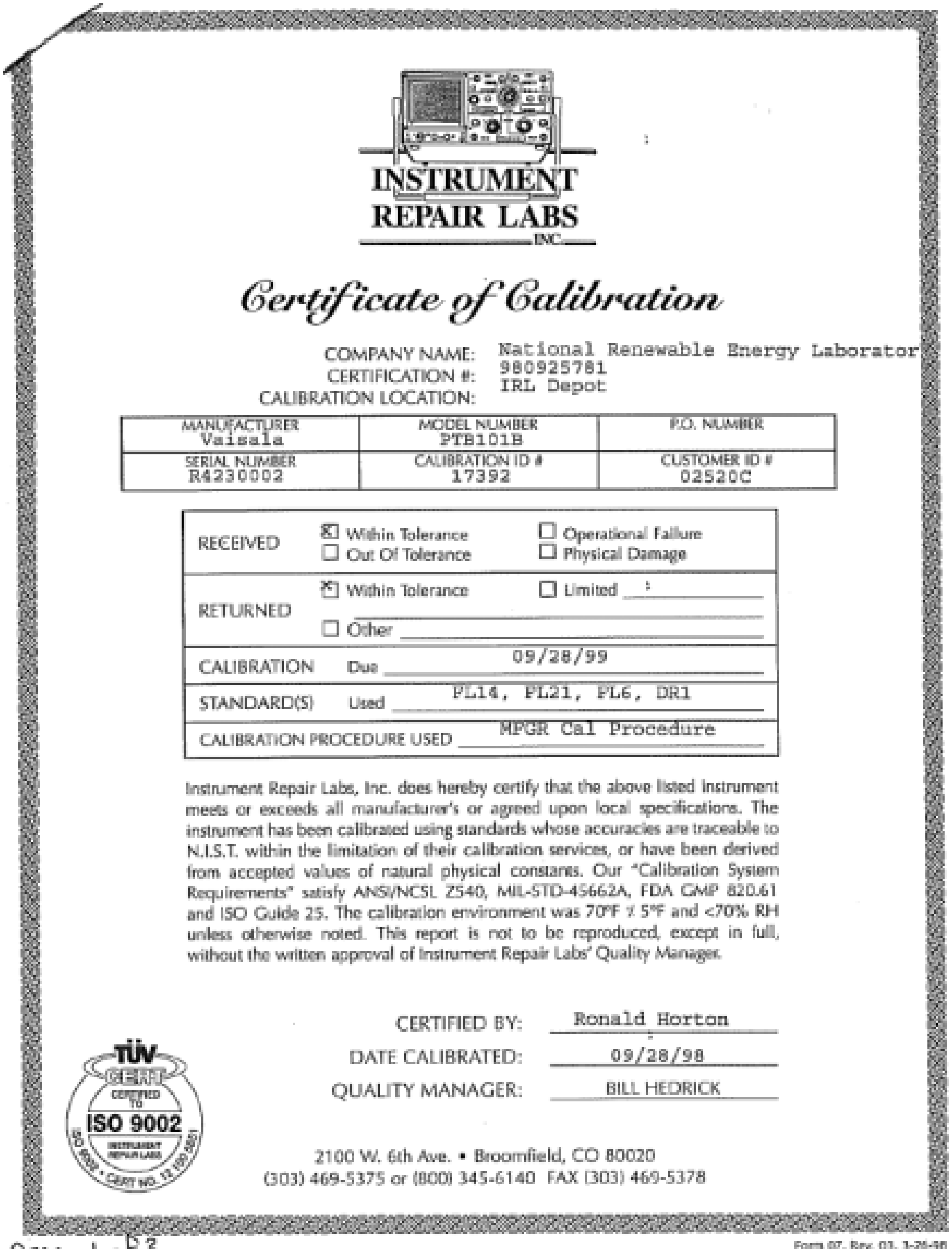
RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 11/03/99	
STANDARD(S)	Used MD1 FL8	
CALIBRATION PROCEDURE USED	MPGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: Mark Shann
DATE CALIBRATED: 11/03/98
QUALITY MANAGER: BILL HEDRICK

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

Pressure Sensor R4230002



INSTRUMENT REPAIR LABS INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Laborator
CERTIFICATION #: 980925781
CALIBRATION LOCATION: IRL Depot

MANUFACTURER Vaisala	MODEL NUMBER PTB101B	P.O. NUMBER
SERIAL NUMBER R4230002	CALIBRATION ID # 17392	CUSTOMER ID # 02520C

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 09/28/99	
STANDARD(S)	Used FL14, FL21, FL6, DR1	
CALIBRATION PROCEDURE USED	MPGR Cal Procedure	

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

CERTIFIED BY: Ronald Horton
DATE CALIBRATED: 09/28/98
QUALITY MANAGER: BILL HEDRICK

TÜV CERT
CERTIFIED TO ISO 9002

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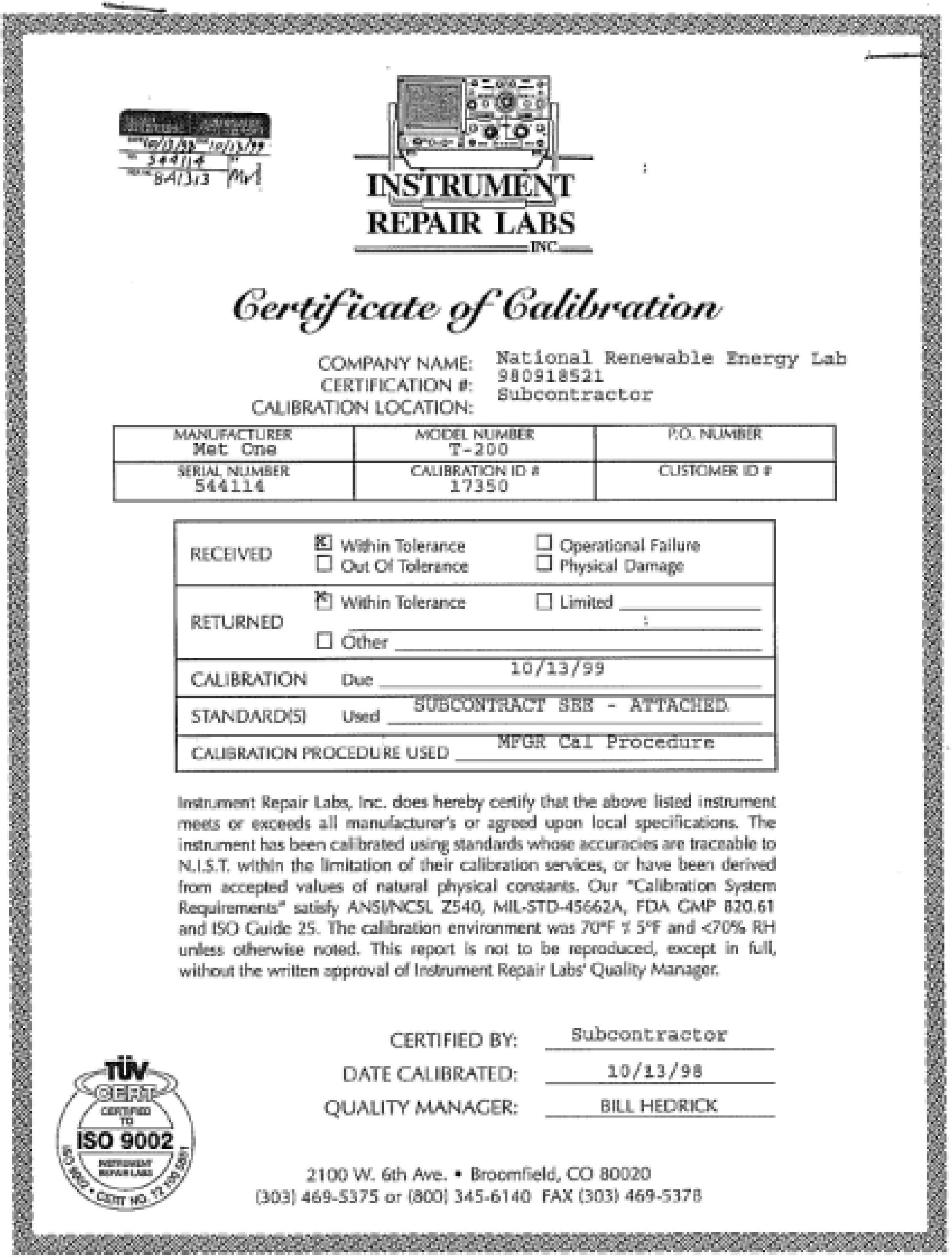
Form 07, Rev. 03, 3-26-98

Temperature Sensor 544114



10/13/98 10/13/99
544114
BA1313 MM

INSTRUMENT REPAIR LABS INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 980918521
CALIBRATION LOCATION: Subcontractor

MANUFACTURER Met One	MODEL NUMBER T-200	P.O. NUMBER
SERIAL NUMBER 544114	CALIBRATION ID # 17350	CUSTOMER ID #

RECEIVED ☒ Within Tolerance ☐ Operational Failure ☐ Out Of Tolerance ☐ Physical Damage

RETURNED ☒ Within Tolerance ☐ Limited ☐ Other

CALIBRATION Due 10/13/99

STANDARD(S) Used SUBCONTRACT SEE - ATTACHED.

CALIBRATION PROCEDURE USED MFGR Cal Procedure

Instrument Repair Labs, Inc. does hereby certify that the above listed instrument meets or exceeds all manufacturer's or agreed upon local specifications. The instrument has been calibrated using standards whose accuracies are traceable to N.I.S.T. within the limitation of their calibration services, or have been derived from accepted values of natural physical constants. Our "Calibration System Requirements" satisfy ANSI/NCSL Z540, MIL-STD-45662A, FDA GMP 820.61 and ISO Guide 25. The calibration environment was 70°F ± 5°F and <70% RH unless otherwise noted. This report is not to be reproduced, except in full, without the written approval of Instrument Repair Labs' Quality Manager.

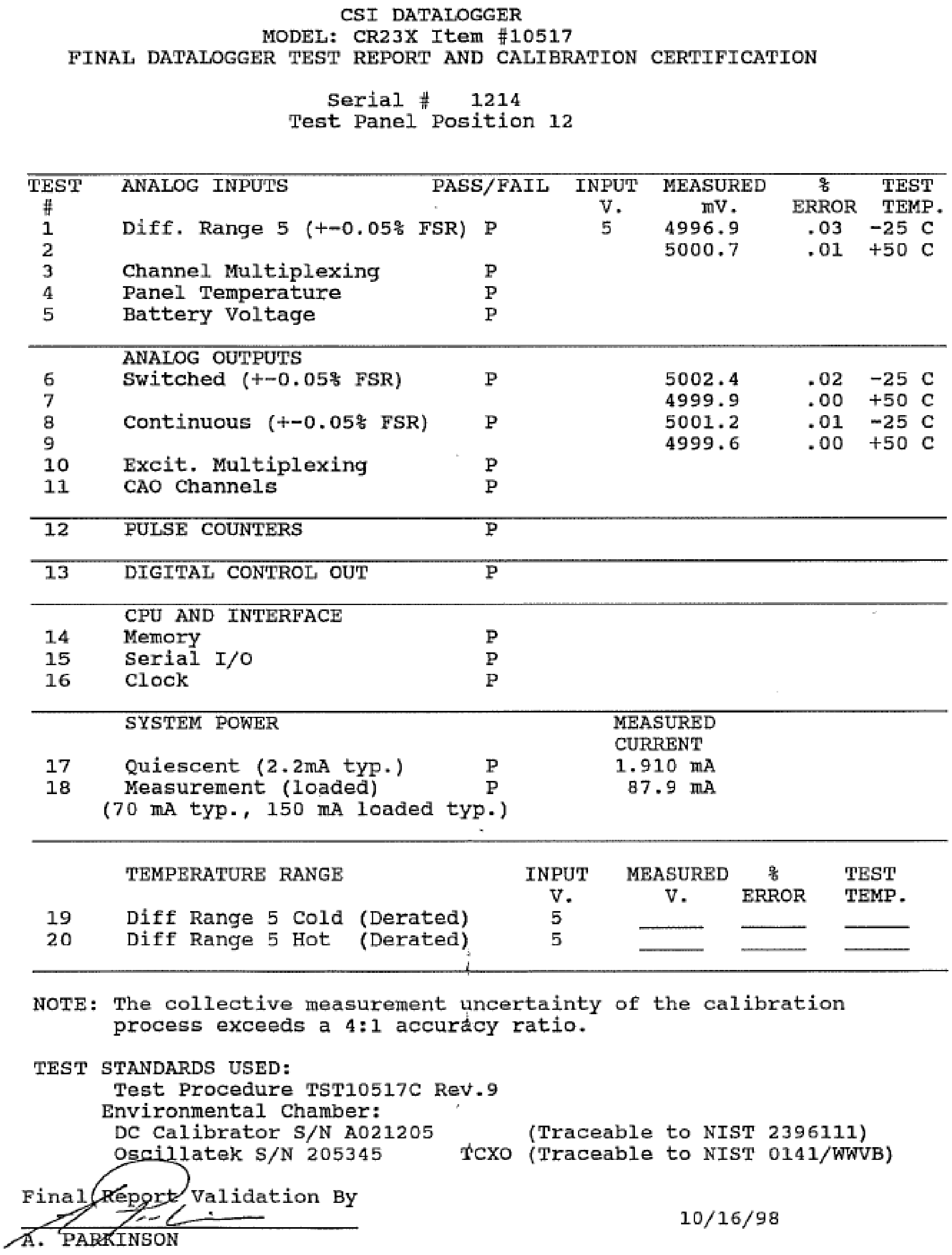
CERTIFIED BY: Subcontractor
DATE CALIBRATED: 10/13/98
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS

2100 W. 6th Ave. • Broomfield, CO 80020
(303) 469-5375 or (800) 345-6140 FAX (303) 469-5378

Form 07, Rev. 03, 3-26-98

Data Logger 1214



CSI DATALOGGER
MODEL: CR23X Item #10517
FINAL DATALOGGER TEST REPORT AND CALIBRATION CERTIFICATION

Serial # 1214
Test Panel Position 12

TEST #	ANALOG INPUTS	PASS/FAIL	INPUT V.	MEASURED mV.	% ERROR	TEST TEMP.
1	Diff. Range 5 (+-0.05% FSR)	P	5	4996.9	.03	-25 C
2				5000.7	.01	+50 C
3	Channel Multiplexing	P				
4	Panel Temperature	P				
5	Battery Voltage	P				
	ANALOG OUTPUTS					
6	Switched (+-0.05% FSR)	P		5002.4	.02	-25 C
7				4999.9	.00	+50 C
8	Continuous (+-0.05% FSR)	P		5001.2	.01	-25 C
9				4999.6	.00	+50 C
10	Excit. Multiplexing	P				
11	CAO Channels	P				
12	PULSE COUNTERS	P				
13	DIGITAL CONTROL OUT	P				
	CPU AND INTERFACE					
14	Memory	P				
15	Serial I/O	P				
16	Clock	P				

	SYSTEM POWER		MEASURED CURRENT
17	Quiescent (2.2mA typ.)	P	1.910 mA
18	Measurement (loaded) (70 mA typ., 150 mA loaded typ.)	P	87.9 mA

	TEMPERATURE RANGE	INPUT V.	MEASURED V.	% ERROR	TEST TEMP.
19	Diff Range 5 Cold (Derated)	5	______	______	______
20	Diff Range 5 Hot (Derated)	5	______	______	______

NOTE: The collective measurement uncertainty of the calibration process exceeds a 4:1 accuracy ratio.

TEST STANDARDS USED:
Test Procedure TST10517C Rev.9
Environmental Chamber:
DC Calibrator S/N A021205 (Traceable to NIST 2396111)
Oscillatek S/N 205345 TCXO (Traceable to NIST 0141/WWVB)

Final Report Validation By

A. PARKINSON

10/16/98

Appendix B: Text from the Draft Revision of IEC61400-2

This text was used for the AOC Duration Test.

9.4 Duration Testing

The purpose of the test is to investigate:

1. Structural integrity and material degradation (corrosion, cracks, deformations)
2. Quality of environmental protection of the wind turbine
3. The dynamic behavior of the turbine.

During the duration test, test procedures shall be implemented to determine if and when the test turbine successfully meets the following test criteria. The wind turbine will pass the duration test when it has achieved:

1. Reliable operation during the test period
2. 6 months of operation
3. 3000 hours of power production in winds of any velocity
4. 250 hours of power production in winds of 1,2 V_{ave} and above
5. 25 hours of power production in winds of 1,8 V_{ave} and above.

Wind speed is the 10-minute average of 1-sec wind speed samples. The highest 3-sec wind speed shall be recorded and the average turbulence intensity at 15 m/s wind speed during the test shall be derived from recorded wind speeds. These results shall be stated in the test report.

Power production means that the turbine is producing positive power, as measured by the power transducer at the connection to the grid or battery bank.

9.4.1 Reliable Operation

Reliable operation means:

1. Operational time fraction of at least 90%
2. No major failure of the turbine or components in the turbine system
3. No significant wear, corrosion, or damage to turbine components found during periodic inspections or the final turbine inspection
4. No significant degradation in time of produced power at comparable wind speeds.

If the turbine is altered in any way during the test, other than to perform scheduled maintenance or for inspections, the test organization will determine whether such an alteration has resulted from a major failure or a significant design change. The test organization's judgement shall be noted in the test report. A major failure of the wind turbine system includes any failure of the system components that affects the turbine safety and function, including blades, charge controller, alternator, yaw bearings, or inverter.

Significant wear is any wear which, extrapolated to the lifetime of the turbine, would result in unacceptable loss of strength or clearance.

9.4.1.1 Operational Time Fraction

For purposes of this test, operational time fraction is defined as the measure of performance given by the ratio of time a wind turbine shows its normal designed behavior to the test time in any evaluation period expressed as a percentage. Normal designed behavior includes the following (where applicable):

1. Turbine producing power
2. Automatic start-up and shut-down due to wind speed transitioning across low wind cut-in and high wind cut-out
3. Idling or parked states at wind speeds under $V_{cut\text{-}in}$ or above $V_{cut\text{-}out}$
4. Extended time between a normal shutdown (not caused by a failure) and a restart of the turbine (e.g. brake cool cycle, retraction of tip brakes).

The Operation time fraction, O, is given by the following equation:

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

where:

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

Note that neither the time during which the turbine status is unknown nor the time that is excluded for the analysis counts against or in favor of the operational time fraction.

The following conditions shall be considered as turbine faults and shall be part of T_N:

1. Any turbine fault condition indicated by the turbine controller that prevents the turbine from operating
2. Any automatic shutdown of the turbine by its controller due to an indicated fault
3. Manual selection of pause, stop, or test mode that prevents the turbine from operating normally for the purpose of routine maintenance or a perceived fault condition
4. Turbine inspections conducted in accordance with the manufacturer's recommendations
5. Down time due to unwrapping of the droop cable.

The following conditions shall be considered as time during which the turbine status is unknown (TU in the equation above):

1. Failure or maintenance of the data acquisition system
2. Lost or unresolvable records of turbine condition.

The following conditions shall be excluded from the test time period and be part of T_E:

1. Turbine inspections conducted as part of this test that are not recommended by the manufacturer (e.g., inspection of data acquisition system)
2. Manual selection of a pause, stop, or test mode that prevents the turbine from operating normally for any purpose other than routine maintenance or a perceived fault condition

3. Failure of the grid, battery system, inverter or any component external to the turbine system being tested (see below). If these components are considered part of the system, this time shall count as T_N.
4. Reduced or no power production due to the turbine control system sensing external conditions outside the designed external conditions.

If a turbine fault, caused during normal external conditions, is present during one of the above situations, this time shall count as $T_{N.}$

The duration test plan shall clearly state which components shall be considered parts of the turbine system and which components shall be considered as external to the turbine. This statement shall consider:

1. The mechanical interface between the turbine and the ground
2. The electrical interface between the turbine and the load
3. The control interface between the turbine and local and/or remote control devices.

In cases in which conditions may exist that are not clearly attributable to a turbine fault or an external condition, the test plan shall define to which category such conditions will be attributed. Examples of such conditions are:

1. Inadvertent actuation of tip brakes or furling
2. Confusion of the controller due to voltage transients.

The test plan shall describe instrumentation and data logging arrangements that allow for determination and recording of turbine operation status at all times during the duration test.

9.4.1.2 Power Production Degradation

To check any hidden degradation in the power performance of the turbine, the following procedure is part of the duration test.

For each month in the duration test, the power levels will be binned by wind speed (bin width 1 m/s). For each wind speed, a plot will be made with the binned power levels as a function of time. There should be no clear trend visible when plotting these points in time and fitting a trendline (slope within 0.9 and 1.1). If there is a visible trend, investigation should take place to the cause of that slope.

For battery charging systems, points with comparable state of charge should be plotted. Only data points that are considered normal operation should be used in this analysis.

9.4.2 Dynamic Behavior

The dynamic behavior of the turbine shall be assessed in order to verify that system natural frequencies do not interfere with operational frequencies. The dynamic behavior of the turbine shall be observed for at least 1 minute at wind speeds near and above 10, 15, and 20 m/s. Special attention should be paid to tower vibrations, turbine noise, tail movements, and yaw behavior.

Assess the dynamic behavior by observation or instrumentation.