April 2003 NREL/EL-500-32748

Wind Turbine Generator System

Power Performance Test Report

for the

Whisper H40

in

Golden, Colorado

by

National Wind Technology Center
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Trudy Forsyth, Arlinda Huskey

December 18, 2001

Approval By: Trudy Forsyth 16 April 03
Trudy Forsyth, NREL Test Engineer Date

Approval By: Arlinda Huskey 10 Apr 2003
Arlinda Huskey, NREL Test Engineer Date

Approval By: Harold F. Link 10 April 03
Harold F. Link, NREL Certification Senior Test Engineer Date

1.0 Table of Contents

2.0 Table of Tables

3.0 Table of Figures

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5.0 Test Summary

Figure 1 is a summary of the results of the power performance test using DC power. Figure 2 is a summary of the results of the power performance test using AC power. These results are normalized to sea-level air density. Further details of these results are given in Section 6.0: Results

This test was conducted on the Whisper H40 wind turbine located at the National Wind Technology Center (NWTC) in Boulder, Colorado. This test began on March 11, 2000, and ended on May 21, 2001. A total of 3,399.3 hours of available data were collected during that time. The highest wind speed bin filled was the 20.0 m/s bin. According to the IEC standard, enough data were collected to construct a complete power curve.

Power Performance Test
Southwest Wind Power Whisper H40

Sea-Level Density DC Power Curve

Report Created: June 18, 2001

Turbine Specifications:

Rated Power:	900 W
Cut-in Wind Speed:	3.4 m/s
Cut-out Wind Speed:	25 m/s
Rated Wind Speed:	12.5 m/s
Rotor Diameter:	2.1 m/s
Control Type:	
Pitch Setting:	13° at root to 1° at tip

Site Conditions:

Average Air Density:	1.007 kg/m^3
Measurement Sectors:	240 - 357

Test Statistics:

Start Date:	March 11, 2000
End Date:	May 21, 2001
Amount of Data Collected:	3399.3 hours
Highest Bin Filled:	20.0 m/s
Test Completed?	Yes

Bin Wind Speed (m/s)	Bin Power (W)	Number Data Points	Cp
2.03	-4.63	2332	-0.26
2.49	-4.56	2687	-0.14
2.98	-3.72	2070	-0.07
3.49	-0.11	1529	0.00
3.99	9.65	1299	0.07
4.50	28.95	1201	0.15
5.00	53.84	1128	0.20
5.49	87.68	941	0.25
5.99	125.58	871	0.28
6.50	170.52	764	0.29
6.99	215.74	687	0.30
7.49	263.61	522	0.30
7.99	310.60	475	0.29
8.49	353.44	376	0.27
8.97	396.66	266	0.26
9.50	433.94	244	0.24
9.99	462.13	191	0.22
10.49	487.12	158	0.20
10.99	503.81	109	0.18
11.50	509.09	106	0.16
11.97	518.99	109	0.14
12.49	525.92	101	0.13
12.99	532.54	76	0.11
13.51	531.85	65	0.10
14.00	539.30	56	0.09
14.47	549.98	51	0.09
15.00	572.91	48	0.08
15.51	590.76	44	0.07
16.00	610.85	43	0.07
16.50	630.79	39	0.07
16.99	622.76	31	0.06
17.50	630.12	29	0.06
17.97	640.08	23	0.05
18.44	680.39	16	0.05
19.01	674.09	10	0.05
19.53	715.79	11	0.05
19.97	725.74	6	0.04

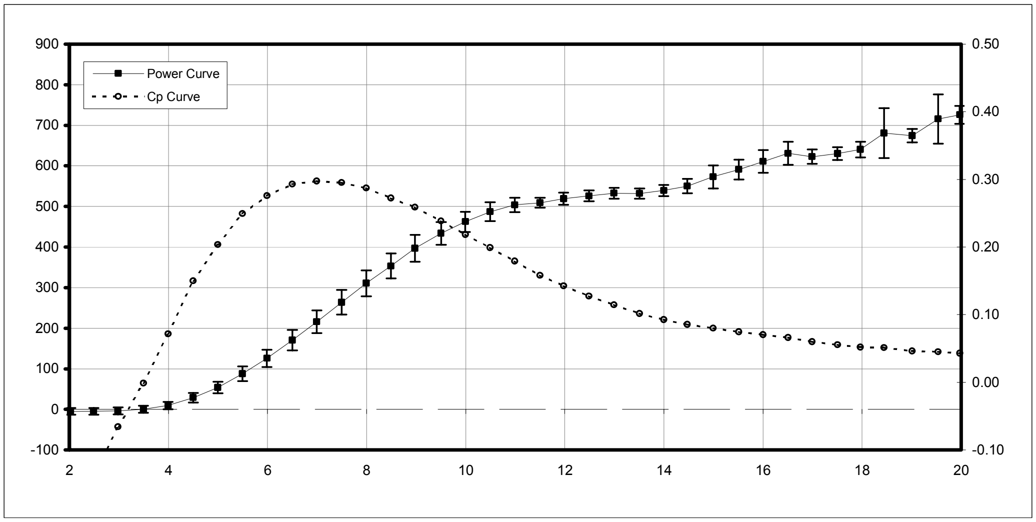


Figure 1. DC power curve summary

Power Performance Test
Southwest Wind Power Whisper H40

Sea-Level Density AC Power Curve

Report Created: June 18, 2001

Turbine Specifications:

Rated Power:	900 W
Cut-in Wind Speed:	3.4 m/s
Cut-out Wind Speed:	25 m/s
Rated Wind Speed:	12.5 m/s
Rotor Diameter:	2.1 m/s
Control Type:	
Pitch Setting:	13° at root to 1° at tip

Site Conditions:

Average Air Density:	1.007 kg/m^3
Measurement Sectors:	240 - 357

Test Statistics:

Start Date:	March 11, 2000
End Date:	May 21, 2001
Amount of Data Collected:	3399.3 hours
Highest Bin Filled:	20.0 m/s
Test Completed?	Yes

Bin Wind Speed (m/s)	Bin Power (W)	Number Data Points	Cp
2.03	-34.94	2332	-1.98
2.49	-37.88	2687	-1.16
2.98	-37.23	2070	-0.66
3.49	-33.89	1529	-0.37
3.99	-24.38	1299	-0.18
4.50	-5.38	1201	-0.03
5.00	19.42	1128	0.07
5.49	52.94	941	0.15
5.99	90.08	871	0.20
6.50	133.59	764	0.23
6.99	177.02	687	0.24
7.49	223.23	522	0.25
7.99	268.05	475	0.25
8.49	309.79	376	0.24
8.97	350.42	266	0.23
9.50	385.74	244	0.21
9.99	412.40	191	0.19
10.49	437.12	158	0.18
10.99	452.61	109	0.16
11.50	457.96	106	0.14
11.97	467.21	109	0.13
12.49	475.13	101	0.12
12.99	480.40	76	0.10
13.51	480.49	65	0.09
14.00	487.67	56	0.08
14.47	494.75	51	0.08
15.00	514.97	48	0.07
15.51	532.86	44	0.07
16.00	550.23	43	0.06
16.50	569.34	39	0.06
16.99	560.99	31	0.05
17.50	569.25	29	0.05
17.97	578.08	23	0.05
18.44	616.97	16	0.05
19.01	614.65	10	0.04
19.53	645.88	11	0.04
19.97	655.88	6	0.04

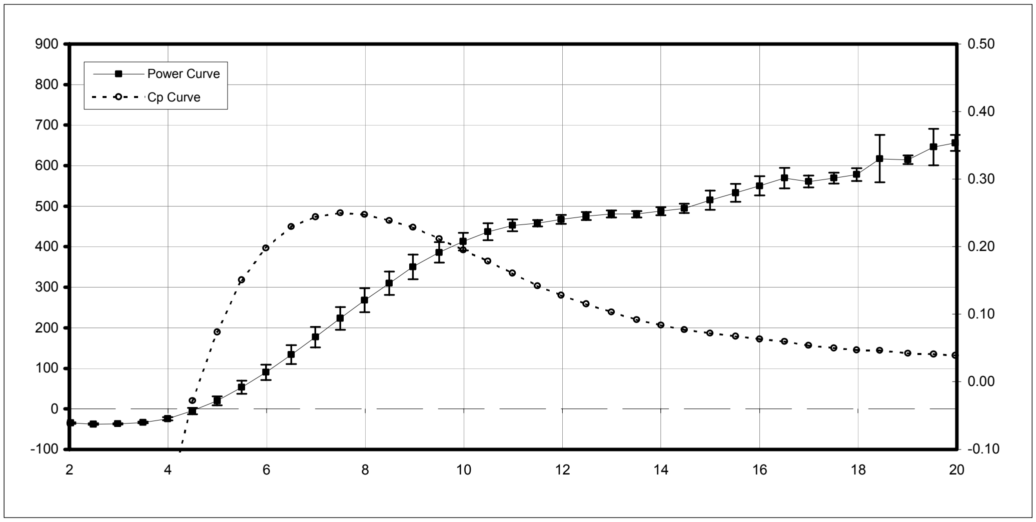


Figure 2. AC power curve summary

6.0 Results

The results of the power performance testing of the H40/Trace turbine system are described in the following sections. The first two sections describe performance based on data obtained when NREL was confident that the turbine was operating in a normal, satisfactory method. The third section describes performance based on all valid data obtained during the test period. The full data set includes data obtained when the turbine was "stuck" in a furled position when it should have returned to an unfurled position. This problem is discussed in more detail in the Whisper H40 Duration Test Report.

6.1 DC Power Performance

All the tables and figures in this section are from measurements taken on the 24-volt DC bus, between the EZ-wire controller and the Trace inverter.

6.1.1 DC Performance at Site Average Air Density

Figure 3 shows the DC power curve using data that have been normalized to the site average air density of 1.007 kg/m3. Each 10-minute data set is normalized by adjusting wind speed prior to binning. Wind speed is adjusted by multiplying measured wind speed by the cube root of the ratio of measured air density to the average air density during the entire power performance test.

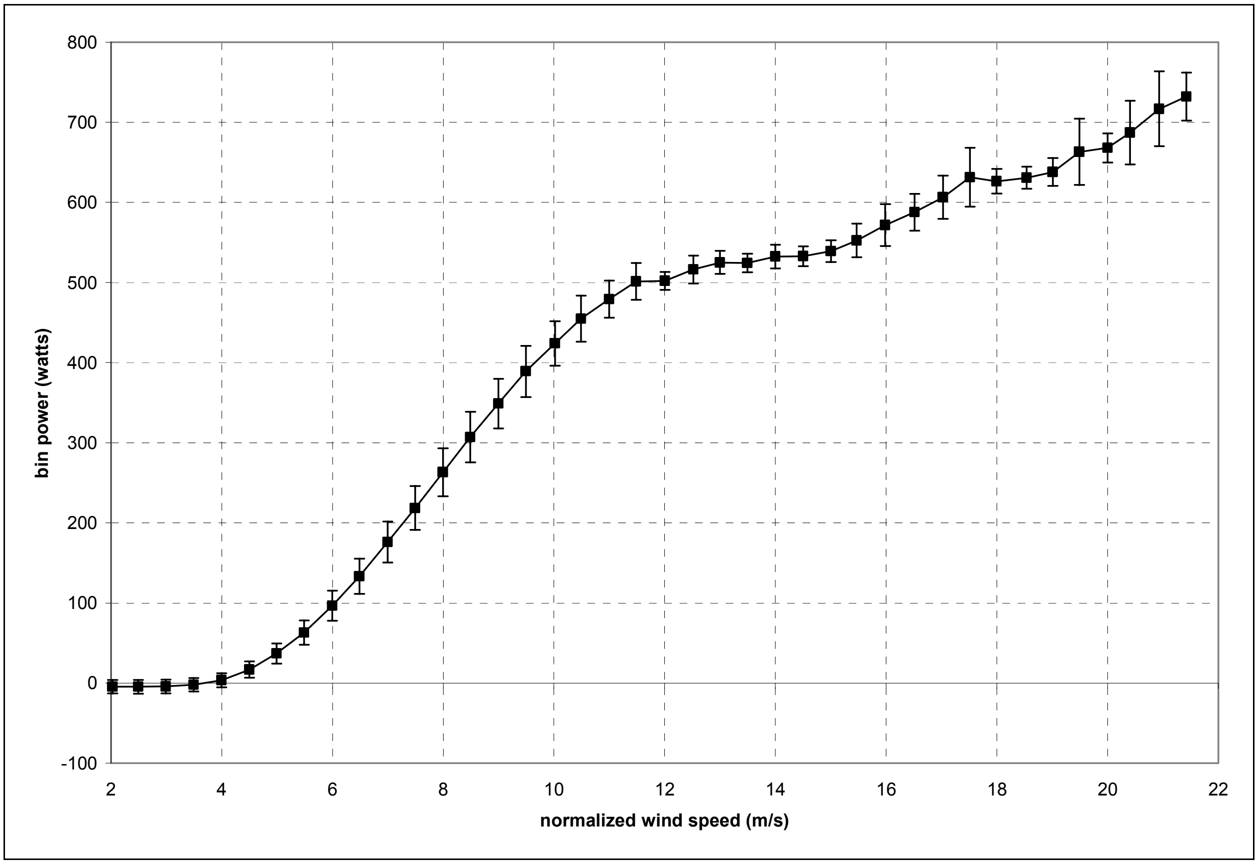


Figure 3. DC power curve at site average air density, 1.007 kg/m^3

Table 1 shows the DC power curve at site average air density in tabular form. Figure 3 and this table show results up 21.5 m/s in accordance with the IEC standard, which requires at least three 10-minute data points per bin and contiguous bins. Lack of higher wind data should not be interpreted as an indication that the turbine does not produce power at higher wind speeds.

Table 1. DC Power Performance at Site Average Air Density, 1.007 kg/m^3

Bin	Normalized Wind Speed	Power Output	Number of 10-Minute Data Sets	Category A Uncertainty	Category B Uncertainty	Combined Uncertainty
(m/s)	(m/s)	(W)		(W)	(W)	(W)
2	2.03	-4.58	1868	0.03	8.51	8.51
2.5	2.49	-4.65	2644	0.03	8.51	8.51
3	2.99	-4.24	2187	0.04	8.51	8.51
3.5	3.49	-2.06	1578	0.13	8.55	8.55
4	4.00	3.62	1339	0.25	8.78	8.78
4.5	4.50	16.90	1126	0.42	10.09	10.10
5	4.99	37.01	1096	0.52	12.41	12.42
5.5	5.49	62.97	1026	0.60	15.02	15.03
6	6.00	96.44	876	0.65	18.72	18.73
6.5	6.49	133.22	782	0.66	21.92	21.93
7	7.00	175.99	716	0.73	25.52	25.53
7.5	7.49	218.52	635	0.80	27.57	27.58
8	8.00	263.20	489	1.01	29.93	29.94
8.5	8.49	307.07	447	1.22	31.45	31.47
9	9.00	348.93	377	1.44	30.81	30.84
9.5	9.49	389.03	271	2.09	31.76	31.83
10	10.02	423.76	213	2.38	27.61	27.71
10.5	10.49	454.72	205	2.94	28.50	28.65
11	11.00	479.14	157	3.56	22.83	23.10
11.5	11.48	501.33	118	3.95	22.72	23.06
12	12.00	502.02	103	4.82	9.98	11.08
12.5	12.52	516.20	101	5.33	16.65	17.48
13	13.00	524.85	100	4.86	13.55	14.40
13.5	13.49	524.21	85	5.45	10.10	11.48
14	14.00	532.46	67	6.26	13.38	14.77
14.5	14.50	532.69	60	7.05	10.13	12.34
15	15.00	539.10	52	5.47	12.57	13.70
15.5	15.47	552.49	47	7.25	19.72	21.01
16	15.99	571.69	44	7.88	24.92	26.14
16.5	16.51	587.79	44	7.47	21.79	23.03
17	17.03	606.43	42	6.99	25.87	26.80
17.5	17.51	631.34	33	8.51	35.78	36.78
18	17.99	626.42	35	8.66	12.75	15.41
18.5	18.54	630.68	27	6.59	12.04	13.72
19	19.01	637.87	24	8.10	15.40	17.40
19.5	19.49	662.94	19	11.18	39.89	41.43
20	20.00	667.79	8	12.48	13.11	18.10
20.5	20.41	687.13	9	10.49	38.39	39.80
21	20.93	716.65	11	8.88	45.78	46.63
21.5	21.42	732.01	4	11.22	27.88	30.05
>21.5	no data					

Table 2 shows projections of annual energy production (AEP) at sites with average wind speeds varying from 4 to 11 m/s. These projections assume a) that the turbine operates as measured, b) 100% turbine availability, c) that winds correspond to the Rayleigh wind speed distribution shown, and d) that annual average air density is the same as the average air density measured during the test

AEP-measured is based on no power production in winds above the highest wind bin in Table 1. AEP-extrapolated is based on power production equal to the highest wind speed bin in Table 1 in winds between that bin and cut-out. For these AEP calculations, cut-out was assumed to be 25 m/s.

The standard requires the word “Incomplete” to be used when the measured and calculated AEP differ more then 5%. This indicates that annual energy cannot be estimated closer than 5% because high wind bins were not filled.

It is typical in projections of AEP to have a relatively high percentage uncertainty at low wind speed sites. This is due to a) uncertainty in the power curve at low and moderate wind speeds, and b) small AEP-measured.

Table 2. DC Annual Energy Production at Site Average Air Density, 1.007 kg/m^3

Cut-out wind speed: 25 m/s (extrapolation by constant power from last bin)					
Hub Height Annual Avg. Wind Speed	AEP-Measured (from measured power curve)		Uncertainty of AEP-Measured		AEP-Extrapolated (from extrapolated power curve)
(m/s)	(kWh/yr)		(kWh/yr)	(%)	(kWh/yr)
4	395	Complete	114	28.9%	395
5	819	Complete	139	17.0%	819
6	1,288	Complete	156	12.1%	1,289
7	1,746	Complete	165	9.5%	1,749
8	2,156	Complete	170	7.9%	2,175
9	2,495	Complete	172	6.9%	2,553
10	2,750	Complete	171	6.2%	2,872
11	2,917	Incomplete	169	5.8%	3,126

6.1.2 DC Performance at Sea-Level Air Density

Figure 4 shows the DC power curve after normalizing data to an air density of 1.225 kg/m3, which corresponds to a site at sea level. Each 10-minute data set is normalized by adjusting wind speed prior to binning. Wind speed is adjusted by multiplying measured wind speed by the cube root of the ratio of measured air density to the air density at sea level. As noted above, DC measurements are taken on the 24-volt DC bus, between the EZ-wire controller and the Trace inverter.

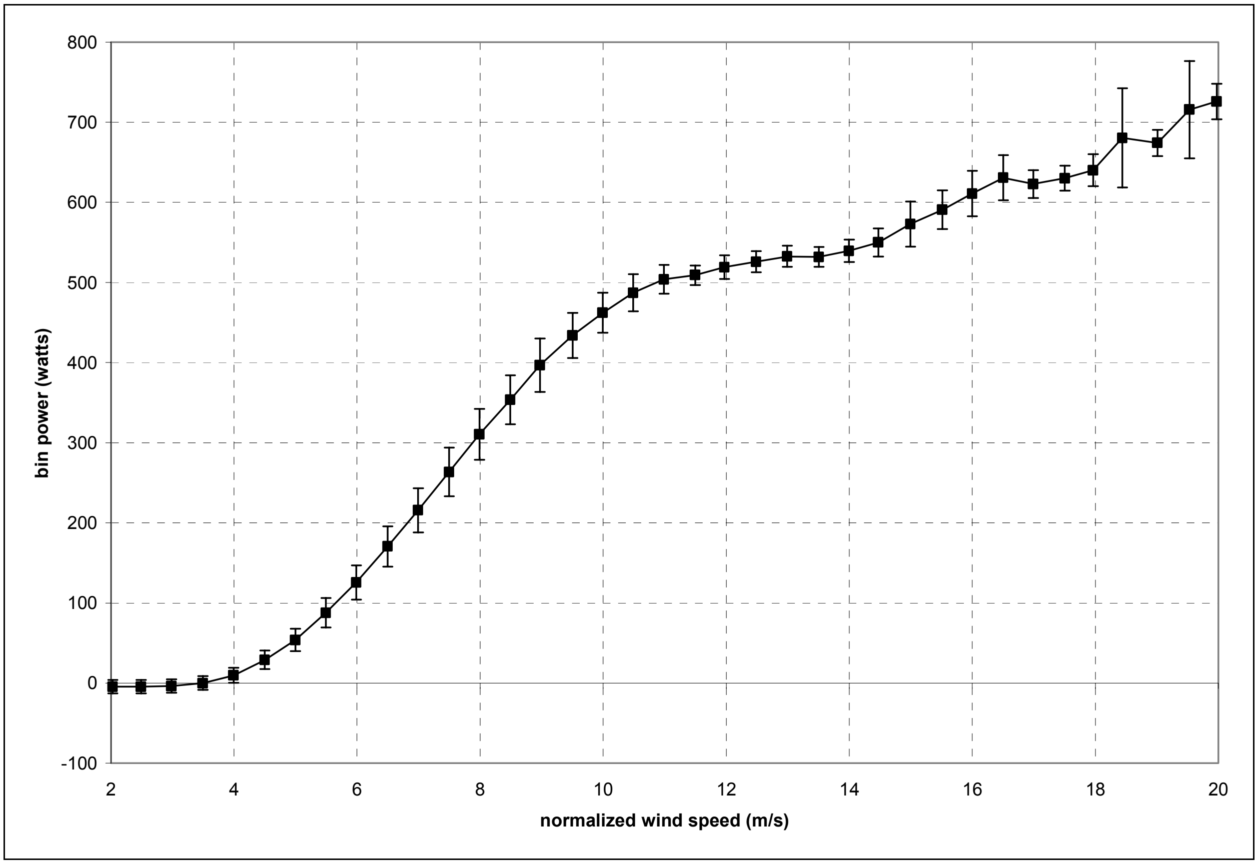


Figure 4. DC power curve at sea-level air density, 1.225 kg/m^3

Table 3 shows the DC power curve in tabular form. Both Figure 4 and this table show results up 20 m/s in accordance with the IEC standard, which requires at least three 10-minute data points per bin and contiguous bins. Lack of higher wind data should not be interpreted as an indication that the turbine does not produce power at higher wind speeds.

Table 3. DC Power Performance at Sea-Level Air Density, 1.225 kg/m^3

Bin	Normalized Wind Speed	Power Output	Number of 10-Minute Data Sets	Category A Uncertainty	Category B Uncertainty	Combined Uncertainty
(m/s)	(m/s)	(W)		(W)	(W)	(W)
2	2.03	-4.63	2332	0.03	8.51	8.51
2.5	2.49	-4.56	2687	0.03	8.51	8.51
3	2.98	-3.72	2070	0.07	8.52	8.52
3.5	3.49	-0.11	1529	0.17	8.60	8.61
4	3.99	9.65	1299	0.33	9.29	9.30
4.5	4.50	28.95	1201	0.48	11.56	11.57
5	5.00	53.84	1128	0.55	13.93	13.94
5.5	5.49	87.68	941	0.63	18.27	18.28
6	5.99	125.58	871	0.68	21.18	21.19
6.5	6.50	170.52	764	0.74	25.28	25.29
7	6.99	215.74	687	0.78	27.68	27.69
7.5	7.49	263.61	522	1.01	30.29	30.31
8	7.99	310.60	475	1.17	31.82	31.85
8.5	8.49	353.44	376	1.48	30.47	30.51
9	8.97	396.66	266	2.13	33.11	33.18
9.5	9.50	433.94	244	2.38	28.02	28.12
10	9.99	462.13	191	3.22	24.69	24.90
10.5	10.49	487.12	158	3.57	22.77	23.05
11	10.99	503.81	109	4.32	17.41	17.94
11.5	11.50	509.09	106	5.30	11.02	12.23
12	11.97	518.99	109	4.82	13.89	14.71
12.5	12.49	525.92	101	5.11	12.02	13.06
13	12.99	532.54	76	5.48	12.05	13.23
13.5	13.51	531.85	65	7.00	10.14	12.32
14	14.00	539.30	56	5.07	13.02	13.98
14.5	14.47	549.98	51	6.87	16.12	17.52
15	15.00	572.91	48	7.63	27.14	28.19
15.5	15.51	590.76	44	7.32	22.96	24.10
16	16.00	610.85	43	7.51	27.21	28.23
16.5	16.50	630.79	39	7.66	27.11	28.17
17	16.99	622.76	31	8.91	15.09	17.53
17.5	17.50	630.12	29	6.15	14.33	15.59
18	17.97	640.08	23	7.79	18.24	19.84
18.5	18.44	680.39	16	11.67	60.65	61.77
19	19.01	674.09	10	9.52	13.57	16.57
19.5	19.53	715.79	11	8.83	60.06	60.71
20	19.97	725.74	6	8.68	20.54	22.30
>20	no data					

Table 4 shows projections of AEP at sites with average wind speeds varying from 4 to 11 m/s. These projections assume a) that the turbine operates as measured, b) 100% turbine availability, c) that winds correspond to the Rayleigh wind speed distribution shown, and d) that annual average air density is the same as the average air density measured during the test.

AEP-measured is based on no power production in winds above the highest wind bin in Table 3. AEP-extrapolated is based on power production equal to the highest wind speed bin in Table 3 in winds between that bin and cut-out. For these AEP calculations, cut-out was assumed to be 25 m/s.

The standard requires the word “Incomplete” to be used when the measured and calculated AEP differ more then 5%. This indicates that annual energy cannot be estimated closer than 5% because high wind bins were not filled.

It is typical in projections of AEP to have a relatively high percentage uncertainty at low wind speed sites. This is due to a) uncertainty in wind speed measurements, b) high slope of the power curve in moderate winds (small errors in wind speed result in large errors in power), and c) small AEP-measured.

Table 4. DC Annual Energy Production at Sea-Level Air Density, 1.225 kg/m^3

Cut-out wind speed: 25 m/s (extrapolation by constant power from last bin)					
Hub Height Annual Avg. Wind Speed	AEP-Measured (from measured power curve)		Uncertainty of AEP-Measured		AEP-Extrapolated (from extrapolated power curve)
(m/s)	(kWh/yr)		(kWh/yr)	(%)	(kWh/yr)
4	502	Complete	122	24.4%	502
5	976	Complete	146	15.0%	976
6	1,478	Complete	161	10.9%	1,479
7	1,947	Complete	168	8.6%	1,957
8	2,347	Complete	172	7.3%	2,391
9	2,656	Complete	173	6.5%	2,772
10	2,864	Incomplete	171	6.0%	3,092
11	2,979	Incomplete	168	5.6%	3,343

6.2 AC Power Performance

All the tables and figures in this section are from power measurements taken on the AC output of the turbine system, between the Trace inverter and a transformer connected to the NWTC electrical grid. These results include inverter losses of approximately 30 watts when the turbine was not producing power and 6% of the power when the turbine was producing power.

6.2.1 AC Performance at Site Average Air Density

Figure 5 shows the AC power curve using data that have been normalized to the site average air density of 1.007 kg/m^3. Each 10-minute data set is normalized by adjusting wind speed prior to binning. Wind speed is adjusted by multiplying measured wind speed by the cube root of the ratio of measured air density to the average air density during the entire power performance test.

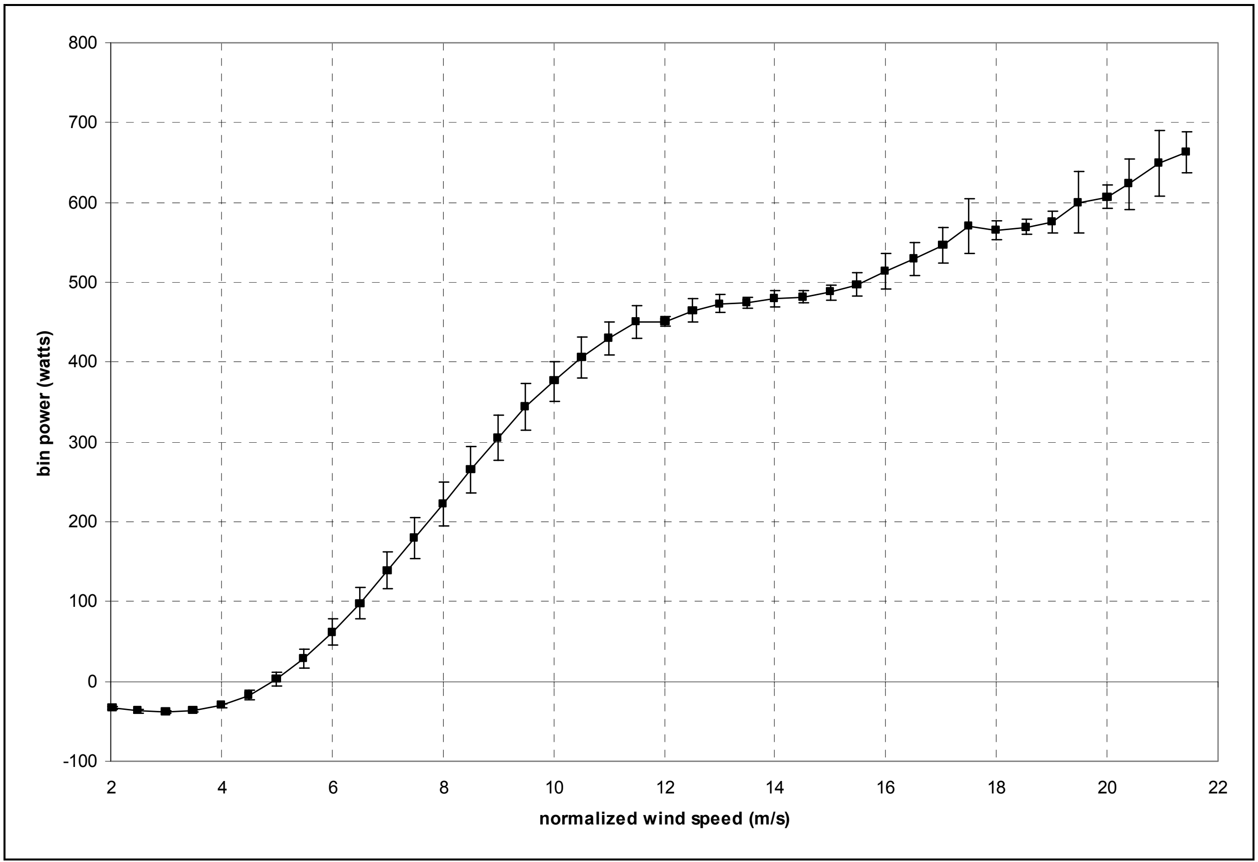


Figure 5. AC power curve at site average air density, 1.007 kg/m^3

Table 5 shows the AC power curve at site average air density in tabular form. Both Figure 5 and this table show results up 21.5 m/s in accordance with the IEC standard, which requires at least three 10-minute data points per bin and contiguous bins. Lack of higher wind data should not be interpreted as an indication that the turbine does not produce power at higher wind speeds.

Table 5. AC Power Performance at Site Average Air Density, 1.007 kg/m^3

Bin	Normalized Wind Speed	Power Output	Number of 10-Min Sets	Category A Uncertainty	Category B Uncertainty	Combined Uncertainty
(m/s)	(m/s)	(W)		(W)	(W)	(W)
2	2.03	-33.83	1868	0.15	1.83	1.84
2.5	2.49	-37.37	2644	0.15	2.11	2.12
3	2.99	-37.67	2187	0.16	1.79	1.79
3.5	3.49	-35.99	1578	0.23	1.88	1.89
4	4.00	-30.24	1339	0.31	2.81	2.82
4.5	4.50	-17.22	1126	0.46	5.58	5.60
5	4.99	2.62	1096	0.56	9.08	9.09
5.5	5.49	28.68	1026	0.63	12.53	12.54
6	6.00	61.39	876	0.68	16.36	16.38
6.5	6.49	97.59	782	0.72	19.93	19.95
7	7.00	139.00	716	0.77	23.32	23.33
7.5	7.49	179.51	635	0.87	25.00	25.01
8	8.00	222.72	489	1.04	27.74	27.76
8.5	8.49	264.90	447	1.23	29.10	29.13
9	9.00	305.04	377	1.42	28.36	28.40
9.5	9.49	343.59	271	2.01	29.38	29.45
10	10.02	376.13	213	2.31	24.55	24.66
10.5	10.49	405.49	205	2.77	25.71	25.86
11	11.00	429.33	157	3.44	20.54	20.83
11.5	11.48	450.20	118	3.79	19.70	20.06
12	12.00	450.96	103	4.60	4.39	6.36
12.5	12.52	464.64	101	4.88	13.58	14.42
13	13.00	473.23	100	4.61	10.06	11.07
13.5	13.49	473.51	85	5.08	4.53	6.80
14	14.00	479.76	67	5.85	8.06	9.96
14.5	14.50	481.61	60	6.31	5.02	8.06
15	15.00	487.58	52	4.70	8.30	9.54
15.5	15.47	496.97	47	6.44	12.73	14.26
16	15.99	513.99	44	6.95	20.68	21.81
16.5	16.51	529.92	44	6.53	19.58	20.64
17	17.03	545.94	42	6.16	20.92	21.81
17.5	17.51	570.27	33	7.32	33.78	34.57
18	17.99	564.95	35	7.68	9.22	11.99
18.5	18.54	568.82	27	5.63	7.32	9.23
19	19.01	575.82	24	7.00	12.00	13.89
19.5	19.49	600.00	19	9.36	37.43	38.58
20	20.00	607.10	8	9.37	12.00	15.22
20.5	20.41	622.60	9	8.87	30.03	31.32
21	20.93	648.89	11	7.16	39.97	40.61
21.5	21.42	662.80	4	7.95	23.86	25.15
>21.5	no data					

Table 6 shows projections of AEP at sites with average wind speeds varying from 4 to 11 m/s. These projections assume a) that the turbine operates as measured, b) 100% turbine availability, c) that winds correspond to the Rayleigh wind speed distribution shown, and d) that annual average air density is the same as the average air density measured during the test

AEP-measured is based on no power production in winds above the highest wind bin in Table 5. AEP-extrapolated is based on power production equal to the highest wind speed bin in Table 5 in winds between that bin and cut-out. For these AEP calculations, cut-out was assumed to be 25 m/s.

The standard requires the word "Incomplete" to be used when the measured and calculated AEP differ more then 5%. This indicates that annual energy cannot be estimated closer than 5% because high wind bins were not filled.

It is typical in projections of AEP to have a relatively high percentage uncertainty at low wind speed sites. This is due to a) uncertainty in wind speed measurements, b) high slope of the power curve in moderate winds (small errors in wind speed result in large errors in power), and c) small AEP-measured.

Table 6. AC Annual Energy Production at Site Average Density, 1.007 kg/m^3

Cut-out wind speed: 25 m/s (extrapolation by constant power from last bin)					
Hub Height Annual Avg. Wind Speed	AEP-Measured (from measured power curve)		Uncertainty of AEP-Measured		AEP-Extrapolated (from extrapolated power curve)
(m/s)	(kWh/yr)		(kWh/yr)	(%)	(kWh/yr)
4	104	Complete	72	69.6%	104
5	511	Complete	102	20.0%	511
6	963	Complete	122	12.6%	963
7	1,403	Complete	132	9.4%	1,406
8	1,797	Complete	138	7.7%	1,814
9	2,124	Complete	140	6.6%	2,176
10	2,371	Complete	140	5.9%	2,482
11	2,537	Incomplete	138	5.4%	2,725

6.2.2 AC Performance at Sea-Level Air Density

Figure 6 shows the AC power curve after normalizing data to an air density of 1.225 kg/m^3, which corresponds to a site at sea level. Each 10-minute data set is normalized by adjusting wind speed prior to binning. Wind speed is adjusted by multiplying measured wind speed by the cube root of the ratio of measured air density to the air density at sea level. As noted above, AC measurements are taken on the AC output of the turbine system, between the Trace inverter and a transformer connected to the NWTC electrical grid.

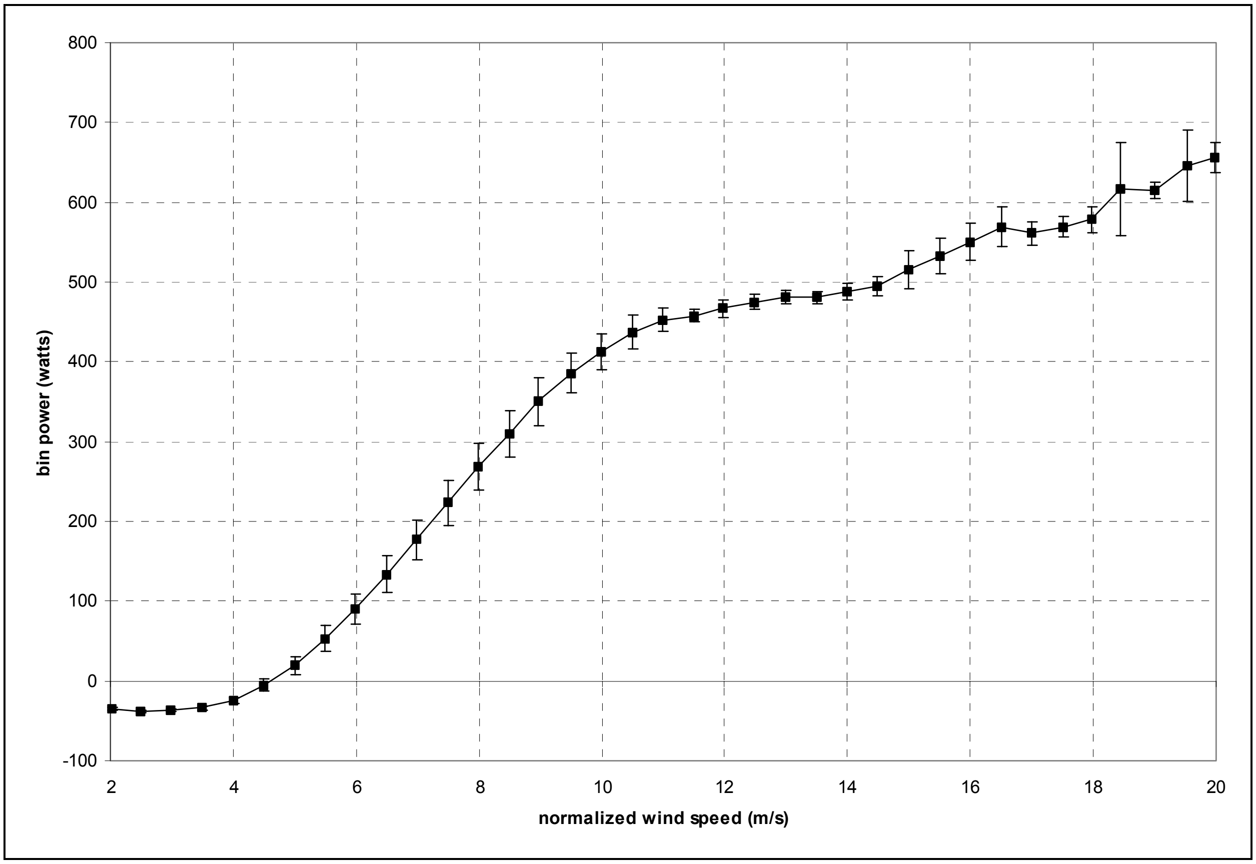


Figure 6. AC power curve at sea-level air density, 1.225 kg/m^3

Table 7 shows the AC power curve in tabular form. Both Figure 6 and this table show results up 20 m/s in accordance with the IEC standard, which requires at least three 10-minute data points per bin and contiguous bins. Lack of higher wind data should not be interpreted as an indication that the turbine does not produce power at higher wind speeds.

Table 7. AC Power Performance at Sea-Level Air Density, 1.225 kg/m^3

Bin	Normalized Wind Speed	Power Output	Number of 10-Minute Data Sets	Category A Uncertainty	Category B Uncertainty	Combined Uncertainty
(m/s)	(m/s)	(W)		(W)	(W)	(W)
2	0.59	-34.94	2332	0.14	1.94	1.94
2.5	1.06	-37.88	2687	0.14	2.02	2.03
3	1.54	-37.23	2070	0.18	1.80	1.80
3.5	2.03	-33.89	1529	0.26	2.12	2.13
4	2.49	-24.38	1299	0.39	4.03	4.05
4.5	2.98	-5.38	1201	0.52	7.90	7.91
5	3.49	19.42	1128	0.58	11.10	11.12
5.5	3.99	52.94	941	0.66	16.09	16.11
6	4.50	90.08	871	0.71	19.06	19.08
6.5	5.00	133.59	764	0.78	23.08	23.10
7	5.49	177.02	687	0.83	25.31	25.33
7.5	5.99	223.23	522	1.04	28.06	28.08
8	6.50	268.05	475	1.19	29.24	29.27
8.5	6.99	309.79	376	1.45	28.46	28.50
9	7.49	350.42	266	2.08	30.05	30.12
9.5	7.99	385.74	244	2.30	25.23	25.33
10	8.49	412.40	191	3.07	21.83	22.04
10.5	8.97	437.12	158	3.41	20.73	21.01
11	9.50	452.61	109	4.15	13.95	14.55
11.5	9.99	457.96	106	4.95	6.43	8.11
12	10.49	467.21	109	4.46	10.01	10.96
12.5	10.99	475.13	101	4.79	8.74	9.97
13	11.50	480.40	76	5.15	6.93	8.63
13.5	11.97	480.49	65	6.31	4.58	7.79
14	12.49	487.67	56	4.32	9.11	10.08
14.5	12.99	494.75	51	6.12	9.51	11.31
15	13.51	514.97	48	6.71	22.66	23.63
15.5	14.00	532.86	44	6.38	21.09	22.03
16	14.47	550.23	43	6.69	22.29	23.27
16.5	15.00	569.34	39	6.59	24.45	25.33
17	15.51	560.99	31	7.86	12.29	14.59
17.5	16.00	569.25	29	5.34	11.95	13.09
18	16.50	578.08	23	6.62	14.13	15.61
18.5	16.99	616.97	16	9.05	57.84	58.54
19	17.50	614.65	10	8.84	6.44	10.93
19.5	17.97	645.88	11	7.75	44.59	45.25
20	18.44	655.88	6	6.67	18.28	19.46
>20	no data					

Table 8 shows projections of AEP at sites with average wind speeds varying from 4 to 11 m/s. These projections assume a) that the turbine operates as measured, b) 100% turbine availability, c) that winds correspond to the Rayleigh wind speed distribution shown, and d) that annual average air density is the same as the average air density measured during the test.

AEP-measured is based on no power production in winds above the highest wind bin in Table 7. AEP-extrapolated is based on power production equal to the highest wind speed bin in Table 7 in winds between that bin and cut-out. For these AEP calculations, cut-out was assumed to be 25 m/s.

The standard requires the word “Incomplete” to be used when the measured and calculated AEP differ more then 5%. This indicates that annual energy cannot be estimated closer than 5% because high wind bins were not filled.

It is typical in projections of AEP to have a relatively high percentage uncertainty at low wind speed sites. This is due to a) uncertainty in wind speed measurements, b) high slope of the power curve in moderate winds (small errors in wind speed result in large errors in power), and c) small AEP-measured.

Table 8. AC Annual Energy Production at Sea-Level Air Density, 1.225 kg/m^3

Cut-out wind speed: 25 m/s (extrapolation by constant power from last bin)					
Hub Height Annual Avg. Wind Speed	AEP-Measured (from measured power curve)		Uncertainty of AEP-Measured		AEP-Extrapolated (from extrapolated power curve)
(m/s)	(kWh/yr)		(kWh/yr)	(%)	(kWh/yr)
4	206	Complete	82	39.9%	206
5	663	Complete	111	16.8%	663
6	1,145	Complete	128	11.2%	1,146
7	1,596	Complete	137	8.6%	1,605
8	1,981	Complete	140	7.1%	2,021
9	2,280	Complete	141	6.2%	2,385
10	2,484	Incomplete	140	5.6%	2,690
11	2,602	Incomplete	137	5.3%	2,931

6.3 Impaired Power Performance

This section quantifies the performance obtained from the turbine during the entire test period. It includes data obtained when the turbine was experiencing a problem with the furling mechanism that caused it to remain furled in low wind speeds. Results are presented in terms of DC power output normalized to sea-level air density. They can be compared with the results shown in Section 6.1.2.

Figure 7 shows the DC power curve using ALL performance data (including impaired performance data) after normalizing data to an air density of 1.225 kg/m3, which corresponds to a site at sea level. Each 10-minute data set is normalized by adjusting wind speed prior to binning. Wind speed is adjusted by multiplying measured wind speed by the cube root of the ratio of measured air density to the air density at sea level. As noted above, DC measurements are taken on the 24-volt DC bus, between the EZ-wire controller and the Trace inverter.

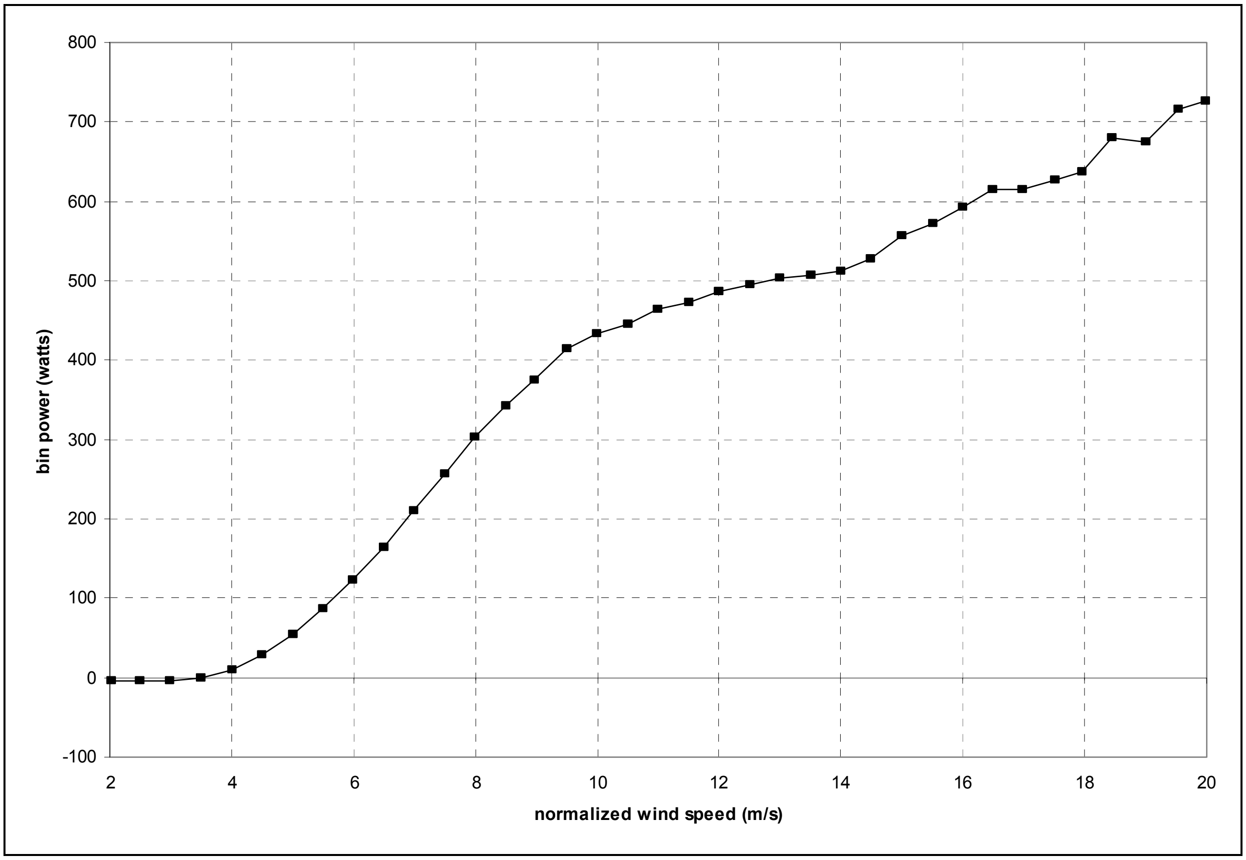


Figure 7. DC power curve based on ALL data at sea-level air density, 1.225 kg/m^3

Table 9 shows the DC power curve in tabular form. This table is based on ALL performance data (including impaired performance data) after normalizing data to an air density of 1.225 kg/m^3, which corresponds to a site at sea level. Both Figure 7 and this table show results up 20 m/s in accordance with the IEC standard, which requires at least three 10-minute data points per bin and contiguous bins. Lack of higher wind data should not be interpreted as an indication that the turbine does not produce power at higher wind speeds.

Table 9. DC Power Performance Based on ALL Data at Sea-Level Air Density, 1.225 kg/m^3

Bin	Normalized Wind Speed	Power Output	Number of 10-Minute Data Sets	Category A Uncertainty	Category B Uncertainty	Combined Uncertainty
(m/s)	(m/s)	(W)		(W)	(W)	(W)
2	2.03	-4.63	2,332	0.03	1.75	1.75
2.5	2.49	-4.56	2,687	0.03	1.75	1.75
3	2.98	-3.72	2,070	0.07	1.77	1.78
3.5	3.49	-0.11	1,529	0.17	2.15	2.16
4	3.99	9.65	1,299	0.33	4.11	4.13
4.5	4.50	28.95	1,201	0.48	8.02	8.03
5	5.00	53.84	1,128	0.55	11.16	11.17
5.5	5.49	86.96	949	0.68	15.89	15.91
6	5.99	122.44	894	0.93	18.23	18.25
6.5	6.50	164.47	796	1.29	22.30	22.34
7	6.99	209.90	711	1.43	26.53	26.57
7.5	7.49	256.07	542	2.00	28.13	28.20
8	7.99	303.70	492	2.09	31.24	31.31
8.5	8.49	341.60	401	2.93	25.63	25.80
9	8.98	374.50	296	4.72	24.48	24.93
9.5	9.50	414.91	274	4.25	28.91	29.22
10	9.99	432.66	226	5.72	14.81	15.88
10.5	10.49	445.32	204	6.41	11.21	12.92
11	10.99	464.42	136	8.02	17.18	18.96
11.5	11.50	473.08	134	7.58	8.78	11.60
12	11.98	486.15	133	7.62	13.35	15.37
12.5	12.50	494.47	121	8.02	9.11	12.14
13	12.99	503.35	92	8.27	10.11	13.06
13.5	13.51	507.62	77	8.87	6.43	10.96
14	13.99	512.42	68	8.51	7.20	11.14
14.5	14.48	527.80	61	8.83	18.09	20.13
15	14.99	556.87	53	9.87	33.10	34.54
15.5	15.51	571.83	52	8.80	17.88	19.92
16	16.00	591.89	50	9.36	25.86	27.50
16.5	16.49	614.77	44	9.69	29.47	31.02
17	16.98	615.43	33	9.80	5.80	11.39
17.5	17.51	627.26	30	6.59	16.16	17.45
18	17.96	636.72	24	8.18	15.42	17.46
18.5	18.44	680.39	16	11.67	64.06	65.12
19	19.01	674.09	10	9.52	10.13	13.90
19.5	19.53	715.79	11	8.83	59.37	60.02
20	19.97	725.74	6	8.68	18.40	20.35
>20	no data					

Table 10 shows projections of annual energy production (AEP) at sites with average wind speeds varying from 4 to 11 m/s. These projections assume a) the turbine operates as measured, b) 100% turbine availability, c) that winds correspond to the Rayleigh wind speed distribution shown, and d) that annual average air density is the same as the average air density measured during the test.

AEP-measured is based on no power production in winds above the highest wind bin in Table 9. AEP-extrapolated is based on power production equal to the highest wind speed bin in Table 9 in winds between that bin and cut-out. For these AEP calculations, cut-out was assumed to be 25 m/s.

The standard requires the word "Incomplete" to be used when the measured and calculated AEP differ more then 5%. This indicates that annual energy cannot be estimated closer than 5% because high wind bins were not filled.

It is typical in projections of AEP to have a relatively high percentage uncertainty at low wind speed sites. This is due to a) uncertainty in wind speed measurements, b) high slope of the power curve in moderate winds (small errors in wind speed result in large errors in power), and c) small AEP-measured.

Table 10. DC Annual Energy Production based on ALL Data at Sea-Level Air Density, 1.225 kg/m^3

Cut-out wind speed: 25 m/s (extrapolation by constant power from last bin)					
Hub Height Annual Avg. Wind Speed	AEP-Measured (from measured power curve)		Uncertainty of AEP-Measured		AEP-Extrapolated (from extrapolated power curve)
(m/s)	(kWh/yr)		(kWh/yr)	(%)	(kWh/yr)
4	486	Complete	80	24.4%	486
5	939	Complete	108	15.0%	939
6	1,413	Complete	125	10.9%	1,414
7	1,857	Complete	134	8.6%	1,868
8	2,240	Complete	140	7.3%	2,284
9	2,538	Complete	143	6.5%	2,655
10	2,742	Incomplete	144	6.0%	2,970
11	2,857	Incomplete	142	5.6%	3,221

6.4 Other Characterizations of Performance Data

In accordance with the IEC standard, this section reports other characterizations of performance data. Normally these characterizations would include graphs of:

a. The statistical parameters of the power measurements (mean, standard deviation, minimum, and maximum) as a function of wind speed
b. Mean wind speed and turbulence intensity as a function of wind direction
c. Coefficient of performance as a function of wind speed.

This test report reports only the scatter plot of the 10-minute mean power readings and the coefficient of performance as a function of wind speed. Figure 8 shows the scatter plot for 10-minute averages of the DC power data. Dark blue data points shown in this graph that do not have a corresponding light purple point in the middle are points where the turbine appeared to have a furling or other operational problem.

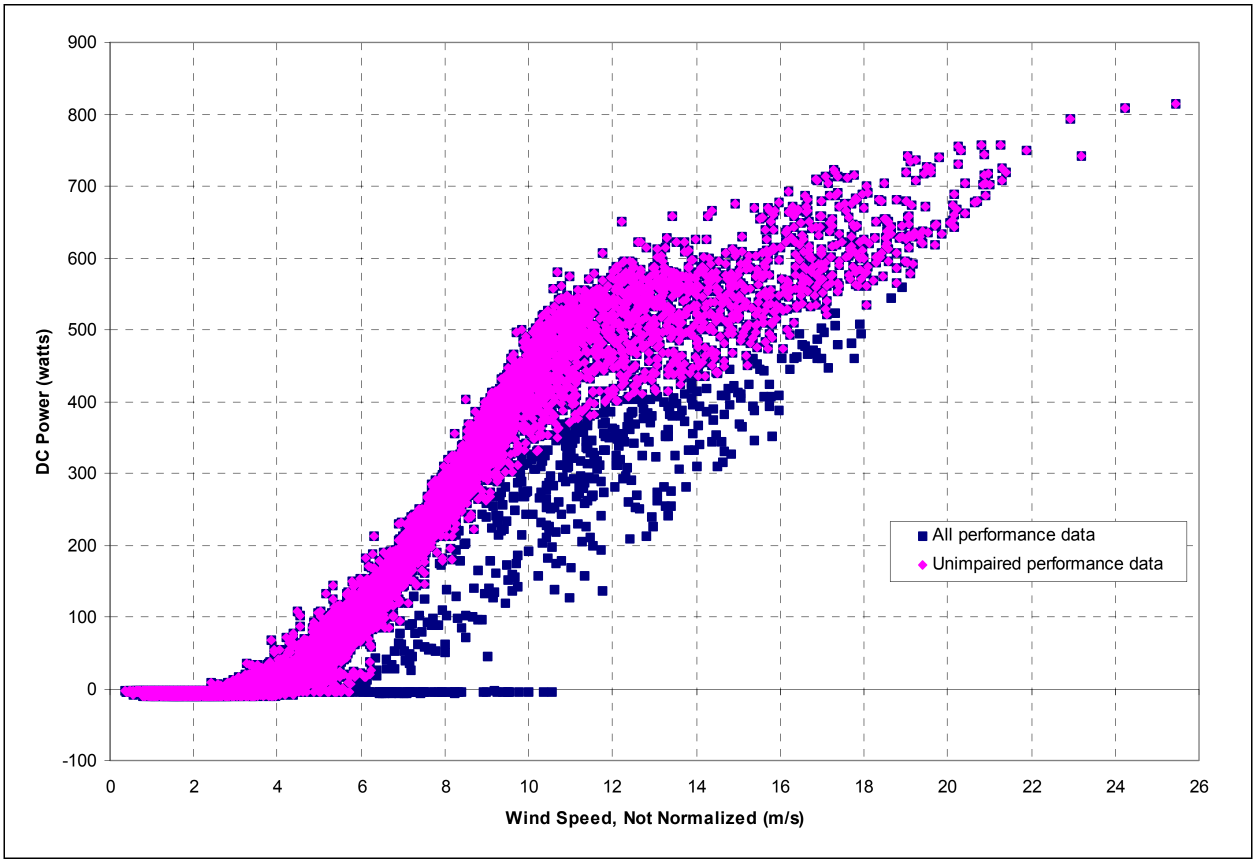


Figure 8. Scatter plot of DC power data

Figure 9 shows the coefficient of performance as a function of wind speed normalized to sea-level air density and DC power. Inclusion of data from the times that the turbine exhibited some performance impairment causes the Cp curve to be lowered slightly.

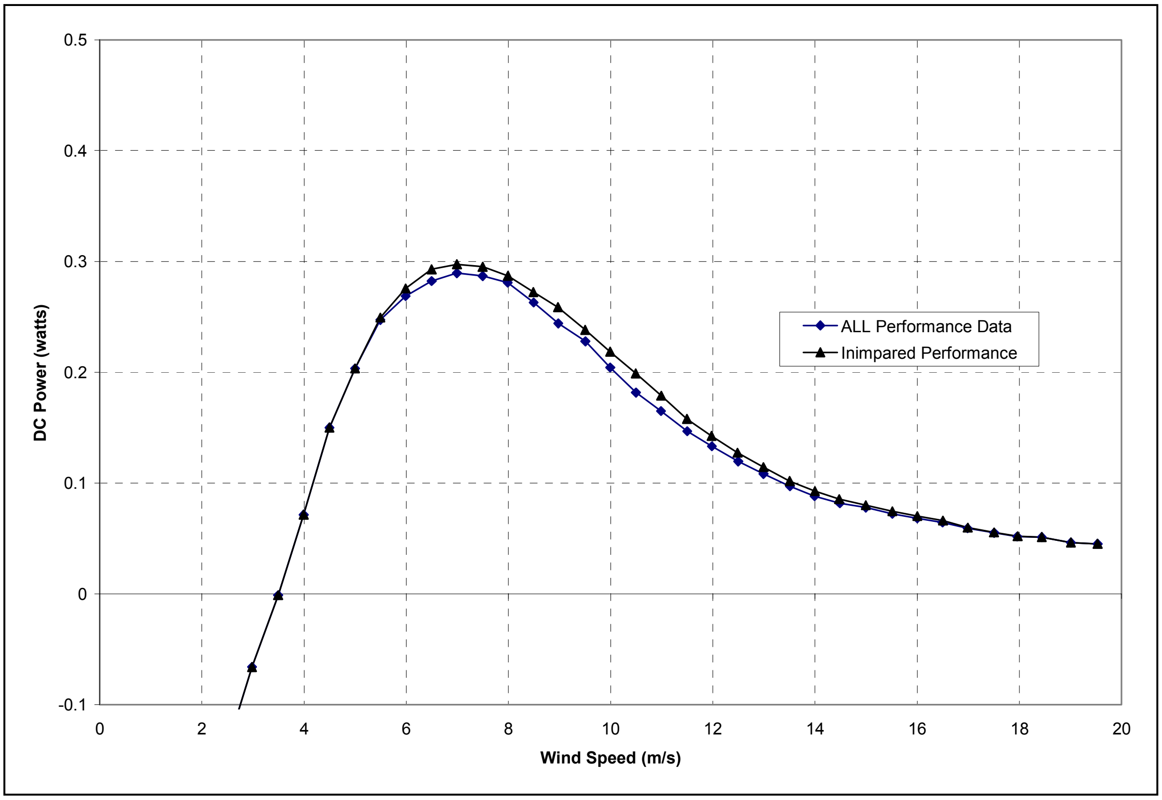


Figure 9. Coefficient of performance at sea-level air density (using DC power), 1.225 kg/m^3

7.0 Discussion of Results

The power curve (see Figure 3) shows a flattening around 11 m/s, which is probably due to furling. But even after furling, the power continues to rise, possibly due to the slight vertical furl incorporated in the patented Angle Governor.

The power curve scatter plot (see Figure 8) shows the effect of furling. The lower bounds of the data scatter indicate the power production when furled. The upper bounds indicate power level when unfurled. Data between these limits provide a coarse indication of the percentage of time that the turbine was furled during the data set. When the turbine exhibited a furling problem, the percentage of time was significantly increased during moderate wind operation.

8.0 Exceptions

8.1 Exceptions to Standard

The following exceptions were taken from the IEC standard:

1. Data normalization was performed using monthly averages of temperature and pressure as recorded by instruments at an adjacent test site. Pressure measurements were adjusted for the difference in pressure sensor height from the hub height of the Whisper H40 test turbine. And NREL added additional uncertainty. This method should cause no significant biasing error. It does add slightly to scatter of the normalized data.
2. Plots of standard deviation, minimum, and maximum power levels for each 10-minute data set were not reported.
3. A plot of mean wind and turbulence intensity as functions of wind direction was not reported.

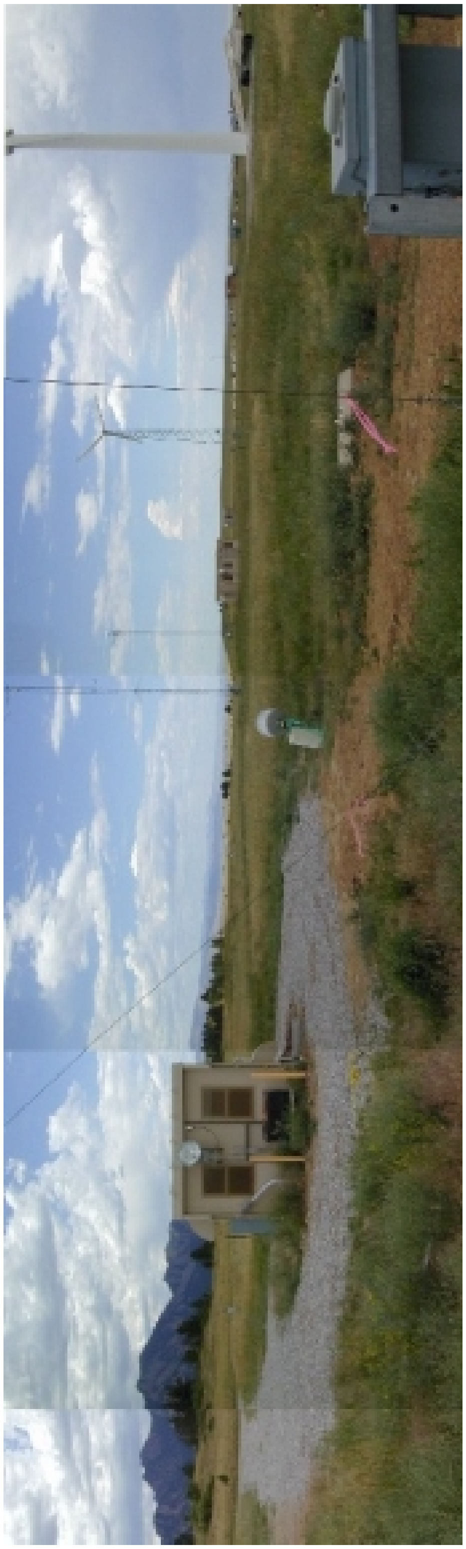
8.2 Exceptions to NWTC-CT Quality Assurance System

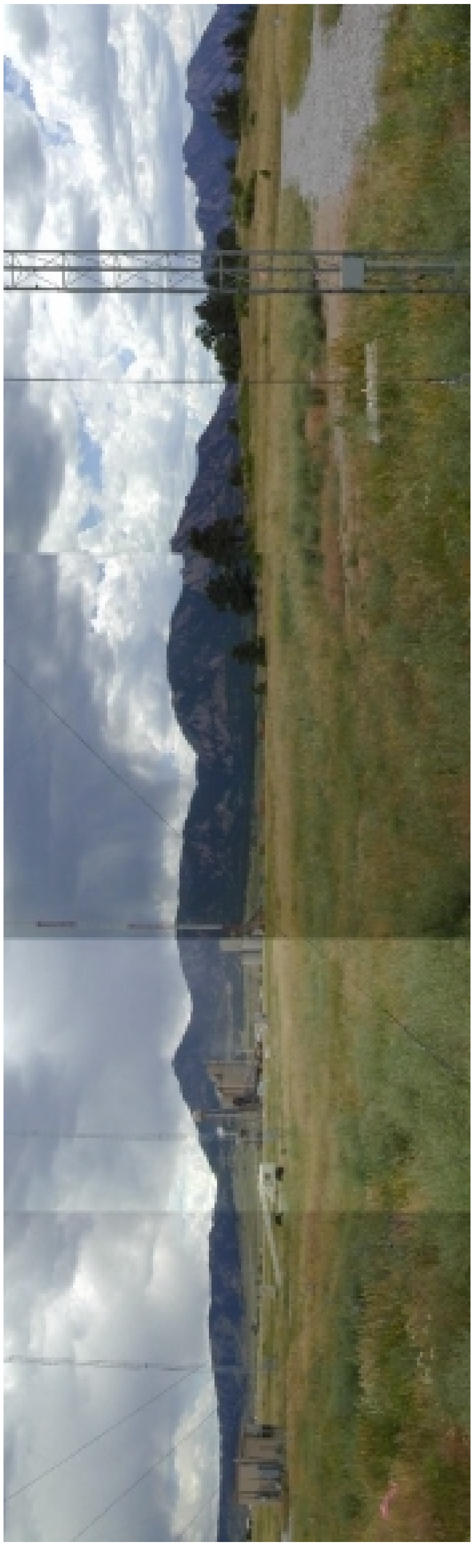
1. This test was conducted for purposes other than wind turbine certification. So several quality assurance procedures were not followed. In particular, forms used for laboratory/client interactions and to document instrumentation checks were not completed.

8.3 Deviations from the Test Plan

No exceptions were taken from the Whisper H40 Power Performance Test Plan.

Appendix A Pictures of Test Site





Appendix B Whisper H40 Power Performance Test Plan

Wind Turbine Generator System

Power Performance Test Plan

for the

Whisper H40

in

Golden, Colorado

by

National Wind Technology Center
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401

Trudy Forsyth

June 29, 2001

Approval By: Trudy Forsyth 6/29/01
Trudy Forsyth, NREL Test Engineer and FVP Project Leader — Date

Approval By: Harold F. Link 29 Jun 01
Harold F Link, NREL Certification Test Manager — Date

1.0 Table of Contents

2.0 Table of Tables

3.0 Table of Figures

4.0 Test Objective

The objective of this test is to obtain the power performance characteristics of the Whisper H40 (900 W) wind turbine for participation in the DOE/Golden Field Office (DOE/GO) Field Verification Project testing program.

5.0 Background

The Whisper H40 was developed by World Power Technologies, the turbine and it's technology was then purchased by Southwest Windpower. The test turbine, located at the National Wind Technology Center, is owned by Windward Engineering in Spanish Forks, Utah. As part of the DOE/GO Field Verification Project each turbine must pass a suite of IEC tests including: duration, system safety and function, power performance and noise tests. This turbine was erected at the NWTC in December 1999. This test was conducted in accordance to the IEC standard, Wind Turbine Generator Systems, Part 12: Wind Turbine Power Performance Testing, Edition 1, IEC 61400-12 (hereafter referred to as the IEC standard).

6.0 Test Turbine

The Whisper H40 has a rotor diameter 2.1 m and a peak power rating of 900 watts. Figure 1 shows the Whisper H40 wind turbine as it was installed at Site 1.3 at the National Wind Technology Laboratory. The Whisper H40 is a three-bladed, upwind, variable speed turbine that uses furling for power regulation and overspeed control. The turbine is mounted on a 10-cm (4-in) tube tower at a hub height of 9.1 m (30 ft.). The tower is supported by four guy wires and can be easily lowered to ground level for turbine inspection and maintenance.

The turbine uses a direct-drive, permanent magnet, brushless alternator to produce three-phase, variable-frequency, variable-voltage, and AC power. This, "wild AC" power is directed through slip rings in the nacelle to the turbine's EZ Wire controller.

The EZ wire is a proprietary, SCR-based rectifier and features turbine control and a dump load. In this test, it was configured to produce 24 volts DC. DC voltage is stabilized with four batteries. A Trace sine-wave inverter (model number SW4024) converts the DC power to 120 volts AC and feeds it to the NWTC electrical grid. In case of a utility outage or inverter failure, the resistive dump load dissipates energy from the turbine. A manual switch provides braking for the turbine by disconnecting it from the load and shorting two of the generator leads together.

Table 1 lists configuration and operational data for the Whisper H40.

The test turbine's electrical interface with its external environment is at the turbine side of the isolation switch, LP 1.3. This switch connects the turbine to the utility or isolates it from the utility grid. Therefore this is the location for measuring AC power output. However, in order to document the turbine's DC power output, voltage and current will be measured on the DC bus between the EZ Wire and the inverter.

Figure 1. Overall Configuration of the Test Turbine, the Whisper H40

Table 1. Test Turbine Configuration and Operational Data

General Configuration:	
Make, Model, Serial Number	World Power Technologies, Whisper H40 S/N:
Rotation Axis	Horizontal
Orientation	Upwind

Number of Blades	3
Rotor Hub Type	Rigid
Rotor Diameter (m)	2.13
Hub Height (m)	9.1
Performance:	
Rated Electrical Power (W)	900
Rated Wind Speed (m/s)	12.5
Cut-in Wind Speed (m/s)	3.4
Rotor:	
Swept Area (m^2)	3.6
Cut-in Rotational Speed (rpm)	300
Maximum Rotational Speed (rpm)	1200
Tilt Angle (deg)	7
Blade Pitch Angle (deg)	0 (non-linear 13^o at root to 1^o at tip)
Direction of Rotation	CCW
Overspeed Control	Furling
Braking System:	
Electrical Brake: Make, Type, Location	Electrical single pole
Yaw System:	
Wind Direction Sensor	Tail vane
Tower:	
Type	Guyed tube tilt-down
Height (m)	9.1
Control / Electrical System:	
Controller: Make, Type	EZ-wire system 120 SW4024
Power Converter: Make, Type	Trace
Electrical Output: Voltage, Frequency, Number of Phases	480 VAC, 60 Hz, 1-phase

7.0 Test Site

7.1 General Description

The Whisper H40 wind turbine under test is located at Test Site 1.3 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 2 shows a plot plan of the test site with topography lines listed in feet above sea level.

The meteorological tower is located 6.4 m from the test turbine at an azimuth of 291 degrees true. This is three rotor diameters from the turbine in measurement sector as required by the IEC standard.

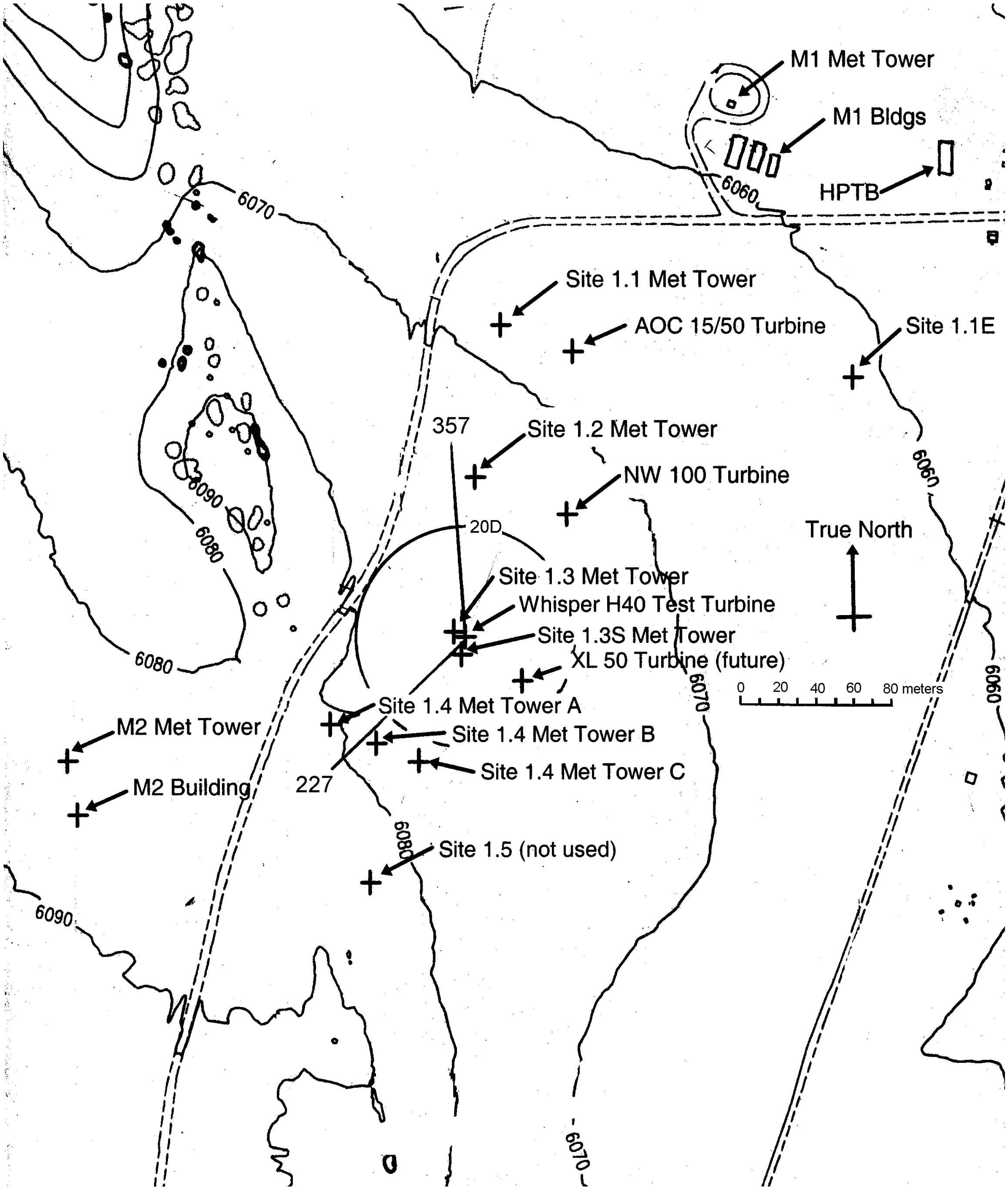


Figure 2. Location and Plot Plan of Whisper H40 Test Site

Figure 3. View of Test Turbine Toward the Prevailing Wind Direction (292°)

7.2 Evaluation of Obstructions

The IEC standard uses the expression, “measurement sector,” to define wind directions that can be used for power performance measurements. NREL defines a “preliminary measurement sector” as part of the site assessment procedure. Using data obtained during site calibration or the power performance test, NREL may change the measurement sector to avoid wind directions where terrain or obstacles affect the wind.

The first step in defining the measurement sector is to consider historic wind data, if available. Experience at the NWTC has shown that the prevailing wind direction is 292° for winds above 4 m/s. These winds usually come during the “wind season”, which normally lasts from November to April.

Next we analyze the site to estimate the wakes from obstructions. The preliminary measurement sector should avoid wake effects on the turbine and the meteorological tower. This includes the potential for the turbine wake to affect the anemometers on the meteorological tower. Table 2 lists the positions and characteristics of structures close to the Whisper H40 and the preliminary measurement sector. This table does not include the data shed as the IEC standard permits small data acquisition sheds within the measurement sector. NREL will evaluate the effect of this shed using the power performance data. If we find that the shed has a significant effect, the measurement sector will be adjusted accordingly. Based on the effects of the obstructions listed in Table 2, the preliminary measurement sector is 227° to 358° true.

Table 2. Obstructions Close to Whisper H40 Test Turbine

Description	*Tower Height (m)*	*Rotor Diameter (equiv. or real) (m)*	*Distance from Test (m)*	*Bearing From Test Turbine (deg true)*	*Start of Excluded Region (deg true)*	*End of Excluded Region (deg true)*
AOC 15/50 Turbine	25	15	146	22	**358**	47
Site 1.3S Met Tower	37	0.5	9	201	177	226
BWC XL10 Turbine	37	7	64	202	177	**227**
Description	*Tower Height (m)*	*Rotor Diameter (equiv. or real) (m)*	*Distance From Test (m)*	*Bearing From Met Tower (deg true)*	*Start of Excluded Region (deg true)*	*End of Excluded Region (deg true)*
Whisper H40	9.1	2.1	6	110	67	153
AOC 15/50 Turbine	25	15	147	24	0	49
Site 1.3S Met Tower	37	0.5	11	167	145	190
BWC XL10 Turbine	37	7	64	196	171	221

7.3 Evaluation of Terrain

To conduct a performance test without a site calibration, the terrain surrounding the test turbine must meet all of the criteria listed given in Section A.1 of the IEC standard. Table 3 lists these criteria and the results of the NWTC-CT’s assessment. The site failed criterion #2 because any terrain irregularity over 17 cm exceeds the 0.08 D limit. In this case, NREL chose to forgo the site calibration. We will evaluate the power performance data to see if small obstructions have any influence on the power curve measurements.

Table 3. Criteria for Acceptance of Test Site without Site Calibration Testing

Criterion	*Description*	*Distance*	*Sector*	*Test Site Condition*	*Pass/Fail*
1	Maximum slope of best fit plane <3%	<2L(1)	360°	2%	Pass
2	Max variation from best fit plane < 0.08 D(3)	<2L	360°	0.14D	Fail
3	Maximum slope of best fit plane <5%	2-4L	Inside prel. meas. sector	2%	Pass

Criterion	*Description*	*Distance*	*Sector*	*Test Site Condition*	*Pass/Fail*
4	Max variation from best fit plane < 0.15 D	2-4L	Inside prel. meas. sector	0.14D	Pass
5	Maximum slope of steepest slope <10%	2-4L	Outside prel. meas. sector	2%	Pass
6	Maximum slope of best fit plane <10%	4-8L	Inside prel. meas. sector	9.6%	Pass
7	Max variation from best fit plane < 0.15 D	4-8L	Inside prel. meas. sector	0.124D	Pass
8	No operating turbines	2Dn(4)	360°		Pass
9	Met tower out of test turbine wake	L	67° – 153°	292°	Pass
10	No obstacles	<8L	Inside prel. meas. sector	None	Pass

(1) L is the distance for the test turbine to the meteorological tower
(2) Unable to fit a plane to the topography that also passes through turbine base
(3) D is the rotor diameter of the test turbine
(4) Dn is the rotor diameter of a neighboring turbine

8.0 Description of Test Equipment

Table 4 lists the instruments to be used in this power performance. Figure 4 shows the locations for the power, voltage, and current sensors. Figure 5 shows the locations of the anemometers and wind vane on the meteorological tower. The temperature and pressure sensors are located at Site 1.1 (AOC 15/50 test site) and Site 1.4 (Bergey XL10 test site) approximately 150 and 65 meters from the test turbine, respectively.

In addition to the instruments listed in Table 2, the performance test requires a signal to determine turbine operational status. The controller of the Whisper H40 has no automatic fault sensing or indicators. Therefore NREL installed a three-position manual switch connected to the datalogger. In position 1, the turbine and system are considered OK for power performance purposes. If a test engineer or technician note that the turbine has a fault condition, they turn the status switch to position 2 to indicate that the turbine is not available. If the test engineer or technician note that external conditions are not suitable for the turbine to operate (i.e., grid outage, turbine turned off for testing), they turn the status switch to position 3 to indicate that the system is not available. The datalogger records what percentage of the 10 averaging time that the switch is in either position 2 or position 3.

Table 4. Power performance test instrumentation

Power Transducer	
Make / model:	OSI, GWV5-001EY24/1
Serial number (Transducer/CTs):	0010301
Range with CTs:	0 - +/-1
Calibration Due Date:	1/5/01
Reactive Power Transducer	
Make / model:	OSI, GWV5-001EY24/2
Serial number (Transducer/CTs):	0010301
Range with CTs:	0 - +/-1
Calibration Due Date:	1/5/01
Turbine Speed	

Make / model:	Action Pak
Serial number:	B7YSV
CT range:	0-1000 RPM
Calibration Due Date:	2/18/01
DC Bus Voltage	
Make / model:	OSI VT7-003E
Serial number:	9111995
CT range:	0-50 Vdc
Calibration Due Date:	1/3/01
DC Bus Amps	
Make / model:	OSI CTA212
Serial number:	0010126
CT range:	0-50 Amp
Calibration Due Date:	1/3/01
Battery Amps	
Make / model:	OSI CTA212y42
Serial number:	00125
CT range:	0 - +/-50 Amp
Calibration Due Date:	1/3/01
Met Anemometer 2/9/2000 to 11/29/2000	
Make / model:	Met One, 010C with Aluminum Cups
Serial number.	W1231
Calibration Due Date:	2/9/01
Met Tower Location:	6.7 meters upwind
Met Anemometer 11/29/2000 to current	
Make / model:	Met One, 010C with Aluminum Cups
Serial number.	W1240
Calibration Due Date:	4/21/01
Met Tower Location:	6.7 meters upwind
Secondary Met Anemometer	
Make / model:	Met One, 010C with Aluminum Vane
Serial number:	W1232
Calibration Due Date:	2/9/01
Met Tower Location:	6.7 meters upwind
Wind Direction Sensor	
Make / model:	Met One, 020C with Aluminum Vane
Serial Number:	P3143
Calibration Due Date:	2/9/01
Met Tower Location:	6.7 meters upwind
Pressure Sensor (from AOC 15/50) 10/14/99 to 11/21/2000	
Make / model:	Vaisala, PTB101B
Serial Number:	T4730007
Calibration Due Date:	6/2/2000
Instrument Location:	Site 1.1 meteorological tower at 22 meters height
Pressure Sensor (from Bergey XL10) 10/20/99 to 8/24/00	
Make / model:	Vaisala, PTB101B
Serial Number:	T4830002
Calibration Due Date:	10/20/2000

Instrument Location:	Site 1.4 meteorological tower at 33.5 meters height
Pressure Sensor (from Bergey XL10) 2/20/01 to current	
Make / model:	Vaisala, PTB101B
Serial Number:	T3330002
Calibration Due Date:	12/19/2001
Instrument Location:	Site 1.4 meteorological tower at 33.5 meters height
Temperature Sensor (from AOC 15/50) 10/14/99 to 11/21/2000	
Make / model:	Met One, T-200
Serial Number:	0653394
Calibration Due Date:	10/20/2000
Instrument Location:	Site 1.1 meteorological tower at 22 meters height
Temperature Sensor (from Bergey XL10) 10/20/99 – 8/24/00	
Make / model:	Met One, T-200
Serial Number:	0602931
Calibration Due Date:	10/20/2000
Instrument Location:	Site 1.4 meteorological tower at 33.5 meters height
Temperature Sensor (from Bergey XL10) 2/20/01 – current	
Make / model:	Met One, T-200
Serial Number:	0653393
Calibration Due Date:	12/12/01
Instrument Location:	Site 1.4 meteorological tower at 33.5 meters height
Datalogger 2/15/2000 to 10/4/2000	
Make / model:	Campbell Scientific CR21X
Serial number:	13185
Calibration Due Date:	Post-calibration on 2/8/2001
Datalogger 10/4/2000 to current	
Make / model:	Campbell Scientific CR23X
Serial number:	3099
Calibration Due Date:	8/30/2001

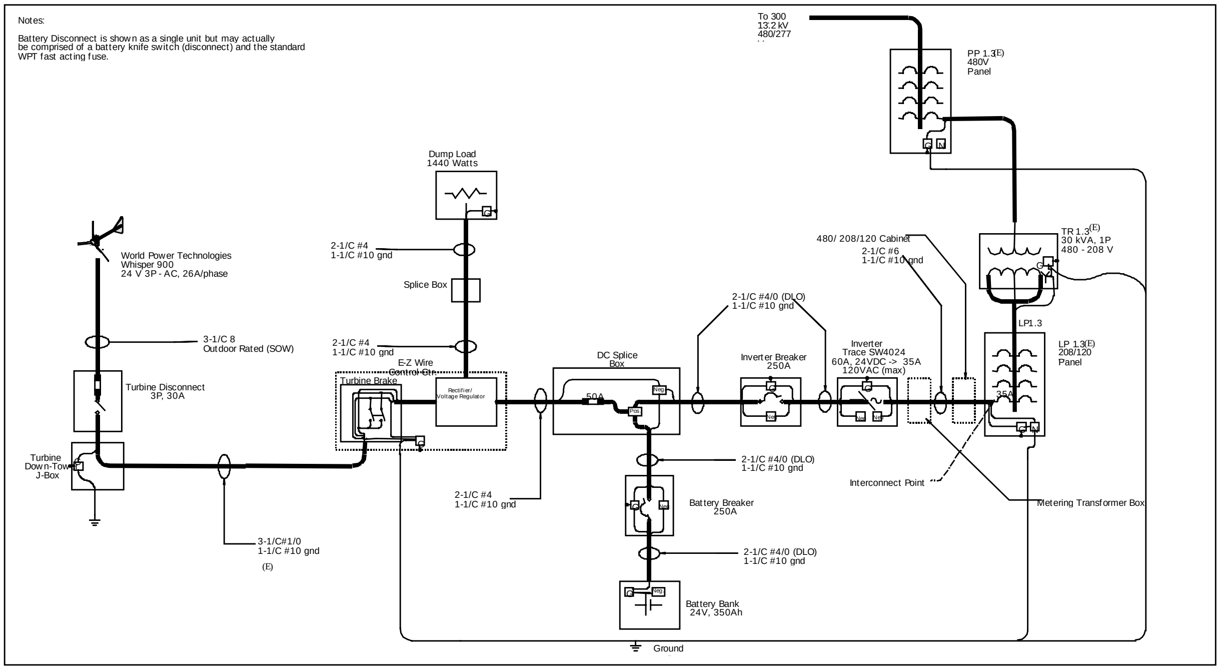


Figure 4. Locations of power, voltage and current sensors

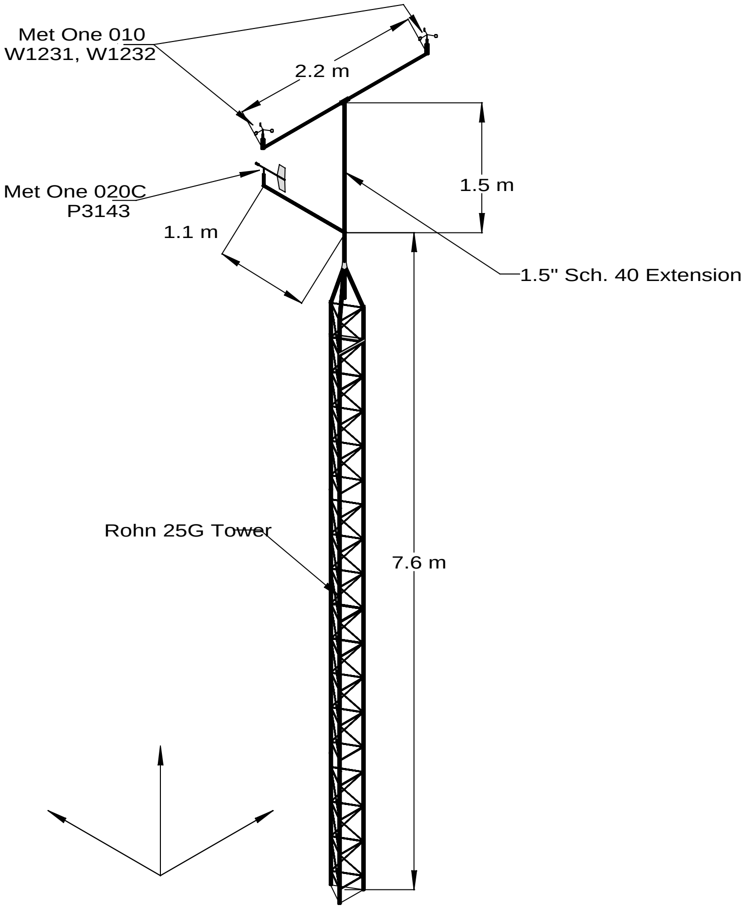


Figure 5. Locations of meteorological instruments

9.0 Measurement Procedures

Measurements during the power performance test will be obtained automatically by the Campbell datalogger at a sample rate of one Hz. At the end of each 10-minutes as indicated on the datalogger's clock, it records the averages of these data with their standard deviations, minimum and maximum values for the ten minutes. It also records the percentage of time that the turbine or system is not available or when the wetness sensor, if used, is wet (as an indication of rain). Finally, the logger records the number of samples in each record. If the datalogger is interrupted by a program change, its first or last record will contain less than 10 minutes. The IEC standard does not allow use of such records.

On a weekly basis, NREL will transfer data from the data logger to computers at NREL offices. Also on a weekly basis NREL personnel will, check instruments located on the meteorological tower from ground level. They will note if 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 the next section, the Test Analyst will note if any problems have arisen. If so, he/she will notify the Test Engineer. 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 for in the determination of power performance and note whether data are used or not in the test report.

If the test site or turbine changes during the test, the Test Engineer will determine if it is appropriate to continue the test, restart the test, or cancel the test. All such actions will be documented in the test report. NREL will monitor the quantity of data obtained during testing and will report on test progress NREL management on a weekly basis.

The power curve must be well defined over a range of wind speeds specified by the IEC standard. In this test the low end of the range is 2.8 m/s, which is 1 m/s below the Whisper H40's cut-in wind speed. The high end of the range is 24 m/s, which is 1.5 times the wind speed at which the turbine produces 85% of its rated power. The test will continue until 180 hours of usable data have been obtained in the specified wind speed range and when each 0.5 m/s wind bin in this range contains at least 30 minutes of data. Once sufficient data are obtained to fulfill these requirements, the NREL test engineer will inform NREL management that the test is complete.

10.0 Analysis Methods

NREL analyzes power performance data in two steps. First we determine which of the data are usable. Then we process the usable data to obtain power curves and to estimate annual energy production and uncertainty.

In the first step, the analyst enters the data into a spreadsheet where time series plots are used to review the various instrument readings. The data acquisition system has failed if:

1) voltage of the datalogger's power supply is below 11 volts DC
2) temperature at the datalogger is less than -40^oC or greater than 80^oC
3) the record contains less than 600 samples
4) any channel is over range as indicated by a record of –99999.

Other checks are made to ensure to the greatest extent practical that all signals are valid. Also the analyst tags as unusable any data obtained when the logbook indicates that the turbine or external conditions prevented normal operation. Occasionally such periods are noted in the logbook but not recorded by the datalogger. Any data that are found to be unusable are filtered from the data set.

The useable data are then entered into a second spreadsheet with custom macros for processing. These macros apply additional filters in accordance with the IEC standard. The IEC standard requires that all data be used unless the following conditions are present:

- Wind turbine is unavailable
- Failure of test equipment
- Wind direction is outside of the valid measurement sector

NREL defines unavailable as:

- Turbine is faulted (the controller does not sense any problem with the turbine nor is the emergency stop button pushed)
- Turbine is not in automatic run mode (i.e. manual mode)
- The utility grid is not available (utility power is not within specifications)

Once the above criteria have been applied, the remaining.g data form the primary test data set, and the resulting power performance from this set are analyzed and reported. The macros perform the following calculations on that data set:

1. When site calibration data are available, Equation 1 is used to adjust the average wind speeds measured on the meteorological tower (MET) to calculate turbine wind speeds according to the site calibration results. If no site calibration test was performed, then the $\Gamma_{\text{Site}} = 1.0$.

$$V_{Turb} = \Gamma_{Site} \cdot V_{MET}$$ **Equation 1**

where: V_{Turb} = wind speed at turbine (m/s)
Γ_{Site} = site calibration factor
V_{MET} = wind speed at MET (m/s)

2. If the pressure sensor is more then 10 meters below hub height, then for each data point the measured pressure is corrected to hub height by Equation 2 (from ISO 2533).

$$p = p_b \cdot \left[1 + \frac{\beta}{T_b} \cdot \left(H - H_b\right)\right]^{-\frac{g_n}{\beta \cdot R}} \qquad \textbf{Equation 2}$$

where: p = pressure at hub height (Pa)
p_b = measured pressure (Pa)
β = temperature gradient (-6.5 K/m)
T_b = measured temperature (K)
H = hub height above ground (m)
H_b = pressure transducer height above ground (m)
g_n = acceleration of gravity (9.807 m/s^2)
R = specific gas constant (287.053 m/Ks^2)

3. For each data point, the average air density is calculated by the Ideal Gas Law (Equation 3):

$$\rho_{10\,\min} = \frac{B_{10\,\min}}{R * T_{10\,\min}} \qquad \textbf{Equation 3}$$

where: ρ_{10min} = derived air density averaged over 10 minutes (kg/m^3)
T_{10min} = measured absolute air temperature averaged over 10 minutes (K)
B_{10min} = measured air pressure averaged over 10 minutes (Pa)
R = gas constant for air (287.05 J/kgK)

4. For each data point, the derived site air density is used to calculate the average site air density for the test period, rounded to the nearest 0.05 kg/m^3.

5. For small turbines that use furling, NREL has determined that the most appropriate method to use for normalize the power curve is to adjust wind speed in accordance with Equation 4. In this test normalization will be performed using monthly averages instead of 10-minute averages of air density:

$$V_n = V_{10\,\min} \cdot \left(\frac{\rho_{10\,\min}}{\rho_0}\right)^{1/3} \qquad \textbf{Equation 4}$$

where: V_n = normalized wind speed (m/s)
V_{10min} = measured wind speed averaged over 10 minutes (m/s)
ρ_0 = site average air density (kg/m^3)
ρ_{10min} = measured air density averaged over 10 minutes (kg/m^3)

6. Equation 6 is applied a second time with ρ_o replaced with the standard sea-level air density (1.225 kg/m^3), creating a standard normalized wind speed (V_{ns})

7. All data are sorted, according to normalized wind speeds, into bins which are 0.5 m/s wide, with bin centers at integer multiples of 0.5 m/s. Each power, DC and AC, is averaged for each bin. As a result, two power curves and AEPs are calculated.

8. For each data bin, the following parameters are calculated:
    - bin average air temperature (K)

- bin average corrected air pressure (Pa)
- bin average measured wind speed (m/s)
- bin average standard deviation of wind speed (m/s)
- bin average measured power (W)
- bin average standard deviation of measured power (W)
- bin average site average density normalized power (W)
- bin average site average density standard deviation normalized power (W)
- bin average sea-level density normalized power (W)
- bin average sea-level density standard deviation normalized power (W)
- site average density (kg/m^3)
- amount of 10 minute data points in bin
- bin average uncorrected air pressure (Pa)
- bin power coefficient

9. The test power curve is then formed by the resulting average normalized wind speed and average power (average for site average density, standard for sea-level density) at each bin. For each bin the generator power coefficient is calculated by Equation 5:

$$C_{P,i} = \frac{P_i}{0.5 * \rho_0 A V_i^3}$$ **Equation 5**

where: $C_{P,i}$ = generator power coefficient in bin i (non-dimensional)
V_i = normalized wind speed in bin i (m/s)
P_i = average power in bin i (W)
A = swept area of the turbine rotor
ρ_0 = reference air density (same as used to normalize V_i)

10. The measured power curve is then used to estimate annual energy production (AEP) for a variety of Rayleigh wind speed distributions, where for each case the distributions are specified at turbine hub height and assumed to be constant over the swept area of the rotor. The AEP estimations are made according to Equations 6 and 7:

$$AEP = N_h \sum_i^N \left[F(V_i) - F(V_{i-1})\right]\left(\frac{P_{i-1} + P_i}{2}\right)$$ **Equation 6**

where: AEP = annual energy production (kWh)
N_h = number of hours in one year ≈ 8760 hr
N = number of bins
V_i = normalized and averaged wind speed in bin i
V_{i-1} = normalized and averaged wind speed in bin i-1
P_i = averaged measured power in bin i
P_{i-1} = averaged measured power in bin i-1
F(V) = the accumulated Rayleigh distribution, given by:

$$F(V) = 1 - \exp\left(-\frac{\pi}{4}\left(\frac{V}{V_{ave}}\right)^2\right)$$ **Equation 7**

where: V_{ave} = annual average wind speed at hub height
V = wind speed

11. The summation of Equation 6 is initiated by setting V_{i-1} equal to V_i-0.5 m/s, and P_{i-1} equal to 0 kW. The AEP calculations are made for integer values of annual average wind speeds ranging between 4 and 11 m/s.

12. An uncertainty analysis is performed per Annex C of the IEC standard for both the measured power curve and estimated AEP.

AEP is calculated in two ways, one designated AEP-measured and the other AEP-extrapolated. AEP-measured is calculated assuming that power in winds above the highest bin in the power curve is zero. AEP-calculated is calculated assuming that power in winds above the highest bin in the power curve is equal to the power in the highest wind bin. If AEP-measured is less than 95% of AEP-calculated, then the table reporting AEP-measured values must indicate "Incomplete."

11.0 Reporting

When the data collection and analysis are completed, NREL will generate a test report. This report will include the power curves and AEP for the Whisper H40, as well as detailed explanations of any deviations from this test plan. The report will also examine the uncertainty of the measurements, and whether the test passes the minimum requirements of the Standard.

12.0 Uncertainty

This section describes NREL estimates of Type B measurement uncertainties based on the selection and installation of instruments. NREL will determine Type A uncertainties based on the scatter of the power performance data. All uncertainty estimates have and will be made accordance with Annex C of the IEC standard for both the measured power curve and estimated AEP.

Table 5 and Table 6 summarize the Category B uncertainty parameters for the power performance measurements. Total Type B uncertainty is obtained by combining each component's uncertainty using the root-sum-squared method. Combined uncertainty is the root-sum-squared combination of Category A and Category B uncertainties of power measurements. At the conclusion of the test, NREL will calculate and report Category A and combined uncertainties for each wind bin for both average site air density and standard conditions.

Table 5. Category B uncertainties for DC Power

Component	*Uncertainty*		*Source*
Power			
voltage transducer	0.05%		specifications
current sensor/signal conditioner	0.50%		specifications
power transducer (>=500 W)*	0.20%		specifications
data acquisition	0.14	W	manual
resistor	0.10%		specifications
Wind Speed			
anemometer	0.11	m/s	calibration
operational characteristics	3.00%		assumption
mounting effects	2.00%		assumption
terrain effects	1.00%		assumption
data acquisition	0.04	m/s	estimate
Temperature			
temperature sensor	0.26	K	specifications
radiation shielding	2.00	K	assumption
mounting effects	1.16	K	assumption
linearization	1.00	K	DAS manual
data acquisition	0.13	K	manual
Air Pressure			
pressure sensor	0.14	hPa	calibration
mounting effects	0.02	hPa	10% of correction
data acquisition	0.09	hPa	manual
* Power transducer uncertainty includes uncertainty in current transformer.			

Table 6. Category B uncertainties for AC Power

Component	*Uncertainty*		*Source*
Power			
power transducer (>500 W)*	1.00	W	specifications
power transducer (>=500 W)*	0.20%		specifications
data acquisition	0.14	W	manual
resistor	0.01%		specifications
Wind Speed			
anemometer	0.11	m/s	calibration
operational characteristics	3.00%		assumption
mounting effects	2.00%		assumption
terrain effects	1.00%		assumption

data acquisition	0.04	m/s	estimate
Temperature (worst case)			
temperature sensor	0.26	K	specifications
radiation shielding	2.00	K	assumption
mounting effects	1.16	K	assumption
linearization	1.00	K	DAS manual
data acquisition	0.13	K	manual
Air Pressure (worst case)			
pressure sensor	0.14	hPa	calibration
mounting effects	0.02	hPa	10% of correction
data acquisition	0.09	hPa	manual
* Power transducer uncertainty includes uncertainty in current transformer.			

13.0 Exceptions to Standard Practice

Power performance instrumentation deviates from the IEC standard as follows:

1. The power transducer was not tested for compliance with IEC 60688.
2. The current transformers were not tested for compliance with IEC 60044.
3. The voltage transformer was not tested for compliance with IEC 60186.
4. The terrain does not meet the requirements of the IEC standard for variations within a distance of 2L from the test turbine.
5. The temperature and pressure instruments are located at an adjacent test site.
6. Normalization for air density will be based on monthly averages of temperature and pressure rather than 10-minute averages.

14.0 Roles and Responsibilities

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

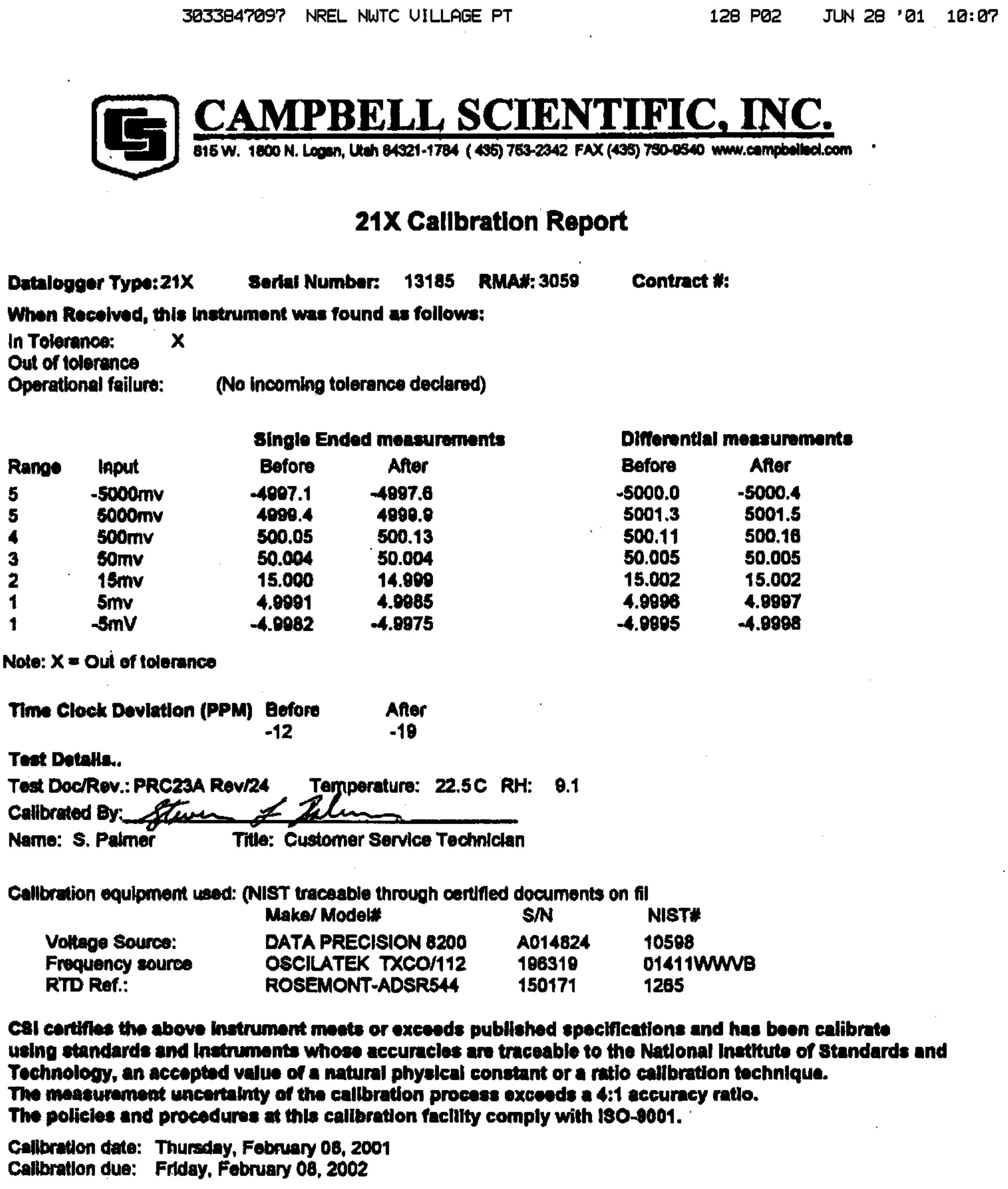
Table 8. Roles of Test Participants

Test Team Title	Name	Employer	Role(s)
NWTC-CT Manager	Hal Link	NREL	NREL approval of test plan.
Test Engineer	Trudy Forsyth	NREL	Overall test management and responsibility. Customer contact person. Authorization for any deviations from planned test procedures. Supervision of performance test set-up, checkout, and conduct. Periodic review of test data. Review and report test results. Primary point of contact between CTG and the test site manager.
Test Technician	Gerry Bianchi	NREL	Selection of instruments Installation and checkout of test equipment Implementation of corrective actions for problems
Test Analyst	Tony Jimenez	NREL	Download and store test data Analyze test data Identify problems based on data analysis results Provide test engineer with updates on test progress Provide tables and graphs of results test reports Assist in writing test report
Site Manager	Trudy Forsyth	NREL	Supervise operation and maintenance of test turbine. Responsible for ensuring safety of personnel and equipment at test site. Reports any change in turbine configuration

Appendix A: Instrument Calibration Sheets

Campbell 23X datalogger serial number 3099 will be post-calibrated.

Campbell Datalogger
Serial Number: 13185



3033847097 NREL NWTC VILLAGE PT 128 P02 JUN 28 '01 10:07

CAMPBELL SCIENTIFIC, INC.

815 W. 1800 N. Logan, Utah 84321-1784 (435) 753-2342 FAX (435) 750-9540 www.campbellsci.com

21X Calibration Report

Datalogger Type: 21X **Serial Number:** 13185 **RMA#:** 3059 **Contract #:**

When Received, this instrument was found as follows:

In Tolerance: X
Out of tolerance
Operational failure: (No incoming tolerance declared)

		Single Ended measurements		Differential measurements	
Range	Input	Before	After	Before	After
5	-5000mv	-4997.1	-4997.6	-5000.0	-5000.4
5	5000mv	4999.4	4999.9	5001.3	5001.5
4	500mv	500.05	500.13	500.11	500.16
3	50mv	50.004	50.004	50.005	50.005
2	15mv	15.000	14.999	15.002	15.002
1	5mv	4.9991	4.9985	4.9996	4.9997
1	-5mV	-4.9982	-4.9975	-4.9995	-4.9998

Note: X = Out of tolerance

Time Clock Deviation (PPM)	Before	After
	-12	-19

Test Details..

Test Doc/Rev.: PRC23A Rev/24 Temperature: 22.5C RH: 9.1
Calibrated By: ____________________
Name: S. Palmer Title: Customer Service Technician

Calibration equipment used: (NIST traceable through certified documents on fil

	Make/ Model#	S/N	NIST#
Voltage Source:	DATA PRECISION 8200	A014824	10598
Frequency source	OSCILATEK TXCO/112	196319	01411WWVB
RTD Ref.:	ROSEMONT-ADSR544	150171	1285

CSI certifies the above instrument meets or exceeds published specifications and has been calibrate using standards and instruments whose accuracies are traceable to the National Institute of Standards and Technology, an accepted value of a natural physical constant or a ratio calibration technique. The measurement uncertainty of the calibration process exceeds a 4:1 accuracy ratio. The policies and procedures at this calibration facility comply with ISO-9001.

Calibration date: Thursday, February 08, 2001
Calibration due: Friday, February 08, 2002

Met One Anemometer

Serial number: W1240

Anemometer 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-99-5-T4

Page: 1 of 1

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**W1240**
Cup Material	Aluminum
Condition	Refurbished: 5 May 99

Estimated Uncertainty:

Vwind	Cres Uncer	Total Uncert:
4 - 5 m/s	0.080	0.090
5 - 10 m/s	0.080	0.090
10 - 15 m/s	0.100	0.109

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

Dates of Calibration:

Test Start:	23-Dec-99
Test End:	**10-Jan-00**
Report:	10-Jan-00

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

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

Results:

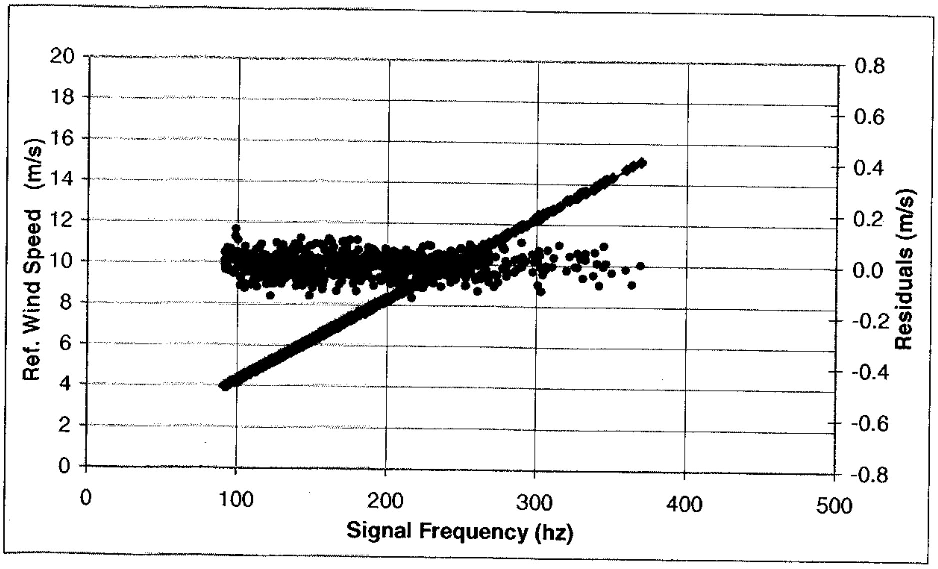
Slope:	**0.04002**	m/s/hertz
Offset:	**0.3288**	

Traceability:

Reference Cup:	Met One, 010C, s/n: T2351
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	2-Mar-99

Approved:
Hal Link

10 Jan 00
Date



Met One Anemometer

Serial number: W1231

Anemometer 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-99-4-T1

Page: 1 of 1

Item Calibrated:

Manufacturer	Met One Instruments, Inc
Model	010C
Cup Serial Number	**W1231**
Cup Material	Aluminum
Condition	Refurbished: 2 June 99

Estimated Uncertainty:

Vwind	Cres Uncer	Total Uncert:
4 - 5 m/s	0.080	0.092
5 - 10 m/s	0.080	0.092
10 - 15 m/s	0.100	0.110

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

Dates of Calibration:

Test Start:	24-Aug-99
Test End:	**29-Nov-99**
Report:	29-Nov-99

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

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

Results:

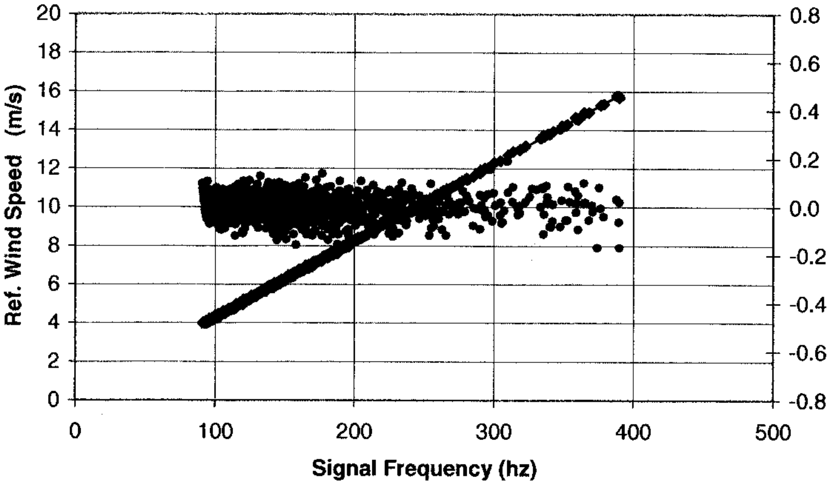
Slope:	**0.03982**	m/s/hertz
Offset:	**0.3100**	m/s

Traceability:

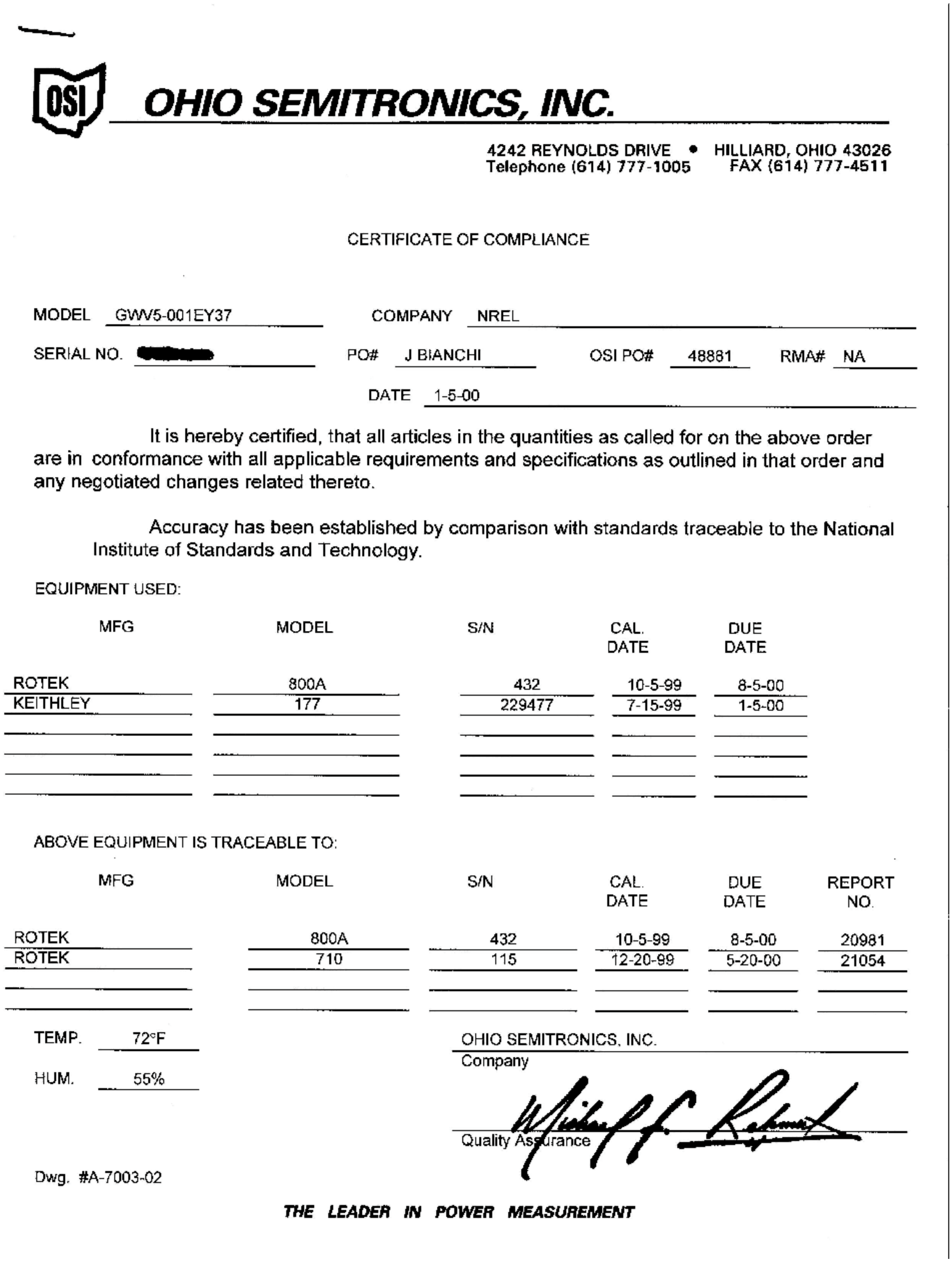
Reference Cup:	Met One, 010C, s/n: U1195
Calibrated by:	CRES, Pikermi, Greece
Calibration date:	2-Mar-99

Approved: Hal Link
Hal Link

29/Nov 99
Date



Power Transducer
Serial number: 0010301



OHIO SEMITRONICS, INC.

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

CERTIFICATE OF COMPLIANCE

MODEL GWV5-001EY37 COMPANY NREL

SERIAL NO. [redacted] PO# J BIANCHI OSI PO# 48881 RMA# NA

DATE 1-5-00

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	432	10-5-99	8-5-00
KEITHLEY	177	229477	7-15-99	1-5-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	800A	432	10-5-99	8-5-00	20981
ROTEK	710	115	12-20-99	5-20-00	21054

TEMP. 72°F

HUM. 55%

OHIO SEMITRONICS, INC.
Company

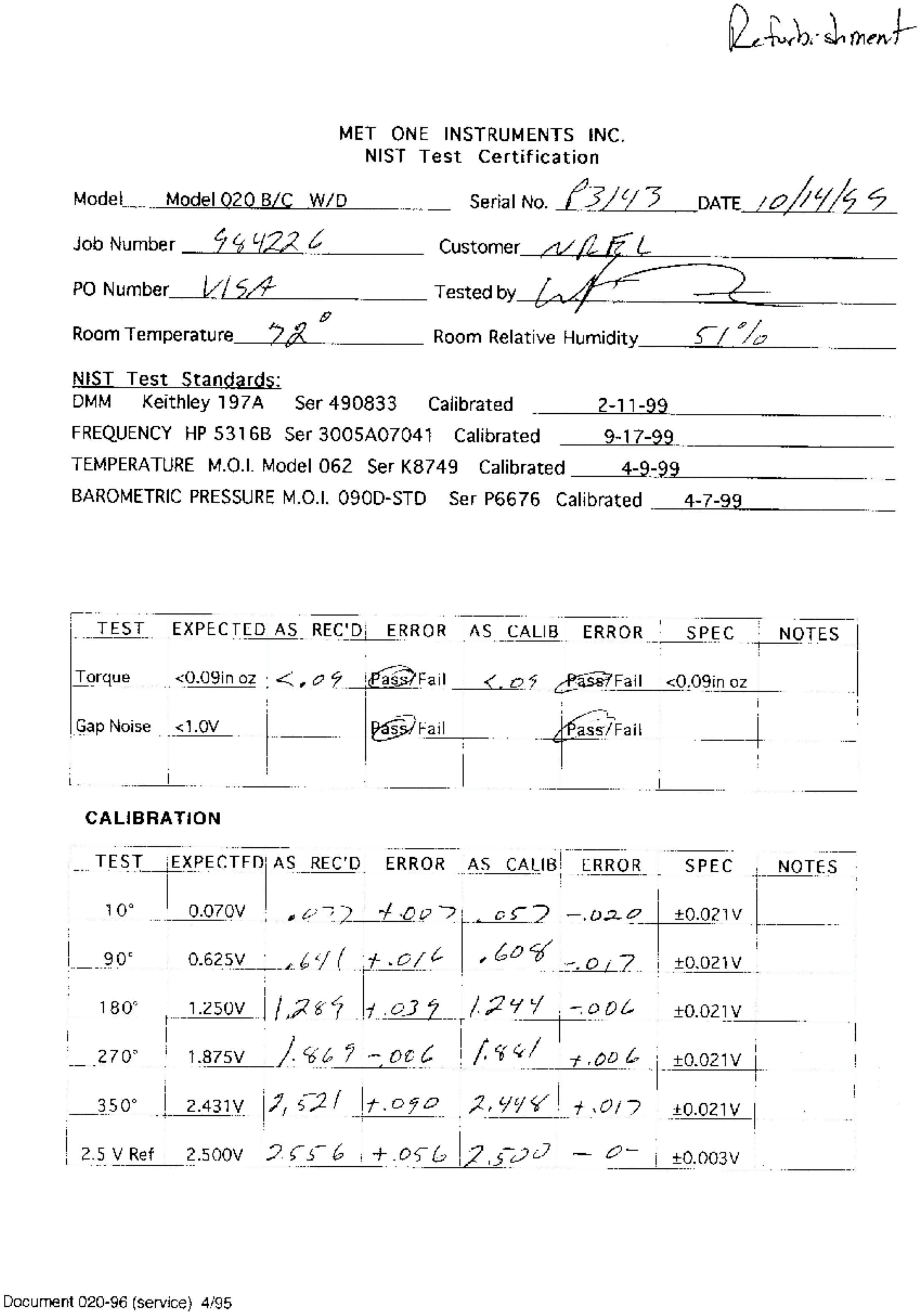
Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Wind Vane

Serial number: P3143



Refurbishment

MET ONE INSTRUMENTS INC.
NIST Test Certification

Model Model 020 B/C W/D Serial No. P3143 DATE 10/14/99

Job Number 994226 Customer NREL

PO Number VISA Tested by

Room Temperature 72° Room Relative Humidity 51%

NIST Test Standards:

DMM Keithley 197A Ser 490833 Calibrated 2-11-99

FREQUENCY HP 5316B Ser 3005A07041 Calibrated 9-17-99

TEMPERATURE M.O.I. Model 062 Ser K8749 Calibrated 4-9-99

BAROMETRIC PRESSURE M.O.I. 090D-STD Ser P6676 Calibrated 4-7-99

TEST	EXPECTED	AS REC'D	ERROR	AS CALIB	ERROR	SPEC	NOTES
Torque	<0.09in oz	<.09	[✓ Pass]/Fail	<.05	[✓ Pass]/Fail	<0.09in oz	
Gap Noise	<1.0V		[✓ Pass]/Fail		[✓ Pass]/Fail		

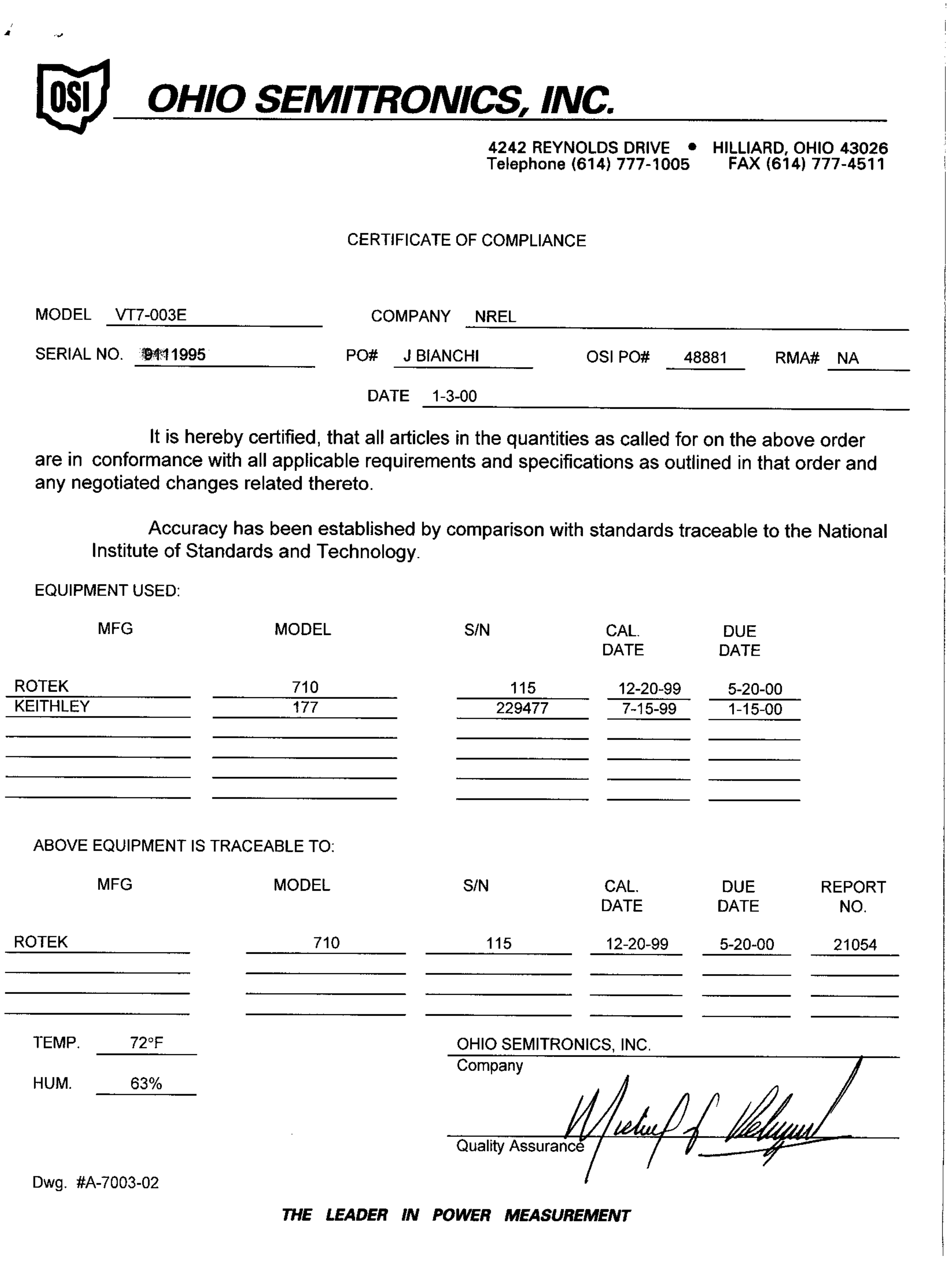
CALIBRATION

TEST	EXPECTED	AS REC'D	ERROR	AS CALIB	ERROR	SPEC	NOTES
10°	0.070V	.077	+.007	.057	-.020	±0.021V	
90°	0.625V	.641	+.016	.608	-.017	±0.021V	
180°	1.250V	1.289	+.039	1.244	-.006	±0.021V	
270°	1.875V	1.869	-.006	1.881	+.006	±0.021V	
350°	2.431V	2.521	+.090	2.448	+.017	±0.021V	
2.5 V Ref	2.500V	2.556	+.056	2.500	-0-	±0.003V	

Document 020-96 (service) 4/95

Voltage Transducer

Serial number: 9111995



OHIO SEMITRONICS, INC.

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

CERTIFICATE OF COMPLIANCE

MODEL VT7-003E

COMPANY NREL

SERIAL NO. 9111995

PO# J BIANCHI

OSI PO# 48881

RMA# NA

DATE 1-3-00

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	710	115	12-20-99	5-20-00
KEITHLEY	177	229477	7-15-99	1-15-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	710	115	12-20-99	5-20-00	21054

TEMP. 72°F

HUM. 63%

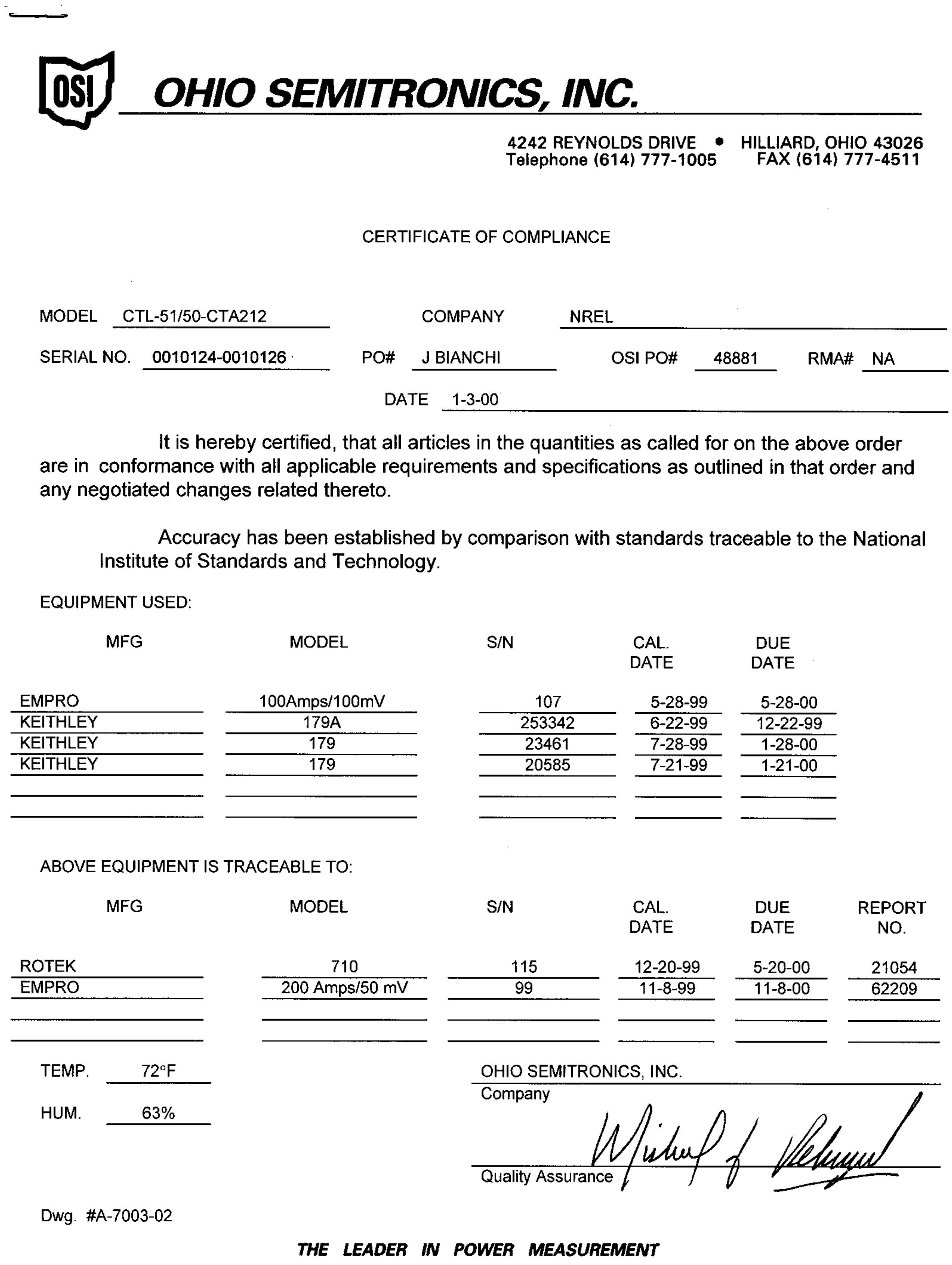
OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Current Signal Conditioner
Serial number: 0010124/0010126



OHIO SEMITRONICS, INC.

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

CERTIFICATE OF COMPLIANCE

MODEL CTL-51/50-CTA212 COMPANY NREL

SERIAL NO. 0010124-0010126 PO# J BIANCHI OSI PO# 48881 RMA# NA

DATE 1-3-00

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
EMPRO	100Amps/100mV	107	5-28-99	5-28-00
KEITHLEY	179A	253342	6-22-99	12-22-99
KEITHLEY	179	23461	7-28-99	1-28-00
KEITHLEY	179	20585	7-21-99	1-21-00

ABOVE EQUIPMENT IS TRACEABLE TO:

MFG	MODEL	S/N	CAL. DATE	DUE DATE	REPORT NO.
ROTEK	710	115	12-20-99	5-20-00	21054
EMPRO	200 Amps/50 mV	99	11-8-99	11-8-00	62209

TEMP. 72°F

HUM. 63%

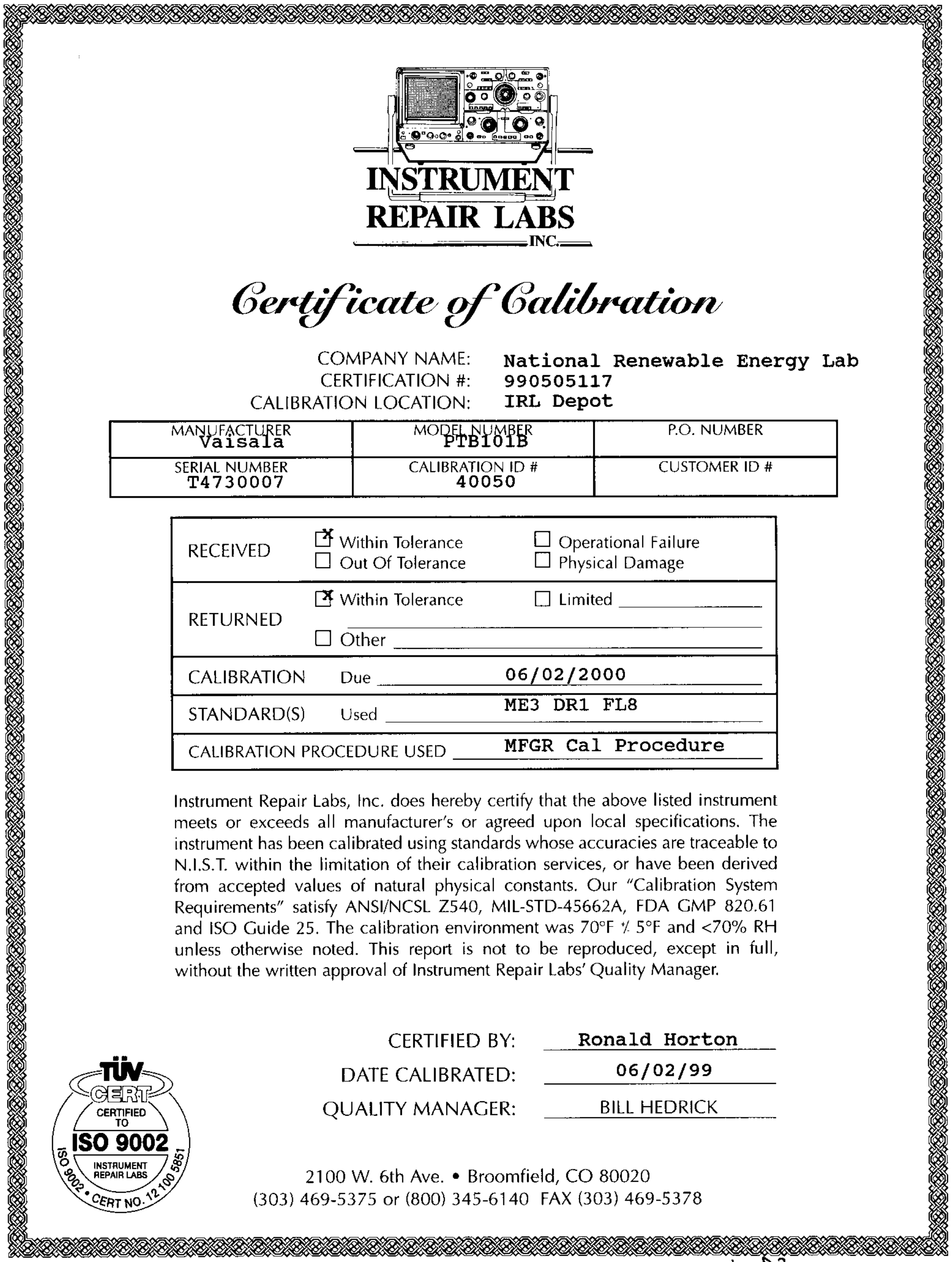
OHIO SEMITRONICS, INC.
Company

Quality Assurance

Dwg. #A-7003-02

THE LEADER IN POWER MEASUREMENT

Pressure Sensor
Serial number: T4730007



INSTRUMENT REPAIR LABS INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 990505117
CALIBRATION LOCATION: IRL Depot

MANUFACTURER	MODEL NUMBER	P.O. NUMBER
Vaisala	PTB101B	
SERIAL NUMBER	**CALIBRATION ID #**	**CUSTOMER ID #**
T4730007	40050	

RECEIVED	☒ Within Tolerance ☐ Out Of Tolerance	☐ Operational Failure ☐ Physical Damage
RETURNED	☒ Within Tolerance ☐ Other	☐ Limited
CALIBRATION	Due 06/02/2000	
STANDARD(S)	Used ME3 DR1 FL8	
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.

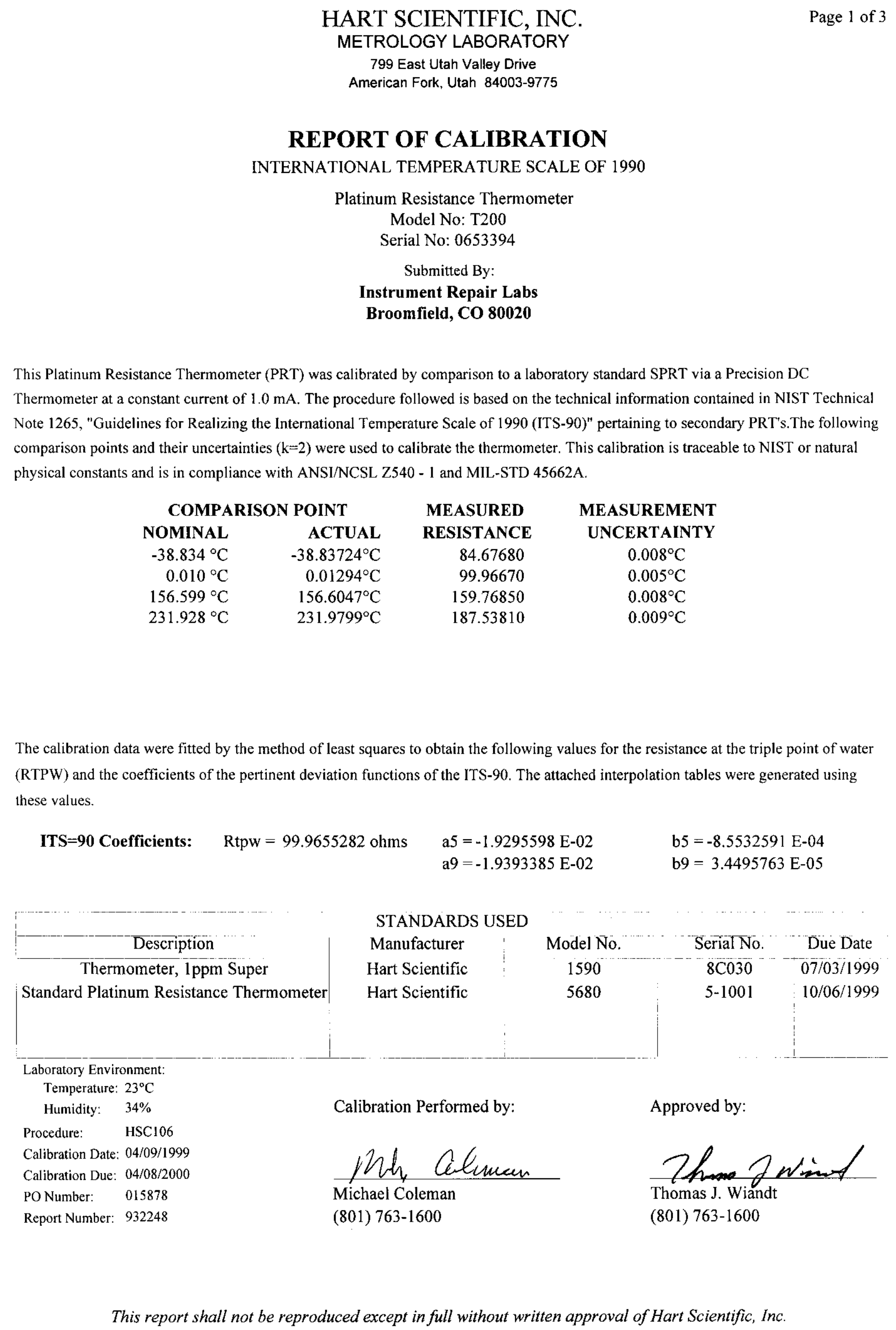
CERTIFIED BY: Ronald Horton
DATE CALIBRATED: 06/02/99
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS
ISO 9002 • CERT NO. 12 100 5851

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

page 1 of 2 Form 07, Rev. 03, 3-26-98

Temperature Sensor
Serial number: 0653394



Page 1 of 3

HART SCIENTIFIC, INC.
METROLOGY LABORATORY
799 East Utah Valley Drive
American Fork, Utah 84003-9775

REPORT OF CALIBRATION

INTERNATIONAL TEMPERATURE SCALE OF 1990

Platinum Resistance Thermometer
Model No: T200
Serial No: 0653394

Submitted By:
Instrument Repair Labs
Broomfield, CO 80020

This Platinum Resistance Thermometer (PRT) was calibrated by comparison to a laboratory standard SPRT via a Precision DC Thermometer at a constant current of 1.0 mA. The procedure followed is based on the technical information contained in NIST Technical Note 1265, "Guidelines for Realizing the International Temperature Scale of 1990 (ITS-90)" pertaining to secondary PRT's.The following comparison points and their uncertainties (k=2) were used to calibrate the thermometer. This calibration is traceable to NIST or natural physical constants and is in compliance with ANSI/NCSL Z540 - 1 and MIL-STD 45662A.

COMPARISON POINT NOMINAL	ACTUAL	MEASURED RESISTANCE	MEASUREMENT UNCERTAINTY
-38.834 °C	-38.83724°C	84.67680	0.008°C
0.010 °C	0.01294°C	99.96670	0.005°C
156.599 °C	156.6047°C	159.76850	0.008°C
231.928 °C	231.9799°C	187.53810	0.009°C

The calibration data were fitted by the method of least squares to obtain the following values for the resistance at the triple point of water (RTPW) and the coefficients of the pertinent deviation functions of the ITS-90. The attached interpolation tables were generated using these values.

ITS=90 Coefficients: Rtpw = 99.9655282 ohms

a5 = -1.9295598 E-02
b5 = -8.5532591 E-04
a9 = -1.9393385 E-02
b9 = 3.4495763 E-05

STANDARDS USED

Description	Manufacturer	Model No.	Serial No.	Due Date
Thermometer, 1ppm Super	Hart Scientific	1590	8C030	07/03/1999
Standard Platinum Resistance Thermometer	Hart Scientific	5680	5-1001	10/06/1999

Laboratory Environment:
Temperature: 23°C
Humidity: 34%
Procedure: HSC106
Calibration Date: 04/09/1999
Calibration Due: 04/08/2000
PO Number: 015878
Report Number: 932248

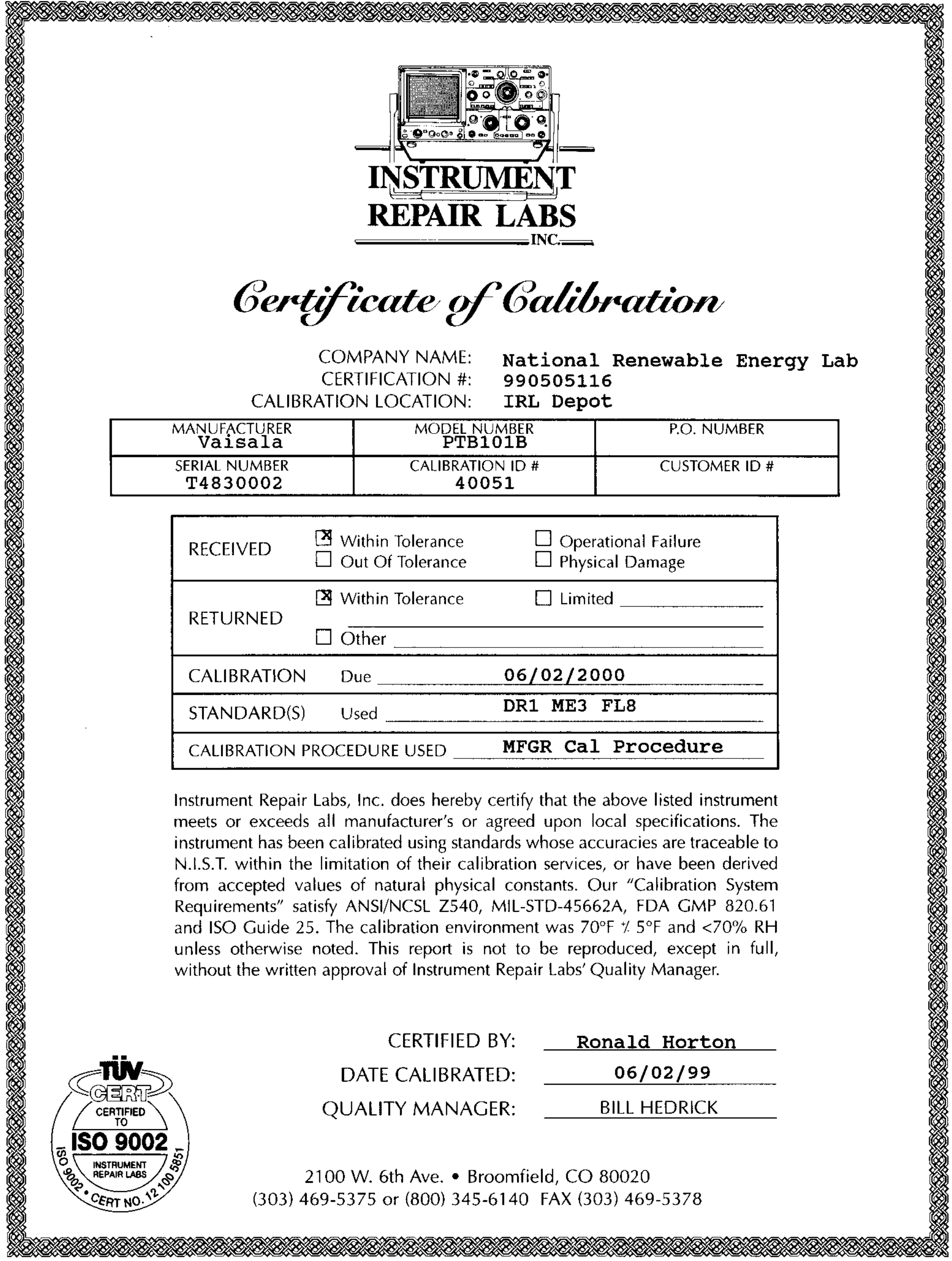
Calibration Performed by:
Michael Coleman
(801) 763-1600

Approved by:
Thomas J. Wiandt
(801) 763-1600

This report shall not be reproduced except in full without written approval of Hart Scientific, Inc.

Pressure Sensor

Serial number: T4830002



INSTRUMENT
REPAIR LABS
INC.

Certificate of Calibration

COMPANY NAME: National Renewable Energy Lab
CERTIFICATION #: 990505116
CALIBRATION LOCATION: IRL Depot

MANUFACTURER Vaisala	MODEL NUMBER PTB101B	P.O. NUMBER
SERIAL NUMBER T4830002	CALIBRATION ID # 40051	CUSTOMER ID #

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

RETURNED ☒ Within Tolerance ☐ Limited ☐ Other

CALIBRATION Due 06/02/2000

STANDARD(S) Used DR1 ME3 FL8

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: Ronald Horton
DATE CALIBRATED: 06/02/99
QUALITY MANAGER: BILL HEDRICK

TÜV CERT CERTIFIED TO ISO 9002 INSTRUMENT REPAIR LABS ISO 9002 • CERT NO. 12 100 5851

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

page 1 of 2

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

Temperature Sensor

Serial number: 0602931

HART SCIENTIFIC, INC.
METROLOGY LABORATORY
799 East Utah Valley Drive
American Fork, Utah 84003-9775

REPORT OF CALIBRATION

INTERNATIONAL TEMPERATURE SCALE OF 1990

Platinum Resistance Thermometer
Model No: T200
Serial No: 0602931

Submitted By:
Instrument Repair Labs
Broomfield, CO 80020

This Platinum Resistance Thermometer (PRT) was calibrated by comparison to a laboratory standard SPRT via a Precision DC Thermometer at a constant current of 1.0 mA. The procedure followed is based on the technical information contained in NIST Technical Note 1265, "Guidelines for Realizing the International Temperature Scale of 1990 (ITS-90)" pertaining to secondary PRT's.The following comparison points and their uncertainties (k=2) were used to calibrate the thermometer. This calibration is traceable to NIST or natural physical constants and is in compliance with ANSI/NCSL Z540 - 1 and MIL-STD 45662A.

COMPARISON POINT		**MEASURED**	**MEASUREMENT**
NOMINAL	**ACTUAL**	**RESISTANCE**	**UNCERTAINTY**
-38.834 °C	-38.83724°C	84.68600	0.008°C
0.010 °C	0.01294°C	100.01520	0.005°C
156.599 °C	156.6047°C	159.81340	0.008°C
231.928 °C	231.9799°C	187.55370	0.009°C

The calibration data were fitted by the method of least squares to obtain the following values for the resistance at the triple point of water (RTPW) and the coefficients of the pertinent deviation functions of the ITS-90. The attached interpolation tables were generated using these values.

ITS=90 Coefficients: Rtpw = 100.0140277

a5 = -1.8451497 E-02
b5 = -8.5217786 E-03
a9 = -1.9255452 E-02
b9 = -1.1259971 E-03

STANDARDS USED

Description	Manufacturer	Model No.	Serial No.	Due Date
Thermometer, 1ppm Super	Hart Scientific	1590	8C030	07/03/1999
Standard Platinum Resistance Thermometer	Hart Scientific	5680	5-1001	10/06/1999

Laboratory Environment:
Temperature: 23°C
Humidity: 34%
Procedure: HSC106
Calibration Date: 04/09/1999
Calibration Due: 04/08/2000
PO Number: 015878
Report Number: 932245

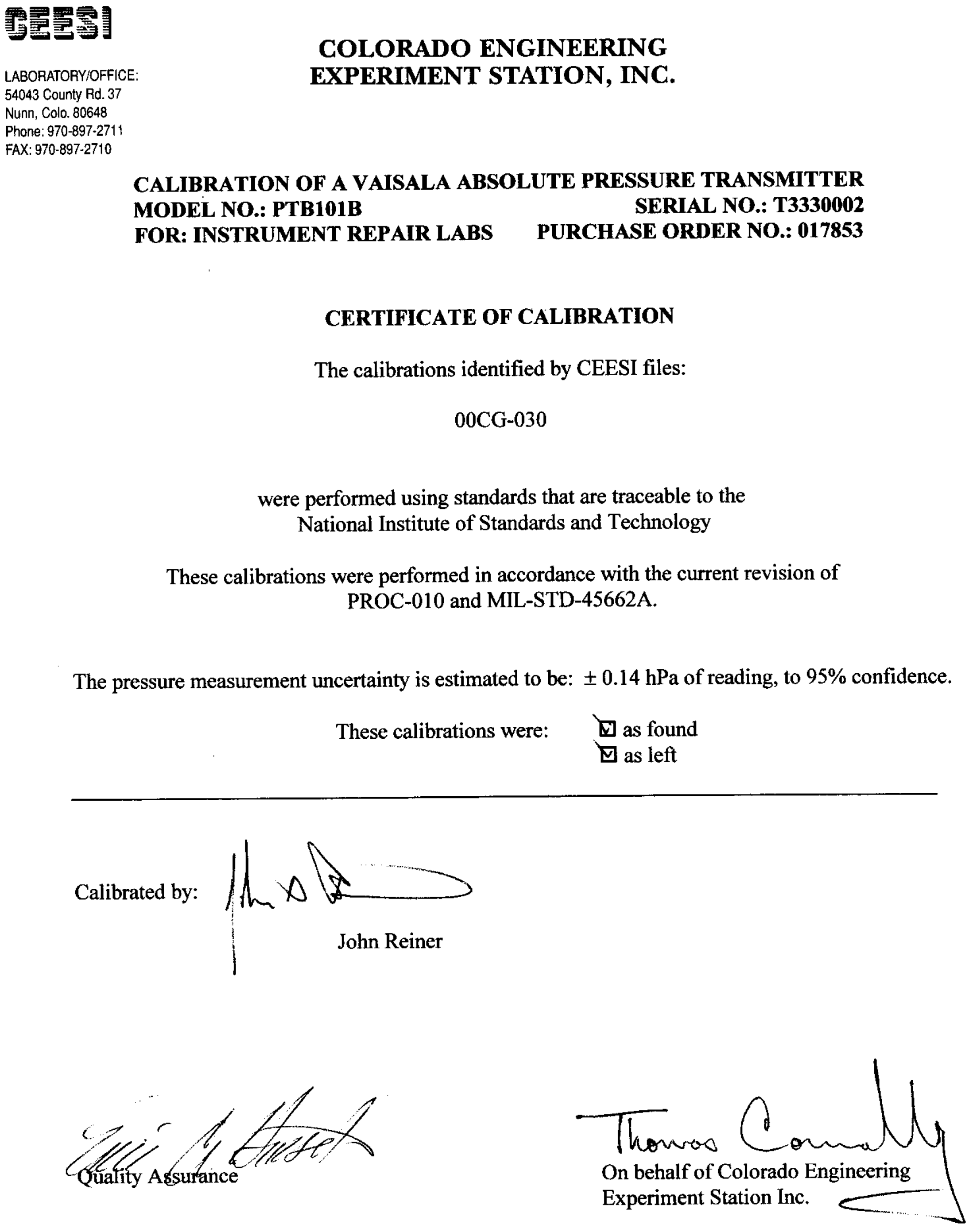
Calibration Performed by:
Michael Coleman
(801) 763-1600

Approved by:
Thomas J. Wiandt
(801) 763-1600

This report shall not be reproduced except in full without written approval of Hart Scientific, Inc.

Pressure Sensor

Serial number: T3330002



CEESI

LABORATORY/OFFICE:
54043 County Rd. 37
Nunn, Colo. 80648
Phone: 970-897-2711
FAX: 970-897-2710

COLORADO ENGINEERING EXPERIMENT STATION, INC.

CALIBRATION OF A VAISALA ABSOLUTE PRESSURE TRANSMITTER
MODEL NO.: PTB101B **SERIAL NO.: T3330002**
FOR: INSTRUMENT REPAIR LABS **PURCHASE ORDER NO.: 017853**

CERTIFICATE OF CALIBRATION

The calibrations identified by CEESI files:

00CG-030

were performed using standards that are traceable to the National Institute of Standards and Technology

These calibrations were performed in accordance with the current revision of PROC-010 and MIL-STD-45662A.

The pressure measurement uncertainty is estimated to be: ± 0.14 hPa of reading, to 95% confidence.

These calibrations were:
☑ as found
☑ as left

Calibrated by:

John Reiner

Quality Assurance

Thomas Connolly

On behalf of Colorado Engineering Experiment Station Inc.

Temperature Sensor
Serial number: 0653393

Branch #: 5000 *sheet: 1 of: 1*

NREL METROLOGY LABORATORY

Test Report

Test Instrument: RTD Probe *DOE #: 02683C*

Model # : N/A *S/N : 0653393*

Calibration Date: 12/12/2000 *Due Date: 12/12/2001*

Nu	*Nominal Values*		*Measured Values*		
	Nominal Resistance	*Equivalent Temperature*	*Measured Resistance*	*Equivalent Temperature*	*Temperature Error(M-N)*
1	*94.12 Ω*	*-15 °C*	*94.131 Ω*	*-14.97 °C*	*0.03 °C*
2	*100.00 Ω*	*0.0 °C*	*100.017 Ω*	*0.04 °C*	*0.04 °C*
3	*105.85 Ω*	*15.0 °C*	*105.872 Ω*	*15.06 °C*	*0.06 °C*
4	*111.67 Ω*	*30.0 °C*	*111.704 Ω*	*30.09 °C*	*0.09 °C*
5	*117.47 Ω*	*45.0 °C*	*117.506 Ω*	*45.09 °C*	*0.09 °C*

Notes:

1. *Total Uncertainty of Nominal Values = ±0.03 °C*
2. *Calibration was performed at 23 °C and 30% RH*
3. *Resistance is measured using 3-wire technique*

Checked By: Reda

Date : 12/12/2000

Appendix C Post-Test Calibration Sheets

Page C2:	AC Real and Reactive Power, Ohio Semitronics, GWV5, s/n 0010301
Page C3:	Turbine Speed, Ultra Slim Pack, s/n B7YSV
Page C4:	DC Bus Volts, Ohio Semitronics, VT7, s/n 9111995
Page C5:	DC Bus Amps, CTA/CTL, s/n 0010125
Page C6:	Battery Amps, CTA/CTL, s/n 0010126
Page C7 & C8:	Datalogger, Campbell Scientific, CR23X, s/n 3099

Branch #: 5000

sheet: 1 **of:** 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer

DOE #: 02747C

Model # : GWV5-001EY37

S/N : 0010301

Calibration Date: 08/09/2001

Due Date: 08/09/2003

Input Voltage @60 Hz	Input Power (Watt) @60 Hz	Output Nominal Voltage (VDC)	Measured Output Volt (VDC)		(X)Mfr. Specs. OR ( )Data only (VDC)
			AS Found	AS Left	
Watt TEST					
	Watt				
100 V	-1000	0.8	0.7935	0.7982	± 0.0036
"	-500	1.6	1.5912	1.5990	± 0.0052
"	0	2.4	2.3937	2.4008	± 0.0068
"	500	3.2	3.1956	3.2008	± 0.0084
"	1000	4.0	3.9968	4.0006	± 0.0100
VAR TEST					
	VAR				
100 V	-1000	1	0.9929	1.0008	± 0.0045
"	0	3	2.9909	2.9983	± 0.0085
"	1000	5	4.9878	4.9993	± 0.0125

Notes:

1. Uncertainty of nominal values is ± 0.06% of reading with traceability to NIST
2. Calibration was performed at 23°C and 40% RH

Tested By: Reda
Date : 08/09/2001

Frequency Converter Calibration

Date Calibrated: 2/18/2000

Report No: F-to-V B2MCD 000218

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

Cal Location:
National Wind Technology Center
18200 State Hwy 128
Boulder, CO 80303

Technician: Mark Meadors x Mark Meadors

Frequency Source: Fluke Documenting Process Calibrator, Model 743B
S/N: 6965608
Calibrated by: Instrument Repair Labs
Date: 10/12/1999
Cal Due: 10/12/2000

Voltage Measurement: Campbell Scientific Model 23X Datalogger
S/N: 1214
Calibrated by: Campbell Scientific
Date: 2/7/2001
Cal Due: 2/7/2002

Device(s) calibrated: Ultra Slim Pack Frequency Input, Field Configurable Isolator
Model: G478-0001
S/N: B7YSV
Calibration Method: GI27 010227, Calibrate frequency to voltage devices

Device Condition: Good

Calibration Uncertainty:	0.1	hertz	Fluke Calibrator for freq: 11<hz<110
	0.5	hertz	Fluke Calibrator for freq: 110<hz<1100
	5.0	mv	Campbell Datalogger for volt: 0<v<5
	48.1	rpm/mv	Sensitivity Factor for Campbell
	240.5	rpm	Campbell Uncertainty in rpm

Special Limitations: 0-150 Vac input, 4-20 mA output with 250 ohm, .01%, 0.6 ppm/deg C IR

			RPM - to - Voltage Conversion 10-pole alternator 12 rpm/hz
Calibration Factors:			
Slope:	0.0208	mV/hz	0.24952 mV/rpm
Offset:	-20.700	hz	-248.39 rpm

Branch #: 5000

sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Transducer

DOE #: 02748C

Model # : VT7-003E

S/N : 9111995

Calibration Date: 08/09/2001

Due Date: 08/09/2003

No	Function Tested	Nominal Output Voltage (VDC)	Measured Output (VDC)		(X)Mfr. Specs. OR ( )Data only (VDC)
			As Found	As Left	
*	DC Voltage (VDC)				
	0	1	0.9970	Same	± 0.0125
	25	3	2.9990	"	"
	50	5	5.0000	"	"

Notes:

1. Uncertainty of nominal values is ± 20 ppm with traceability to NIST
2. Calibration was performed at 23°C and 40% RH

Tested By: Reda

Date : 08/09/2001

Branch #: 5000 **sheet: 1 of: 1**

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Signal Conditioner **DOE #: 02750C**

Model # : CTA212Y42 **S/N : 0010125**

Calibration Date: 08/09/2001 **Due Date: 08/09/2003**

No	Function Tested	Nominal Output Voltage (VDC)	Measured Output (VDC)		(X)Mfr. Specs. OR ( )Data only (VDC)
			As Found	As Left	
*	DC Current (ADC)				
	-50	1	1.034	1.001	± 0.025
	-25	2	2.021	1.995	"
	0	3	3.030	2.998	"
	25	4	4.029	3.998	"
	50	5	5.040	5.005	"

Notes:

1. Uncertainty of nominal values is ± 0.1% of reading with traceability to NIST
2. Calibration was performed at 23°C and 40% RH

Tested By: Reda

Date : 08/09/2001

Branch #: 5000

sheet: 1 of: 1

NREL METROLOGY LABORATORY

Test Report

Test Instrument: Signal Conditioner

DOE #: 02749C

Model # : CTA212

S/N : 0010126

Calibration Date: 08/09/2001

Due Date: 08/09/2003

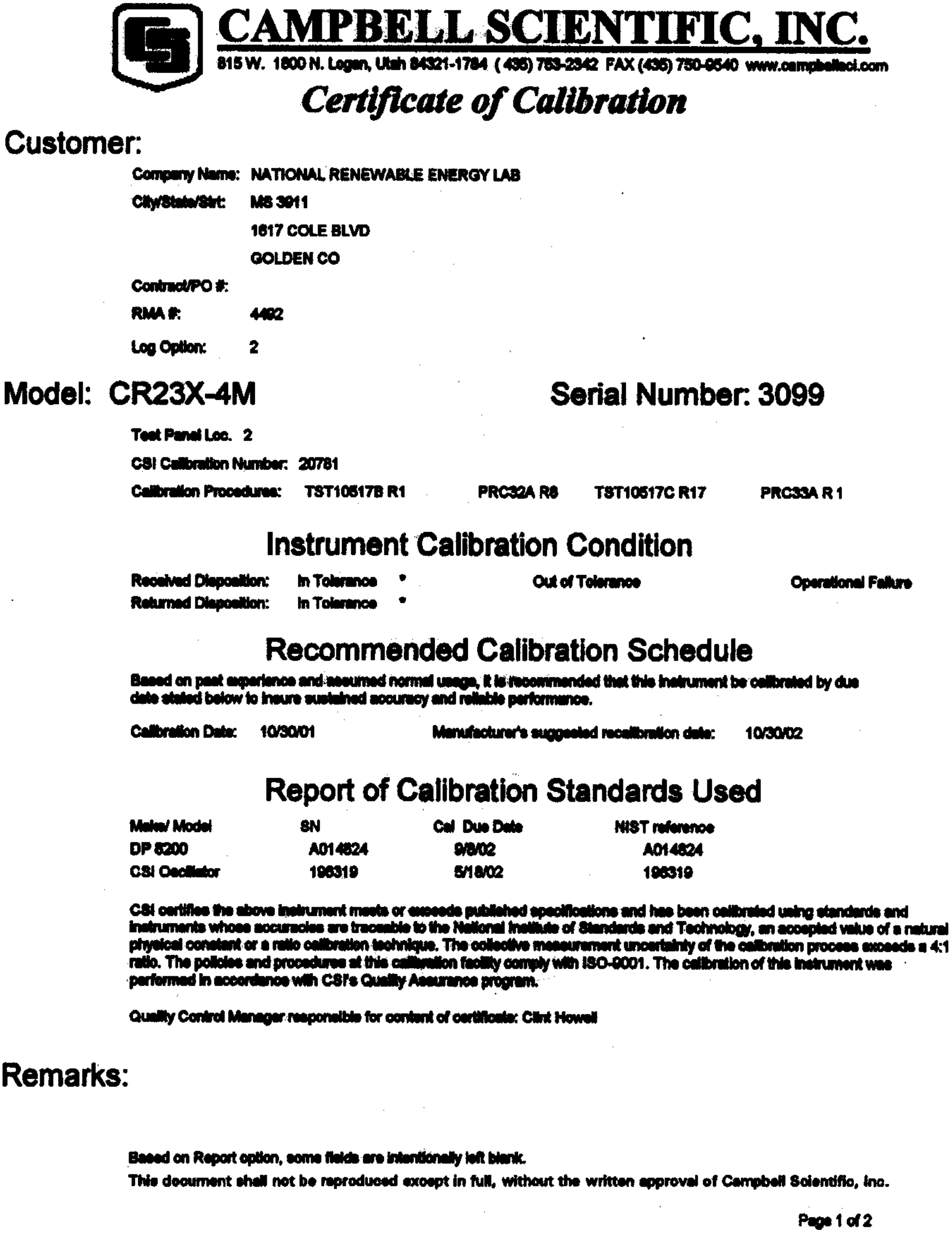
No	Function Tested	Nominal Output Voltage (VDC)	Measured Output (VDC)		(X)Mfr. Specs. OR ( )Data only (VDC)
			As Found	As Left	
*	DC Current (ADC)				
	0	1	0.990	1.001	± 0.025 .01
	25	3	2.978	2.997	" .022
	50	5	4.971	5.000	" .029

Notes:

1. Uncertainty of nominal values is ± 0.1% of reading with traceability to NIST
2. Calibration was performed at 23°C and 40% RH

Tested By: Reda

Date : 08/09/2001



CAMPBELL SCIENTIFIC, INC.

815 W. 1800 N. Logan, Utah 84321-1784 (435) 753-2342 FAX (435) 750-9540 www.campbellsci.com

Certificate of Calibration

Customer:

Company Name: NATIONAL RENEWABLE ENERGY LAB

City/State/Strt: MS 3911

1617 COLE BLVD

GOLDEN CO

Contract/PO #:

RMA #: 4492

Log Option: 2

Model: CR23X-4M

Serial Number: 3099

Test Panel Loc. 2

CSI Calibration Number: 20781

Calibration Procedures: TST10517B R1 PRC32A R8 TST10517C R17 PRC33A R 1

Instrument Calibration Condition

Received Disposition: In Tolerance • Out of Tolerance Operational Failure

Returned Disposition: In Tolerance •

Recommended Calibration Schedule

Based on past experience and assumed normal usage, it is recommended that this instrument be calibrated by due date stated below to insure sustained accuracy and reliable performance.

Calibration Date: 10/30/01 **Manufacturer's suggested recalibration date:** 10/30/02

Report of Calibration Standards Used

Make/ Model	SN	Cal Due Date	NIST reference
DP 8200	A014824	9/8/02	A014824
CSI Oscillator	196319	5/18/02	196319

CSI certifies the above instrument meets or exceeds published specifications and has been calibrated using standards and instruments whose accuracies are traceable to the National Institute of Standards and Technology, an accepted value of a natural physical constant or a ratio calibration technique. The collective measurement uncertainty of the calibration process exceeds a 4:1 ratio. The policies and procedures at this calibration facility comply with ISO-9001. The calibration of this instrument was performed in accordance with CSI's Quality Assurance program.

Quality Control Manager responsible for content of certificate: Clint Howell

Remarks:

Based on Report option, some fields are intentionally left blank.

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Page 1 of 2

Instrument Data Report

Analog Inputs

Log Option: 2 S/N 3099

			Single-Ended (Full Scale)		Differential		
Range	**Input (mV)**	**Tolerance (mV)**	**Before (mV)**	**After (mV)**	**Before (mV)**	**After (mV)**	**Temp (C)**
5	5000	+-2.5	5000.3	5000.3	4999.7	5000.0	24.1
5	-5000	+-2.5	-4999.5	-5000.1	-4999.9	-5000.2	24.1
4	1000	+-0.5			999.98	1000.00	24.1
3	200	+-0.1			199.99	200.01	24.1
2	50	+-0.025			49.998	50.000	24.1
1	10	+-0.005			10.000	10.001	24.1
1	-10	+-0.005			-10.000	-10.000	24.1
5	5000	+-5		4998.8		4998.2	-25
5	5000	+-5		5001.1		5000.9	50
5	5000	+-7.5		4998.6		4997.7	-40
5	5000	+-7.5		5001.0		5001.1	60

Quiescent System Power

Tolerance Max (ma)	As Received (mA)	As Returned (mA)	Temp (C)
2.5	1.29	1.23	24.1

Real-Time Clock

Tolerance (min/month)	As Received (min/month)	As Returned (min/month)	Temp (C)
+-1.33 min	-0.1	0.0	24.1
+-1.33 min		-0.2	-25
+-1.33 min		-0.4	50
+-2.66 min		-0.5	-40
+-2.66 min		-0.6	60

Note: an "*" with data indicates out of tolerance; an "*" without data indicates operational failure.

Laboratory temperature and relative humidity at the time of calibration

Temperature: 24.1 C **Relative Humidity: 19.2 %**

Functions tested per test document (see page 1):

Analog:
- Excitation Channels
- CAO Channels
- Analog Input ranges over temperature

Frequency:
- Pulse Counters
- Period Averaging

Calibration by: T. Kendall **Title: Electronic Technician**

T. KENDALL

Based on Report option, some fields are intentionally left blank.

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Page 2 of 2