Measurements on

Kolibri 5.5 kW

Troels Kildemoes Møller
Lars Christian Christensen

February 1998

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Abstrakt
Rapporten beskriver måling på en 5.5 kW vindmølle fra firmaet Gaia Wind. Målingen har omfattet effektmåling, måling af egenfrekvenser, krøjehastighed samt bremsekarakteristik. Effektmålingen er baseret på "Rekommandation for måling af en vindmølles effektkurve" [1]. Målingen er foretaget på en mølle opstillet på Folkecenterets testområde ved Ydby i Thy.

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1. Introduction

This measurement report contains the results of measurements performed on the Kolibri 5.5 kW erected at Folkecenter for Renewable Energy. The measurements were performed in the period from September 1997 to February 1998.

The measurements were prepared and accomplished in accordance with a test plan and a contract between Gaia Wind and Folkecenter for Renewable Energy.

2. Description of the wind turbine

This chapter describes the main data for the turbine. A photograph of the turbine, erected at Folkecenters testsite, is shown in appendix F.

2.1 Technical description

Table 2.1 Technical description of Kolibri 5.5 kW

Technical description of Kolibri 5.5 kW		
Type	Horizontal downwind turbine	
Rotor	Power regulation	Stall
	Number of blades	3
	Rotor diameter	7.0 m
	Swept area	38.5 m^2
	Hub height exc. foundation	12.85 m
	Hub height inc. foundation	12.85 m
	Rotor speed	127 rpm (sync.)
	Tilt	0°
	Coning	9°
	Blade tip angle	+ 4.5° (from company)
	Cut-in wind speed	4.5 m/s
	Cut-out wind speed	18 m/s
Blade	Make	Olsen
	Type	GFP
	Blade length	3.4 m
	Root chord	303 mm
	Tip chord	150 mm
	Blade profile	Naca 63 xxx
	Airbrakes	Pivotable blade tips
Gear	Make	DK-Miljø - Randers Tandhjul.
	Exchange ratio	5.7
Mechanical brake	Make	Lenze
	Function	Fail safe (active brake system)
	Location	High speed shaft

Table 2.1 Technical description of Kolibri 5.5 kW

Generator	Make	EOF, Berendsen
	Type	Asyncr.
	Nominal power	5.5 kW
	Rotational speed	750 rpm
	Voltage	400 V
	Frequency	50 Hz
Yawing	Type	Forced yawing (side rotor)
Controller	Make	DK-Miljø
	Type	PLC
Tower	Tower	Tubular tower
	Height	12 m

3. Description of the test site

3.1 Location
The turbine is located south at Folkecenters test site.
Address: Kammersgårdsvej 16, 7760 Hurup Thy

3.2 Terrain
Appendix F shows the location of the site. The sector used for measurements is from 265° to 355°. The distance between the turbine and met mast is 2.5 D. The landscape is typical farm land with many windbreaks (roughness class 2-3). In the measurement sector there is a group of houses approximately 400 m away from the turbine (houses with an height of approx. 6 m.).

3.3 Grid connection
The turbine is connected to the 400 V grid. Grid frequency and grid voltage has not been measured.

4. Instrumentation

Table 4.1.A shows the set-up for the power curve measurements. Table 4.1.B shows used sensors and transmitters.

4.1 Measured parameters, sensors and transmitters

Table 4.1.A Measured parameters

Position	Parameter	Name of parameter
Meteorological mast	Wind speed at 12.85 m	WS1
	Wind direction at 11.1 m	WD1
	Air temperature at 11.1 m	TE
Measurement house	Rain 2.5 m	RAIN
	Air pressure at 1 m	AP1
Nacelle	Rotor rotational speed	SPLS
Grid	Electrical power	EPOW

Table 4.1.B Sensors and transmitters

Parameter	Sensor	Transmitter
Wind speed 12.85 m	Risø-anemometer (serial no.307)	Risø P1225 (FC.reg.no.3)
Wind direction 11.1 m	Risø cos-sin resolver (FC.reg.no.66)	Risø P2014 (FC.reg.no.1)
Temperature 11.1 m	SDL PT 100 Ohm	PR-Electronic
Rain	Vaisala DRD 11A rain detector	
Atmosp. pressure	JUMO 4 ABI-55	
Electrical power	Deif	
Current	Garre 200/5, cl. 0.1	
Rotational speed	From controller	PR-Electronic

4.2 Data acquisition system

The data acquisition system is able to handle 64 channels. All signals are transformed to a ± 5 V level. All signals are passing a filter block with a cut-off frequency 20 Hz and a gain of 1. The sampling rate during the measurements was 50 Hz. Table 4.2.A specifies the system.

Table 4.2.A DAQ-system

	Instruments
Filter	FC LP-filter, cut-off 20 Hz, gain 1
A/D-board	National Instruments A/D-board (AT MIO-64, 12 bit)
Computer	486 DX IBM comp. PC with 133 MHz Intel processor, 16 MB RAM
DAQ-software	Labview
DAQ-analysis	FC-DAQ

4.3 Calibration

Sensors and transmission lines were calibrated separately. Certificates for anemometer and power converter is shown in appendix E. Transmission lines inclusive cables, filters, A/D-board and DAQ-program were calibrated.Transmission line for wind speed inclusive transmitter was calibrated with a frequency calibrator (Risø P2333a) at 10 Hz and 40 Hz. Other lines were calibrated with a voltage calibrator.

Table 4.3.A Total calibration - set-up parameters for FC-DAQ

Parameter	gain	offset
Wind speed	3.7314 m/s/V	18.747 m/s
Wind direction	100°/V	0°
Temperature	18°C/V	-30°C
Pressure	50 mbar/V	850 mbar
Electric power	3.75 kW/V	-3.75 kW/V

5. Power measurements

5.1 Measurement procedure

All data for power curve measurements are based on 10 min. time series. After every 10 minutes, calculation of mean, standard deviation, max. and min-value is performed for all measured parameters in the time serie. All data are stored on harddisk for further analysis.

5.2 Data selection for power curve

Data have to fulfill the following criteria:

1) Wind direction:	265 ° < Wind direction < 355 °
2) Precipitation	No rain
3) RPM	110 < RPM < 140

5.3 Data correction

According to ref.[1] the selected data sets are corrected to a standard air density of 1.225 kg/m3, corresponding to dry air at 15 °C and 1013 hPa.

5.4 Database

The power measurements were performed in the period from September 1997 to November 1997. All together 1052 accepted 10. min time series have been the basis for the powercurve. Appendix A shows measured power, calculated turbulence intensity and Cp-values for accepted data.

5.5 Measured power curve

Appendix B shows the power curve. For calculation of annual energy production the power curve has been extrapolated from 15.06 m/s until cut-out wind speed 18 m/s (power set to 6.24 kW).

Ref.[1] recomments a minimum amount of data to give a good representation of power output. This is shown in table 5.5.A. The reference windspeed V_{ref} corresponding to 85 % of nominal power (nominal power set to 6.54 kW according to table 5.6.A) is approx. 10.9 m/s.

Table 5.5.A Minimum amount of data according to ref.[1]

	Ref.[1]	Table 5.6.A
Number of data set in each bin, $V<=V_{ref}$ = 10.9 m/s	10	2
Number of data set in each bin, $V_{ref}<=V<=1.5*V_{ref}$	3	1
Hours of measurements within power interval 15-85 % of P_{nom}	180	≈ 133

5.6 Annual energy production and uncertainty estimate

Table 5.6.A shows tabulated power curve and uncertainty estimates (uncertainty estimates: appendix C). Table 5.6.B shows calculated annual energy production and corresponding uncertainty estimates for different mean wind speeds V_{mean} and a form factor k of 2.

The energy production in each wind speed bin is calculated according to following formula:

$$E_{bin} = (\exp(-(\frac{V_{min}}{A_{weibull}})^k) - (\exp(-(\frac{V_{max}}{A_{weibull}})^k) \times 8760 \times P_{bin}$$

A: Weibull parameter
k: Weibull form parameter
V_{min}: Minimum wind speed in specific bin
V_{max}: Maximum wind speed in specific bin
P_{bin}: Average power in the specific bin

Table 5.6.A Tabulated power curve and uncertainty estimate

Measured Power Curve					Category A Uncertainties	Category B Uncertainties
bin i	Wind speed V m/s	Electric Power P kW	No. of datasets N (10 min.)	Power coefficient Cp	Std.dev. Sp,i kW	Std.dev. Up,i kW
1	4,41	-0,11	2	-	0,02	0,17
2	4,81	0,17	3	0,07	0,13	0,17
3	5,25	0,51	6	0,15	0,14	0,20
4	5,75	1,00	16	0,22	0,09	0,24
5	6,23	1,55	27	0,27	0,06	0,27
6	6,72	2,11	50	0,29	0,05	0,22
7	7,24	2,45	68	0,27	0,04	0,26
8	7,75	3,19	90	0,29	0,03	0,32
9	8,25	3,74	100	0,28	0,03	0,26
10	8,75	4,21	105	0,27	0,03	0,17
11	9,25	4,37	114	0,23	0,03	0,20
12	9,75	4,95	100	0,23	0,03	0,16
13	10,24	4,91	71	0,19	0,04	0,16
14	10,75	5,51	59	0,19	0,05	0,24
15	11,24	5,72	46	0,17	0,05	0,11
16	11,75	5,84	53	0,15	0,04	0,11
17	12,25	6,02	41	0,14	0,05	0,09
18	12,73	6,06	39	0,12	0,05	0,08
19	13,19	6,16	26	0,11	0,05	0,16
20	13,77	6,54	21	0,11	0,07	0,08
21	14,24	6,30	12	0,09	0,09	0,07
22	14,80	6,46	3	0,08	0,15	0,07
23	15,06	6,24	1	0,08	-	0,07

Table 5.6.B Annual energy production

Annual Energy Production		
Rayleigh-distribution Mean wind speed m/s	Annual energy production kWh	Measurement uncertainty Std.dev. kWh
5	10036	1141 (11%)
6	15613	1284 (8%)
7	20695	1324 (6%)
8	24703	1297 (5%)
9	27412	1232 (4%)

5.7 Comments to power curve

The power curve measurement differs from ref.[1] at following points:

1) Data selection. All turbulence intensities have been used.

2) The number of time series is less than recommended for $V<=V_{ref}$

3) The number of time series is less than recommended for $V_{ref}<=V<=1.5*V_{ref}$

4) Number of hours in the interval 15-85 % of P_{nom} is 133 hours.

According to 1)
A house hold turbine like Kolibri 5.5 kW will meet all turbulence intensities. Excluding turbulence intensities > 15 % will not show real conditions for a house hold turbine.

According to 2)
The number of time series at very low wind speeds *(see comments chapter 5.8)* is less than recommended giving a relative high influence on Category A uncertainty. The influence from this on the annual energy production is very small becauce of the low total energy production for wind speeds in bin 1-3 (contribution to the annual energy production from bin 1-3 less than 4 %).

According to 3)
The number of timeseries in the last recorded bin (bin 23) is less than recommended giving a relative high influence on Category A uncertainty. The influence from this on the annual energy production is very small becauce of the few operational hours at high wind speeds.

According to 4)
The number of measurements make influence on Category A uncertainty. However the Category B uncertainty is much more dominant in this wind speed interval (table 5.6.A).

5.8 Special comments to cut-in wind speed and energy production

The Kolibri 5.5 kW needs a relative high wind to start. The cut-in windspeed according to appendix D is between 6.5-7.0 m/s. When the turbine is running in normal production mode, the turbine is able to produce power down to a wind speed of approx. 4.5 m/s. The figure in appendix D shows the time history for connected samples of wind speed and power.

The high cut-in wind speed reduces the estimated annual energy production calculated in chapter 5.6 (cut- in wind speed set to approx. 4.5 m/s in energy calculations). Especially for turbines located on a low wind site, the reduction can be appreciable.

6. Additional measurements

6.1 Frequencies

The dynamic response for rotor and tower has been analysed by use of accelerometer and Fast Fourier Analysis software. Appendix H contains some figures from the analysis. All tests have been made with stopped rotor and the instrumented blade pointing vertical down. Rotor and tower motions have been activated by random shocking, wind excitation and pulling a rope.

Following fundamental frequencies have been found for the turbine:

Rotor - flapwise blade motion

1'st symmetrical rotor mode (1SR)	4.64 Hz
1'st asymmetrical rotor mode (1AR)	4.20 Hz

Comments:
The frequency 4.64 Hz corresponding to the 1'st symmetrical rotor mode is equal to the first flapwise frequency of the blade found in a test stand ([2]).

The frequency 4.20 Hz corresponding to the 1'st asymmetrical rotor mode is lower because of bending flexibility of the shaft.

Rotor - chordwise blade motion

Rotor mode (C1)	13.38 Hz

Comments:
The frequency 13.38 Hz corresponds to the 1'st chordwise natural frequency for the blade found in a test stand ([2]). The frequency is approximately 5 % higher than measured in [2], which may be caused to a counterphase coupling with the tower

Tower

1'st bending tower mode (1BT)	1.47 Hz

6.2 Brake test

Airbrakes and mechanical brake have been tested. The tests were performed close to rated power (average wind speed 11 m/s with gusts up to 15 m/s). Wind speed and rotational speed have been reported. Appendix G contains a figure showing the behavior of the brake systems.

Airbrakes
The airbrake tests have shown that rpm can be maintained below152 rpm in the specific wind speed interval. This is equal to an increase in rpm of approximately 20 % compared to nominal rpm.

Mechanical brake
Each airbrake test has been followed by an activation of the mechanical brake (brake activated because of loss of electric power). The mechanical brake is able to stop the rotor in approximately 5 seconds.

The response for the rpm measurement setup was not fast enough to show the precise rpm sequence at low rpm just before full stop of the rotor. The braking time (5 seconds) has therefore been estimated from the available braking tests and additional measurements made by hand-held equipment.

6.3 Yaw test

The turbine is equipped with a yawing system based on a small side rotor. The side rotor yaws the nacelle by help of a rubber belt. The purpose of the measurements is to investigate, if the yaw system is able to provide a sufficient low yaw velocity.

The yaw test took place in heavy turbulent wind (> 15 %) with wind speeds up to 15 m/s. All together two hours of relevant data for the yaw analysis were acquired. The yaw velocity was measured by use of a multi-turn potentiometer (0-3600 ° = 57 - 5000 mV).

Appendix I contains figures from the yaw test. Yaw position (position of the nacelle) and yaw velocity (degrees/sec) are shown for a period of 300 seconds. For the hole period (two hours) no yaw velocity higher than 11 °/sec has been seen.

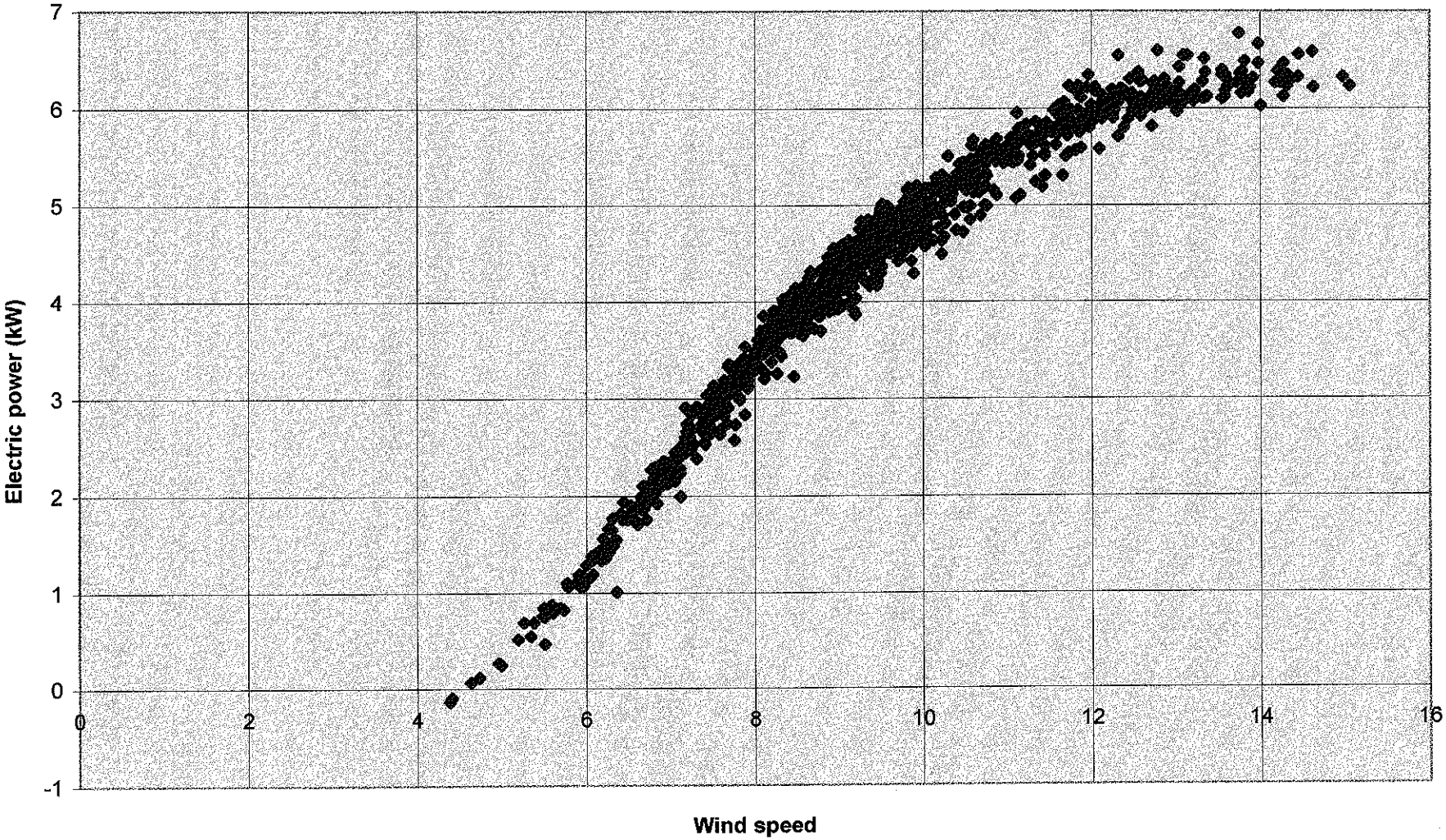
7. References

1) Recommendation for Wind Turbine Power Curve Measurements (Risø-I-745(EN))

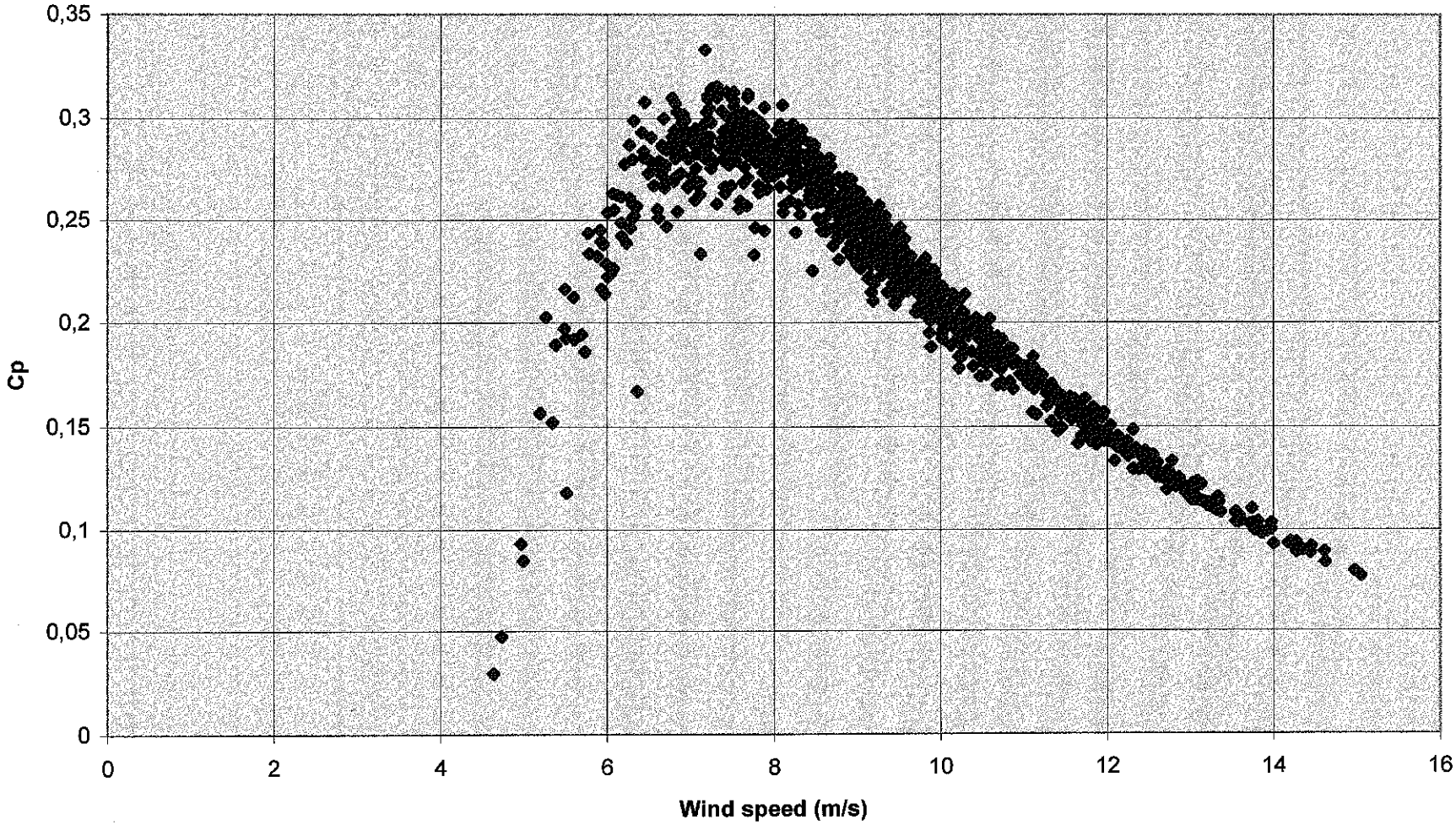
2) Static Load Test of Wind Turbine Blade Manufactured by Olsen Wings (Risø-I-1173 (EN))

Appendix A

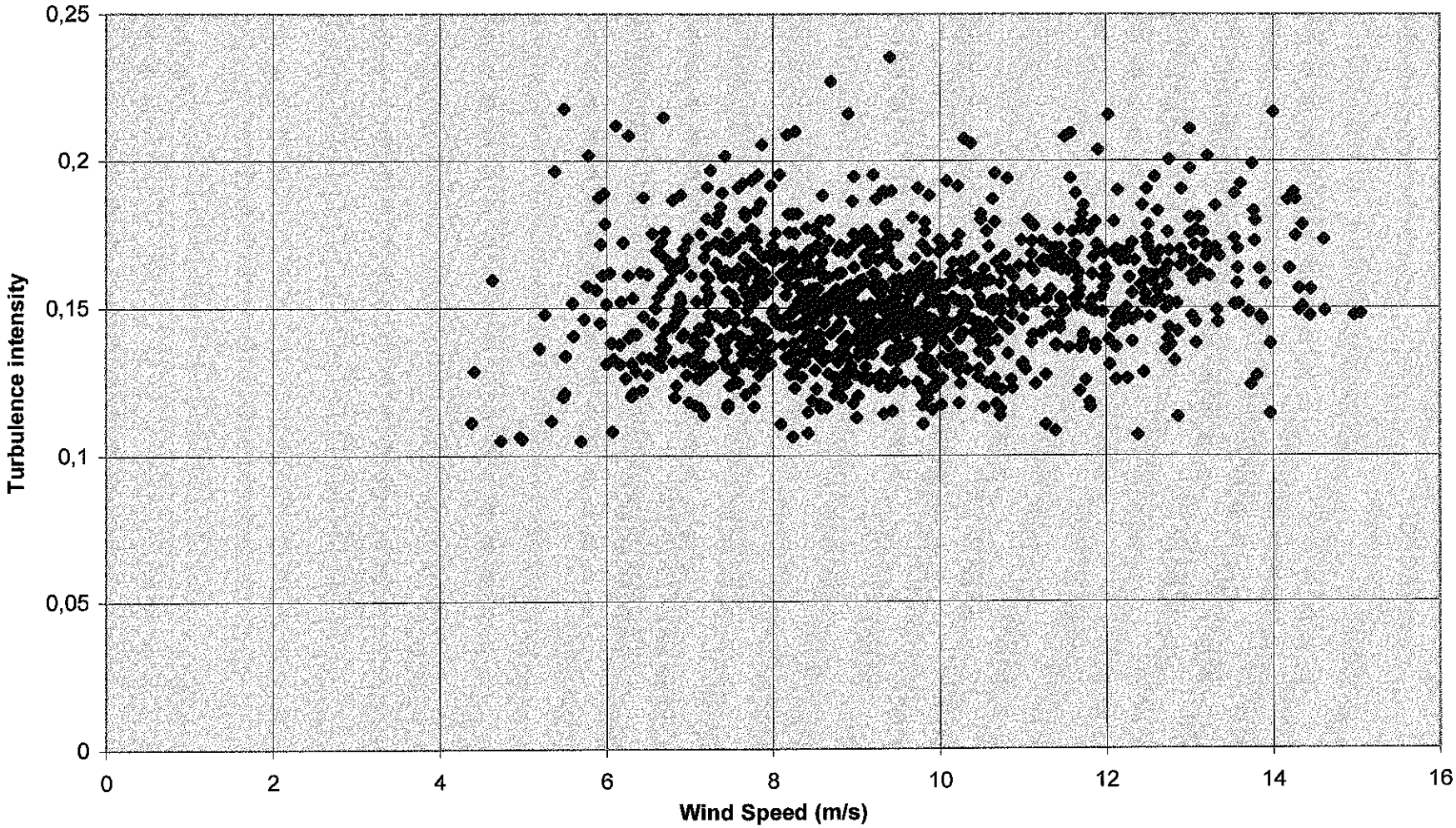
Power Curve - Accepted data - Kolibri 5.5 kW



Cp-Curve - Kolibri 5.5 kW

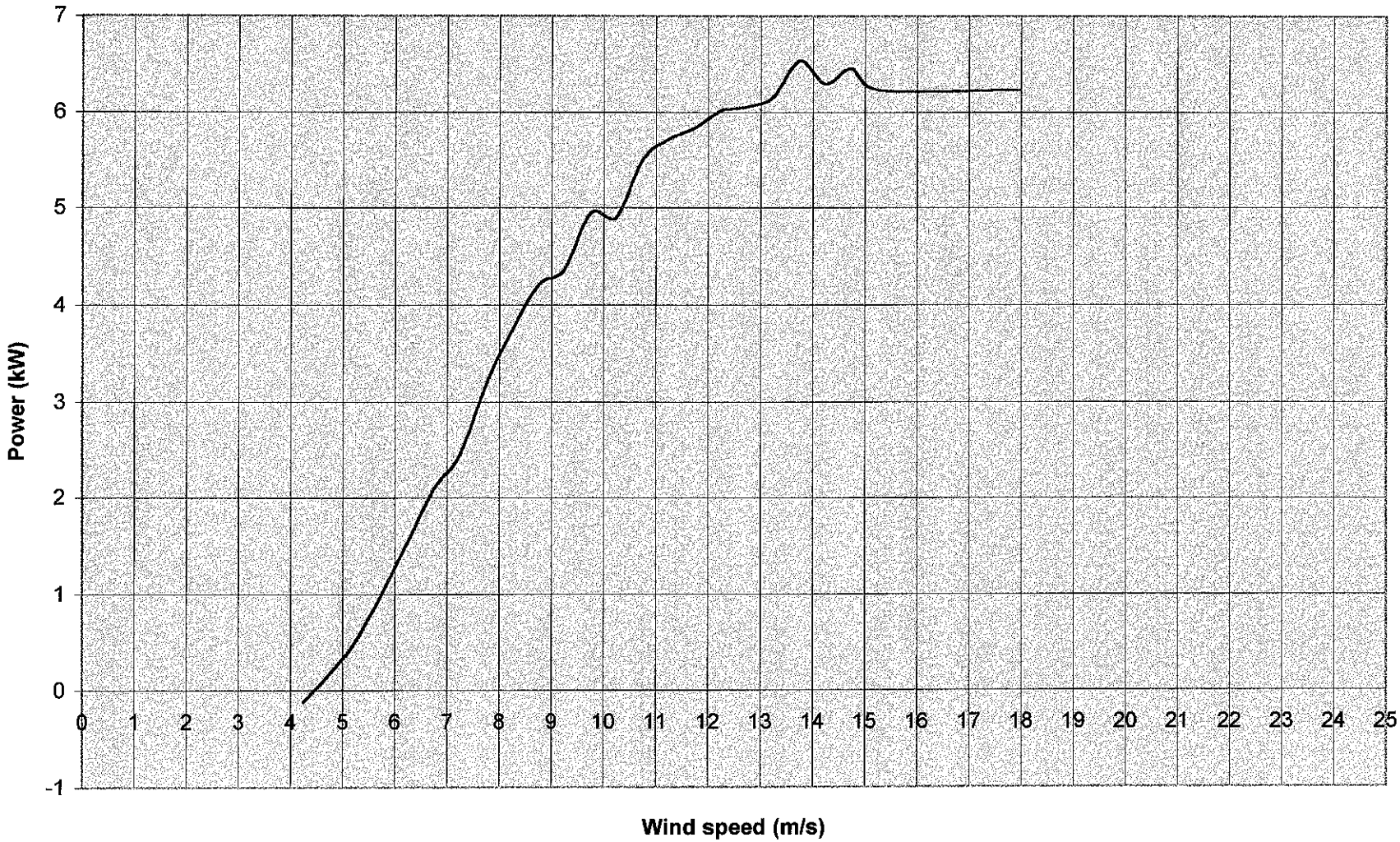


Turbulence intensity - Kolibri 5.5 kW



Appendix B

Power curve - Kolibri 5.5 kW



Appendix C

Appendix C

Uncertainty on measurements

The calculations are done according to ref.[1].

Category B uncertainties

Wind speed
The uncertainty of the anemometer is estimated to be a standard deviation of 0.2 m/s, including data transmission and data acquisition. The uncertainty limit on the anemometer from overspeeding is estimated to be 1 % of the wind speed, and the uncertainty limit due to the measurement site, is estimated to be 3 % of the wind speed. The last two mentioned uncertainties are anticipated to be rectangular distributed then the standard deviation on the measurement of the wind speed in each bin is:

$$u_v=(0.2^2+(0.01*V/\sqrt{3})^2+(0.03*V\sqrt{3})^2)^{0.5}$$

Electric power
The power converter is anticipated to be of class 0.5. With a nominal power of 15 kW for the power converter, the uncertainty limit is 0.075 kW. To this value is added a contribution from different influence factors (temperature, grid frequency etc.), which is estimated to be 10 % of the uncertainty limit. The uncertainty distribution is anticipated to be rectangular distributed. The standard deviation of the power converter is then 0.048 kW.

The current transformers are of class 0.1 giving an uncertainty limit of 0.1 % of the power. To this is added a contribution from the influence factors, which is anticipated to be 10 %. The uncertainty distribution is anticipated to be rectangular distributed. The standard deviation of the power for each bin is:

$$u_P=(0.13^2+(0.0011*P/\sqrt{3})^2)^{0.5}$$

Air density
The temperature sensor is anticipated to have an uncertainty with a standard deviation of 0.1 C °. The shielding of the temperature sensor is anticipated to have an uncertainty with a standard deviation of 1.8 C °. The uncertainty from data transmission and transmission is anticipated to be 0.01 C °. The total uncertainty is thus 1.8 C °.

The pressure sensor inclusive shielding is anticipated to have an uncertainty with a standard deviation of 1.1 hPa. Inclusive correction for the height difference, the total uncertainty is 1.2 hPa.
The standard deviation of the density due to humidity is estimated to 0.004 kg/m3.

Table 1 Measured data and calculated sensivity factors

Power Curve			Sensivity Factor		
bin	V m/s	P Kw	α_v Kw/m/s	α_t Kw/C°	α_B Kw/hPa
1	4,41	-0,11	0,74	0,000	0,000
2	4,81	0,17	0,74	0,001	0,000
3	5,25	0,51	0,88	0,002	0,001
4	5,75	1,00	1,06	0,003	0,001
5	6,23	1,55	1,13	0,005	0,002
6	6,72	2,10	0,89	0,007	0,002
7	7,24	2,45	1,06	0,009	0,002
8	7,75	3,19	1,28	0,011	0,003
9	8,25	3,74	1,02	0,013	0,004
10	8,75	4,21	0,63	0,015	0,004
11	9,25	4,37	0,74	0,015	0,004
12	9,75	4,95	0,55	0,017	0,005
13	10,24	4,91	0,56	0,017	0,005
14	10,75	5,51	0,81	0,019	0,005
15	11,24	5,72	0,33	0,020	0,006
16	11,75	5,84	0,30	0,020	0,006
17	12,25	6,02	0,22	0,021	0,006
18	12,73	6,06	0,15	0,021	0,006
19	13,19	6,16	0,46	0,021	0,006
20	13,77	6,54	0,13	0,023	0,006
21	14,24	6,30	-0,08	0,022	0,006
22	14,80	6,46	-0,07	0,022	0,006
23	15,06	6,24	-0,07	0,022	0,006

Table 2 Category B uncertainties

Category B Uncertainties									
bin	Wind Speed Uv		Electric power Up	Temperature Ut		Pressure U_B		Humidity Uh	
	m/s	kW	kW	C°	kW	hPa	kW	kg/m3	kW
1	0,216	0,160	0,048	1,8	0,00	1,2	0,00	0,004	0,00
2	0,218	0,161	0,048	1,8	0,00	1,2	0,00	0,004	0,00
3	0,222	0,196	0,048	1,8	0,00	1,2	0,00	0,004	0,00
4	0,226	0,240	0,048	1,8	0,01	1,2	0,00	0,004	0,00
5	0,230	0,261	0,048	1,8	0,01	1,2	0,00	0,004	0,01
6	0,235	0,209	0,048	1,8	0,01	1,2	0,00	0,004	0,01
7	0,240	0,254	0,048	1,8	0,02	1,2	0,00	0,004	0,01
8	0,245	0,313	0,048	1,8	0,02	1,2	0,00	0,004	0,01
9	0,250	0,255	0,048	1,8	0,02	1,2	0,00	0,004	0,01
10	0,256	0,161	0,048	1,8	0,03	1,2	0,00	0,004	0,01
11	0,262	0,194	0,048	1,8	0,03	1,2	0,01	0,004	0,01
12	0,268	0,146	0,048	1,8	0,03	1,2	0,01	0,004	0,02
13	0,274	0,153	0,048	1,8	0,03	1,2	0,01	0,004	0,02
14	0,280	0,227	0,048	1,8	0,03	1,2	0,01	0,004	0,02
15	0,286	0,095	0,048	1,8	0,04	1,2	0,01	0,004	0,02
16	0,293	0,087	0,048	1,8	0,04	1,2	0,01	0,004	0,02
17	0,300	0,067	0,048	1,8	0,04	1,2	0,01	0,004	0,02
18	0,307	0,046	0,048	1,8	0,04	1,2	0,01	0,004	0,02
19	0,313	0,144	0,048	1,8	0,04	1,2	0,01	0,004	0,02
20	0,321	0,043	0,048	1,8	0,04	1,2	0,01	0,004	0,02
21	0,328	-0,025	0,048	1,8	0,04	1,2	0,01	0,004	0,02
22	0,336	-0,025	0,048	1,8	0,04	1,2	0,01	0,004	0,02
23	0,340	-0,024	0,048	1,8	0,04	1,2	0,01	0,004	0,02

Table 3 Measured data and calculated uncertainties

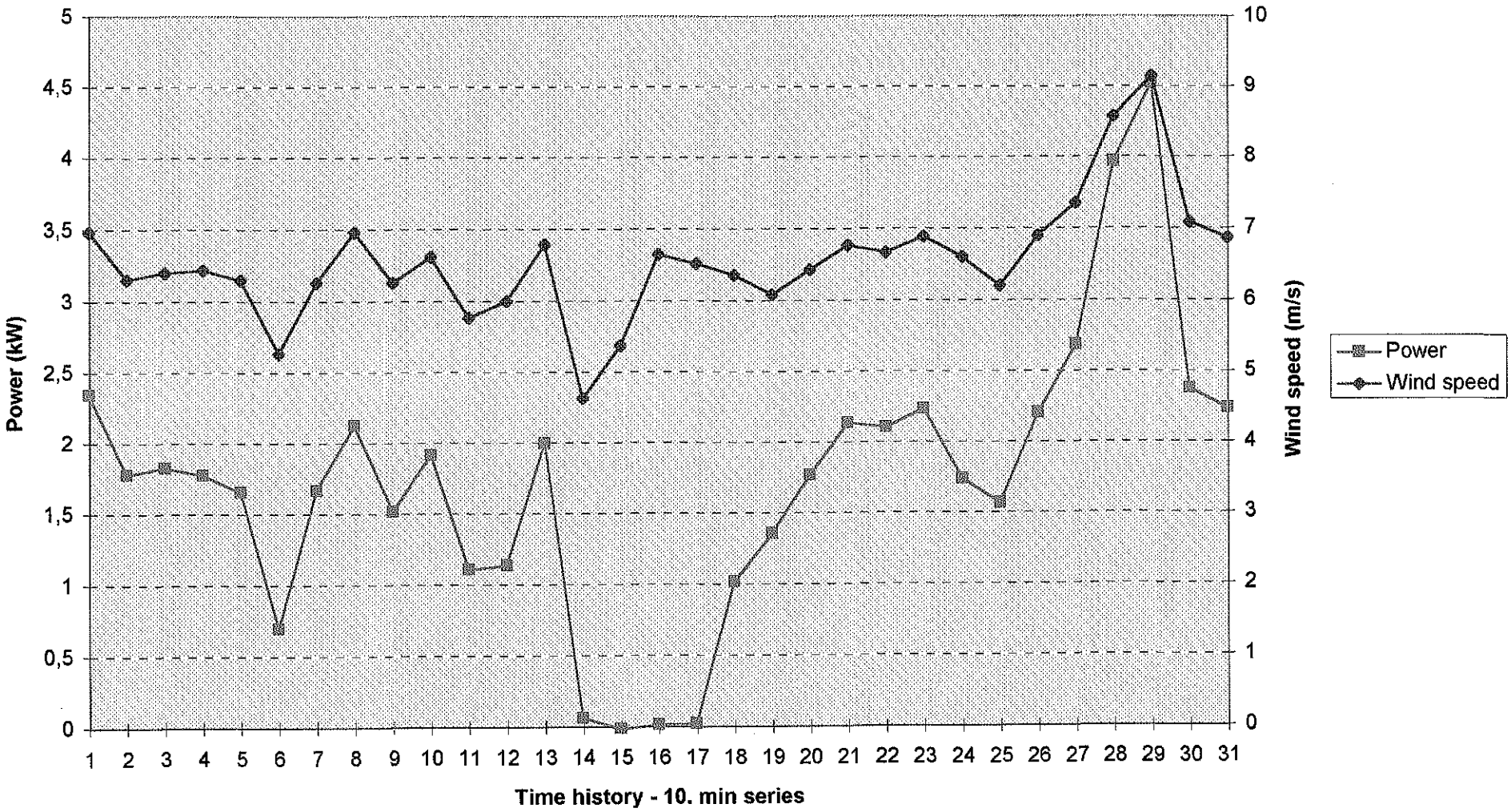
Measured Power Curve					Category A Uncertainties	Category B Uncertainties
bin i	Wind speed V m/s	Electric Power P kW	No. of datasets N (10 min.)	Power coefficient Cp	Std.dev. Sp,i kW	Std.dev. Up,i kW
1	4,41	-0,11	2	-	0,02	0,17
2	4,81	0,17	3	0,07	0,13	0,17
3	5,25	0,51	6	0,15	0,14	0,20
4	5,75	1,00	16	0,22	0,09	0,24
5	6,23	1,55	27	0,27	0,06	0,27
6	6,72	2,10	50	0,29	0,05	0,22
7	7,24	2,45	68	0,27	0,04	0,26
8	7,75	3,19	90	0,29	0,03	0,32
9	8,25	3,74	100	0,28	0,03	0,26
10	8,75	4,21	105	0,27	0,03	0,17
11	9,25	4,37	114	0,23	0,03	0,20
12	9,75	4,95	100	0,23	0,03	0,16
13	10,24	4,91	71	0,19	0,04	0,16
14	10,75	5,51	59	0,19	0,05	0,24
15	11,24	5,72	46	0,17	0,05	0,11
16	11,75	5,84	53	0,15	0,04	0,11
17	12,25	6,02	41	0,14	0,05	0,09
18	12,73	6,06	39	0,12	0,05	0,08
19	13,19	6,16	26	0,11	0,05	0,16
20	13,77	6,54	21	0,11	0,07	0,08
21	14,24	6,30	12	0,09	0,09	0,07
22	14,80	6,46	3	0,08	0,15	0,07
23	15,06	6,24	1	0,08	-	0,07

Table 4 Annual energy production

Annual Energy Production		
Rayleigh-distribution Mean wind speed m/s	Annual energy production kwh	Measurement uncertainty Std.dev. kwh
5	10036	1141 (11%)
6	15613	1284 (8%)
7	20695	1324 (6%)
8	24703	1297 (5%)
9	27412	1232 (4%)

Appendix D

Time history - wind speed & electric power



Appendix E

Skibsteknisk Laboratorium

Kalibreringcertifikat

Certificate of Calibration

Kalibrering af instrument til måling af vindhastighed.

Calibration of instrument to measure windspeed.

Certifikat nr. : 9710-0002
Certificate No.

Side 1 af 3 sider
Page of pages

Instrument / *Instrument :* Fabrikat / *Manufacturer :* Type / *Type :* Serienummer / *Serial No. :*	Cup Anemometer RISØ 2546b (Namur) 307
Rekvirent / *Customer :*	Nordvestjysk Folkecenter for Vedv. Energi Kammersgårdsvej 16, Sdr. Ydby 7760 Hurup Thy
Ordre nr. / *Order No. :*	97106
Instr. modtaget / *Instr. recieved :* Instr. kalibreret / *Instr. calibrated :*	1997-04-24 1997-04-28
Kalibreret af / *Calibrated by :* Godkendt af / *Approved by :*	Benny Holm Uffe Lind
1997-04-29 Dato / *Date*	Torben Sandergaard Underskrift / *Signature*

Certifikatet må ikke gengives, undtagen i sin helhed, uden laboratoriets skriftlige godkendelse.
This certificate may not be reproduced except in full without the written approval of the laboratory.

Skibsteknisk Laboratorium
Kalibreringstjenesten
Vindafdelingen
Hjortekærsvej 99, 2800 Lyngby
Telefon 45 87 93 25
Telefax 45 87 93 33

Danish Maritime Institute
Calibration Services
Wind Engineering Department
Hjortekaersvej 99, DK-2800 Lyngby, Denmark
Telephone +45 45 87 93 25
Fax +45 45 87 93 33

Skibsteknisk Laboratorium

Certifikat nr. : 9710-0002
Certificate No.

Instrument / *Instrument :* Cup Anemometer
RISØ / 2546b (Namur) / 307

Kalibreret af / *Calibrated by :* BHo Godkendt af / *Approved by :* UL

Dato / *Date :* 1997-04-29

Resultater / *Results :*

	U	Frekvens Frequency	Temperatur Temperature	Barometer	RF
	m/s	Hz	C	mBar	%
1	4.1488	6.5100	20.50	996.8	40.1
2	5.1880	8.1204	20.53	996.8	40.0
3	6.2116	9.7877	20.64	996.8	40.0
4	7.2429	11.4872	20.60	996.8	40.0
5	8.2569	13.1350	20.60	996.8	40.0
6	10.3577	16.5018	20.60	996.8	40.0
7	12.4348	19.8627	20.60	996.7	40.0
8	15.5394	24.9148	20.66	996.6	40.0
9	18.6921	29.7693	20.85	996.6	39.9
10	18.4458	29.4105	20.98	996.6	39.8
11	15.4708	24.8644	21.08	996.6	39.7
12	12.3945	19.8805	21.09	996.6	39.6
13	10.3431	16.5861	21.05	996.5	39.6
14	8.2356	13.1324	20.99	996.5	39.6
15	7.2341	11.4992	20.98	996.5	39.6
16	6.2252	9.8146	20.95	996.5	39.6
17	5.1876	8.1561	20.97	996.5	39.6
18	4.1214	6.5400	20.98	996.4	39.6

Usikkerheder / Uncertainties:

Temperatur / Temperature	< +/- 0.1	C
Tryk / Dynamic pressure	< +/- 0.05	mmH2O
Barometer tryk / Barometric pressure	< +/- 0.5	mBar
RF	< +/- 1.0	%
Frekvens / Frequency	< +/- 20	ppm

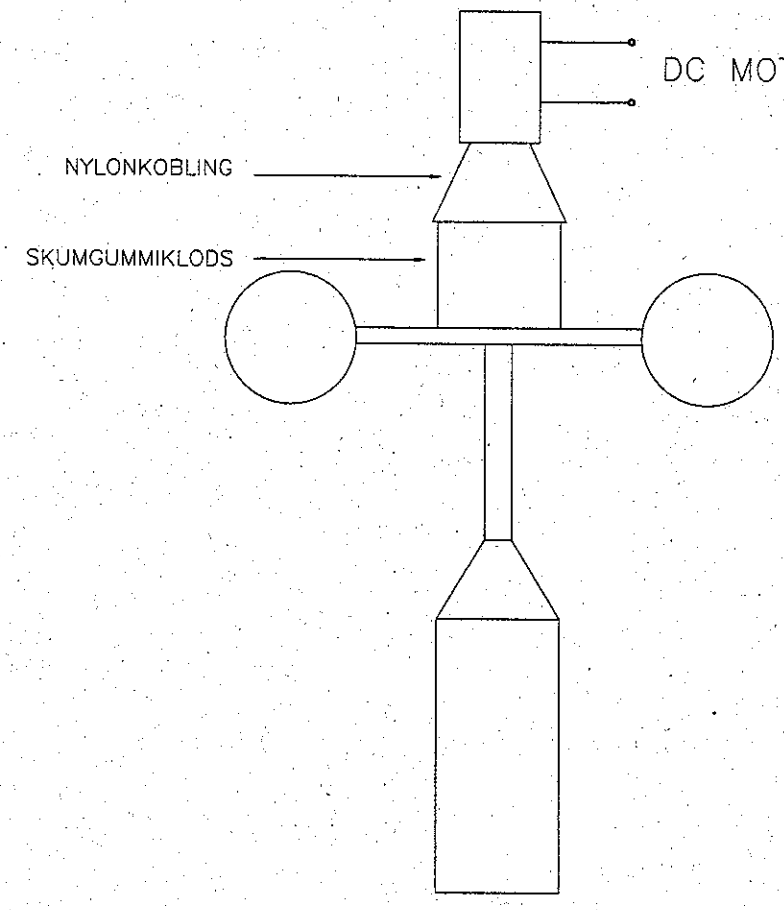
Resultat / Result : U = 0.6219*f + 0.0900 m/s

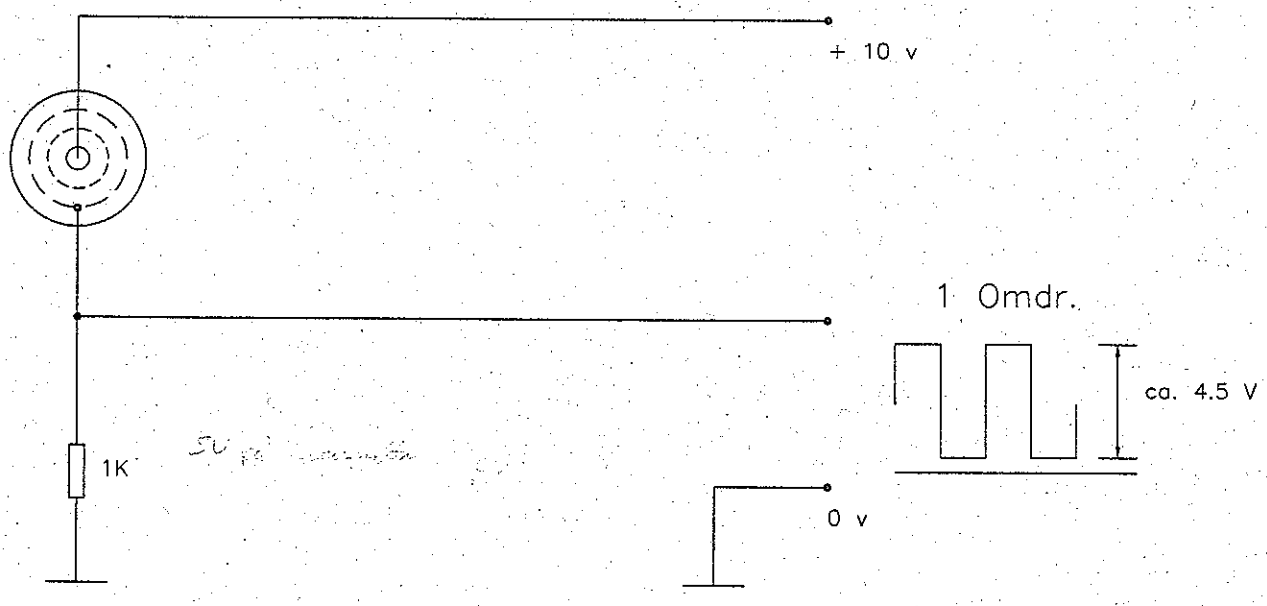
Kalibreringen er udført ved stabile temperaturer ved sammenligning med laboratoriets normaler.
Benyttet udstyr er mærket med *.
The calibration are made at constant temperatures by comparison with laboratory standards.
*Equipment used are indicated by *.*

* Furness FC044 Transducer Serial No. RSN 940739
* Furness FC044 Transducer Serial No. RSN 9309216
    Furness FC044 Transducer Serial No. RSN 9309215
    Furness FC044 Transducer Serial No. RSN 9309214
* Vaisala Humidity Transmitter HMP 230 CB Serial No. 37MI40
* Vaisala Pressure Sensor PTA427 Serial No. 611658
* NOKEVAL 412 Pt 100 Sensor Serial No. 17979113
* NOKEVAL 412 Pt 100 Sensor Serial No. 17980113
* NOKEVAL 412 Pt 100 Sensor Serial No. 17981113
* NOKEVAL 412 Pt 100 Sensor Serial No. 17982113
* RISØ Namur-TTL PFV reg.nr. 0605
* Frequency Normal DCF 77 MFX 10-9 TSI Serial No. 94616
* Coax cable 24m, Lemo-Byrndy

Seneste certifikatdatoer for laboratoriets referencenormaler. *Latest certificate dates for reference standards.*

Furness FC044 Serial No. RSN 940739	960301
Vaisala HMP 230 CB Serial No. 37MI40	951212
Vaisala PTA427 Serial No. 611658	930930
DCF 77 MFX 10-9 TSI Serial No. 94616	
Data Precision Multimeter 125 701 E Ser. No. 22-10917	960130





NOTE: DUTY CYCLE SKAL LIGGE MELLEM 35 OG 65%

RISØ Engineering and Computer Department

Design by. HEHA	P2546B CUP
Drawn by. TOJQ 93-11-09	ANEMOMETER.
Re Draw by. PEHE 97-02-13	TEST OPSTILLING
P2546B\DESIGN\AUT\TEST.DWG	sheet 1 of 1

A/S DEIF	CERTIFICATE OF CALIBRATION FOR WATT/VAR TRANSDUCERS	Page 1 of 1 Date 970113 Ref. TFN

SERIAL No.	54496.1
TYPE	INWATT NGS
COUPLING	2W4
MEASURING RANGE Pnom	0-3000 W
VOLTAGE Unom ± 2%	380 V
CURRENT Inom	5 A
AUXILIARY SUPPLY Uaux ± 2%	380 VAC
OUTPUT Pout	4-20 mA
ACCURACY CLASS	0,5
REF. EQUIPMENT No.	5120090013, 5120020037
TEMP. 18..30°C T_N	23 °C
MEAS. FREQ: f_N	55 Hz

TESTONDITIONS:

Meas. Volt: U_N ±2%
Meas. Current: Secundary
Aux Supply: U_N ±2%
Output Load: 50%
3-phase balance: acc. IEC 688

INTRINSIC ERROR acc. IEC 688

W VAR	COS phi = 1 SIN phi = 1	0,8C 0,8C	0,8I 0,8I
INPUT			
100%	20,00 mA 0,00 %		
80%	16,79 mA 0,05 %	14,18 mA 0,30 %	14,28 mA 0,20 %
60%	13,60 mA 0,00 %		
40%	10,40 mA 0,00 %		
20%	7,20 mA 0,00 %		
0%	4,00 mA 0,00 %		
-20%*	0,79 mA 0,05 %		
-40%			
-60%			
-80%			
-100%			

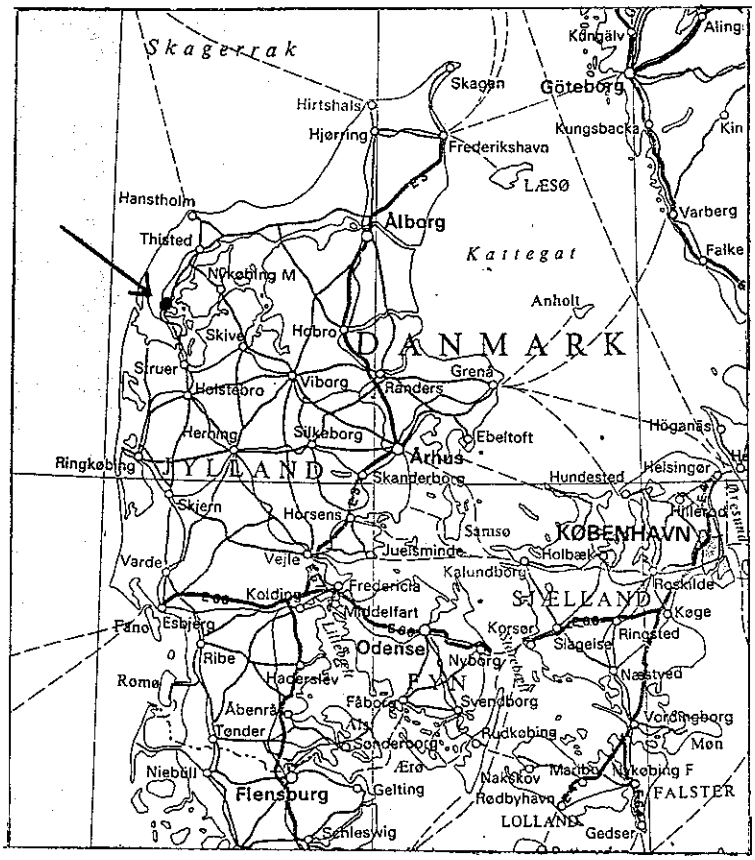
*Bipolar only

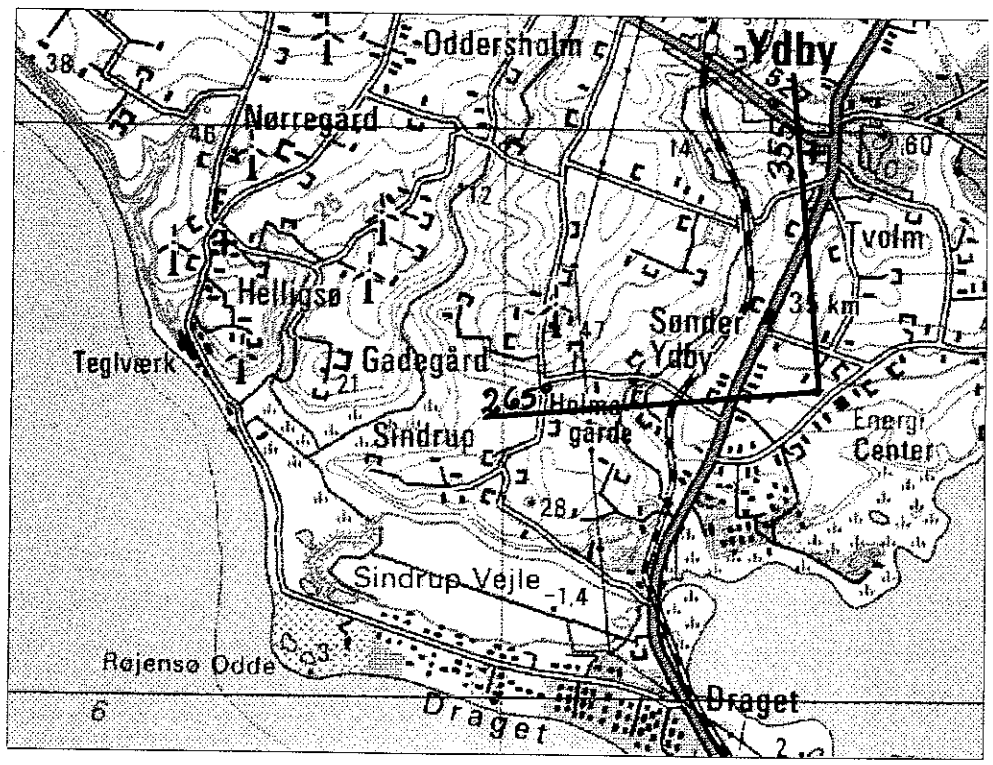
PLACE	A/S DEIF Frisenborgvej 33 DK-7800 Skive Denmark	**SIGNATURE**
DATE	970114	Torben F. Nørgaard

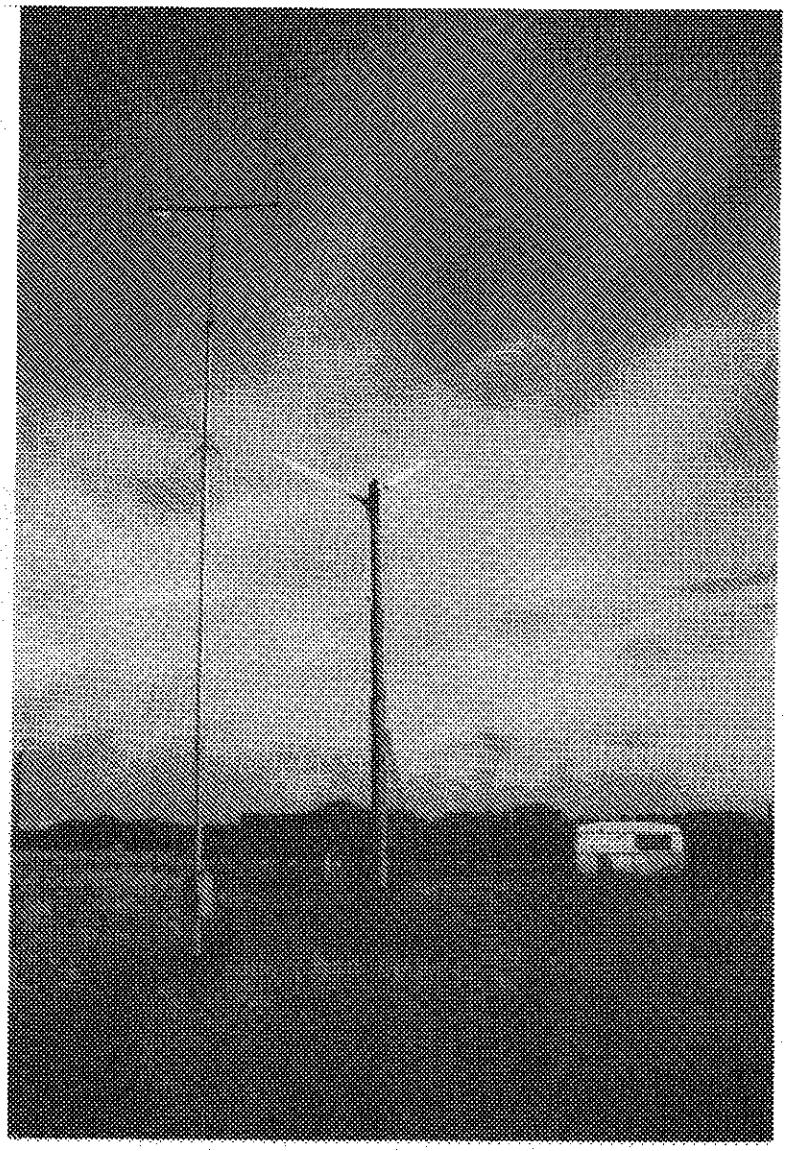
4930010037C

Appendix F

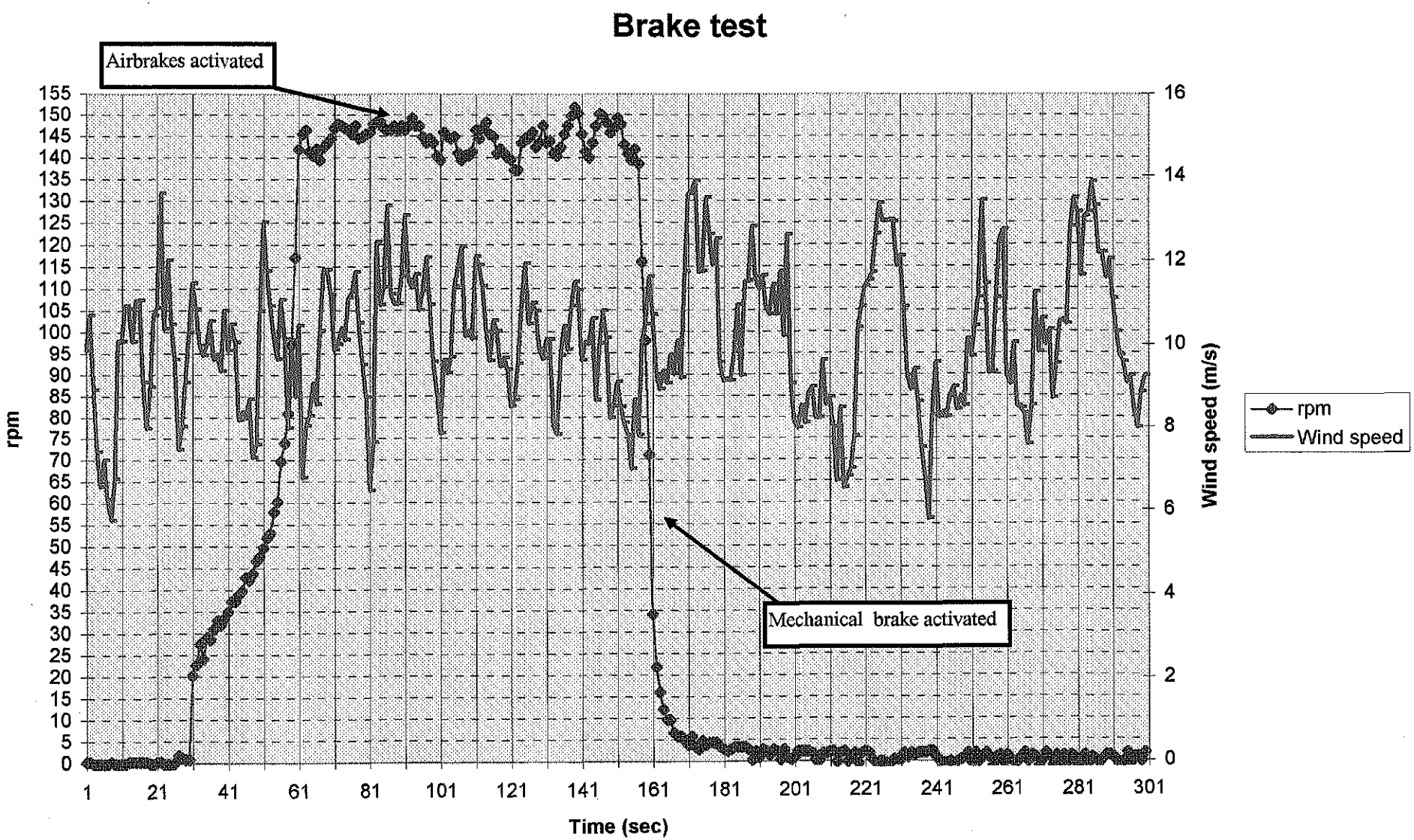
Location of test site







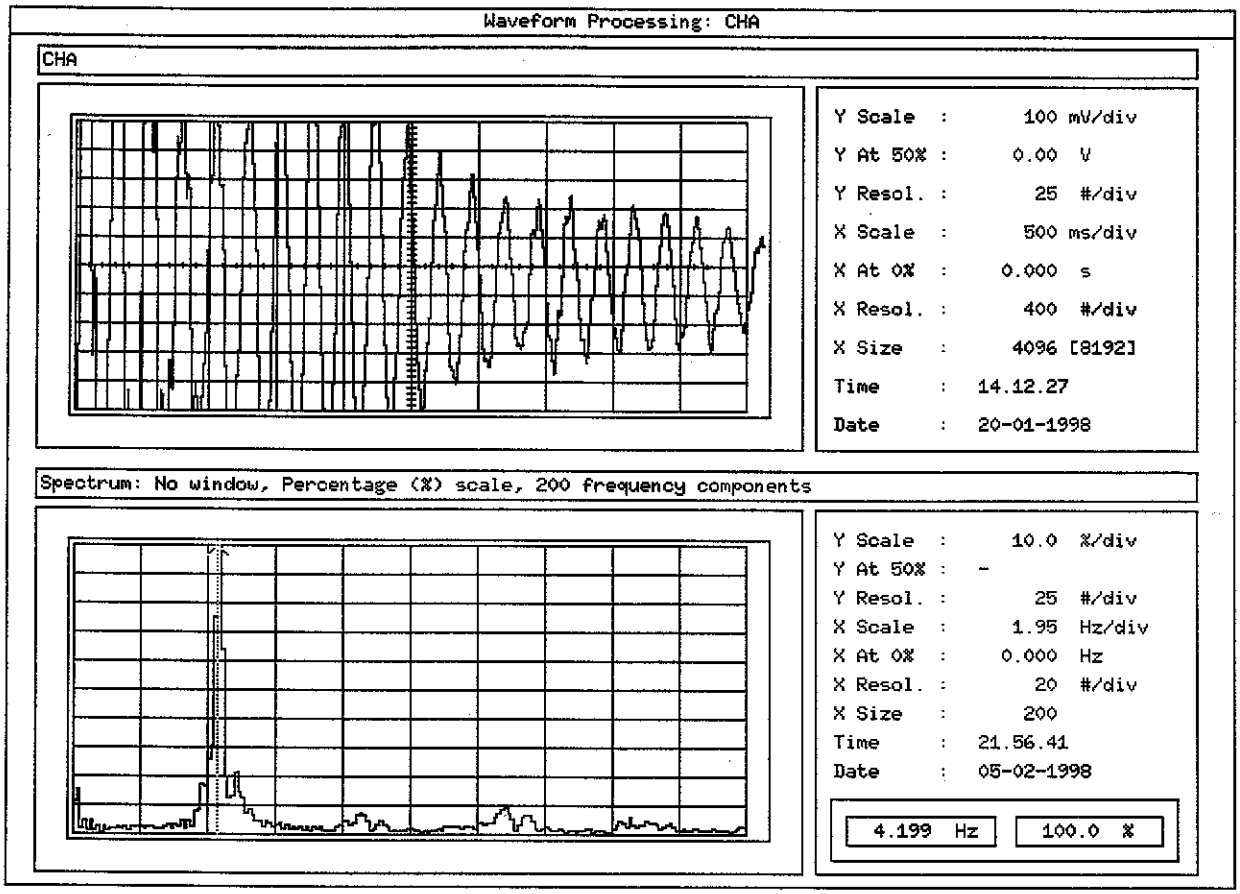
Appendix G


Brake test
Airbrakes activated
Mechanical brake activated
rpm
Wind speed (m/s)
Time (sec)
rpm
Wind speed

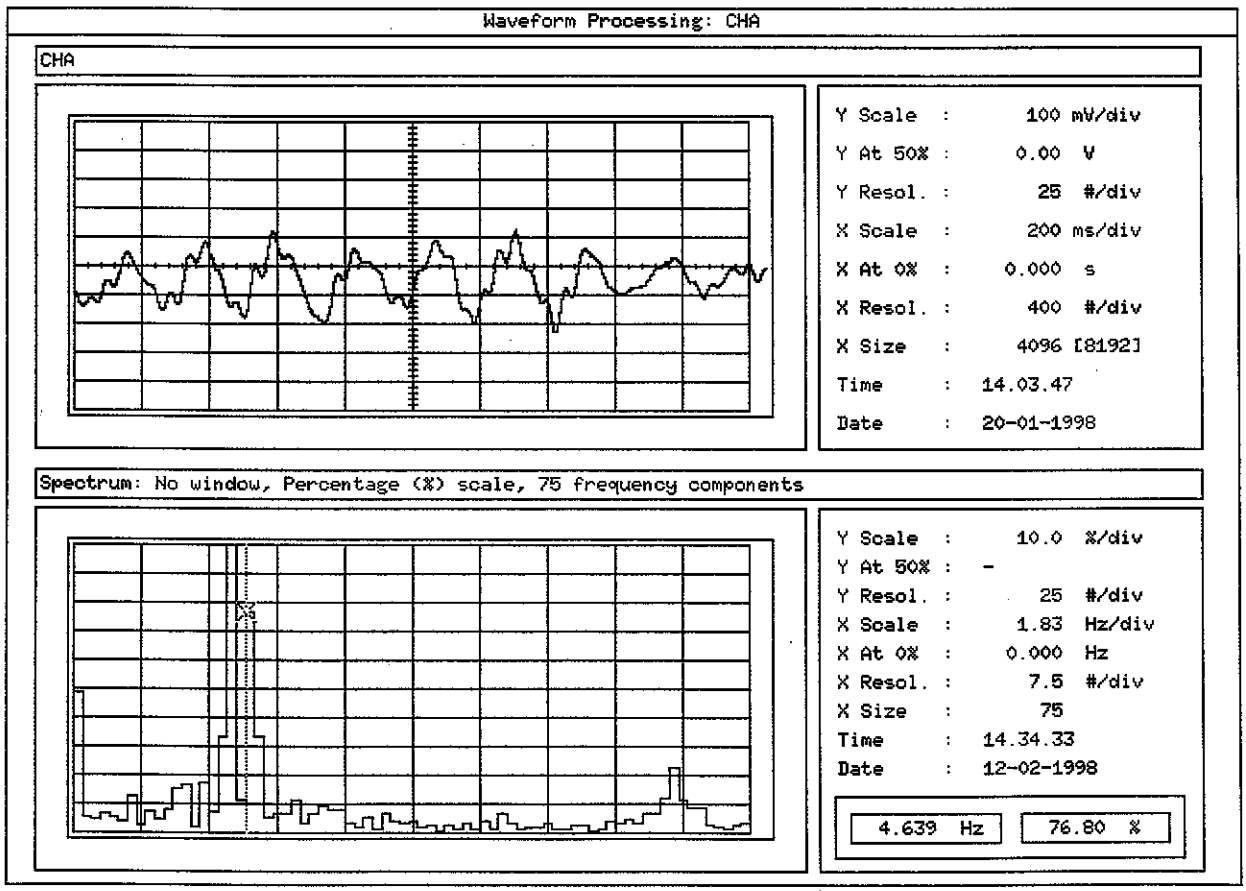
Appendix H

Rotor - flapwise blade motion

Random shocking

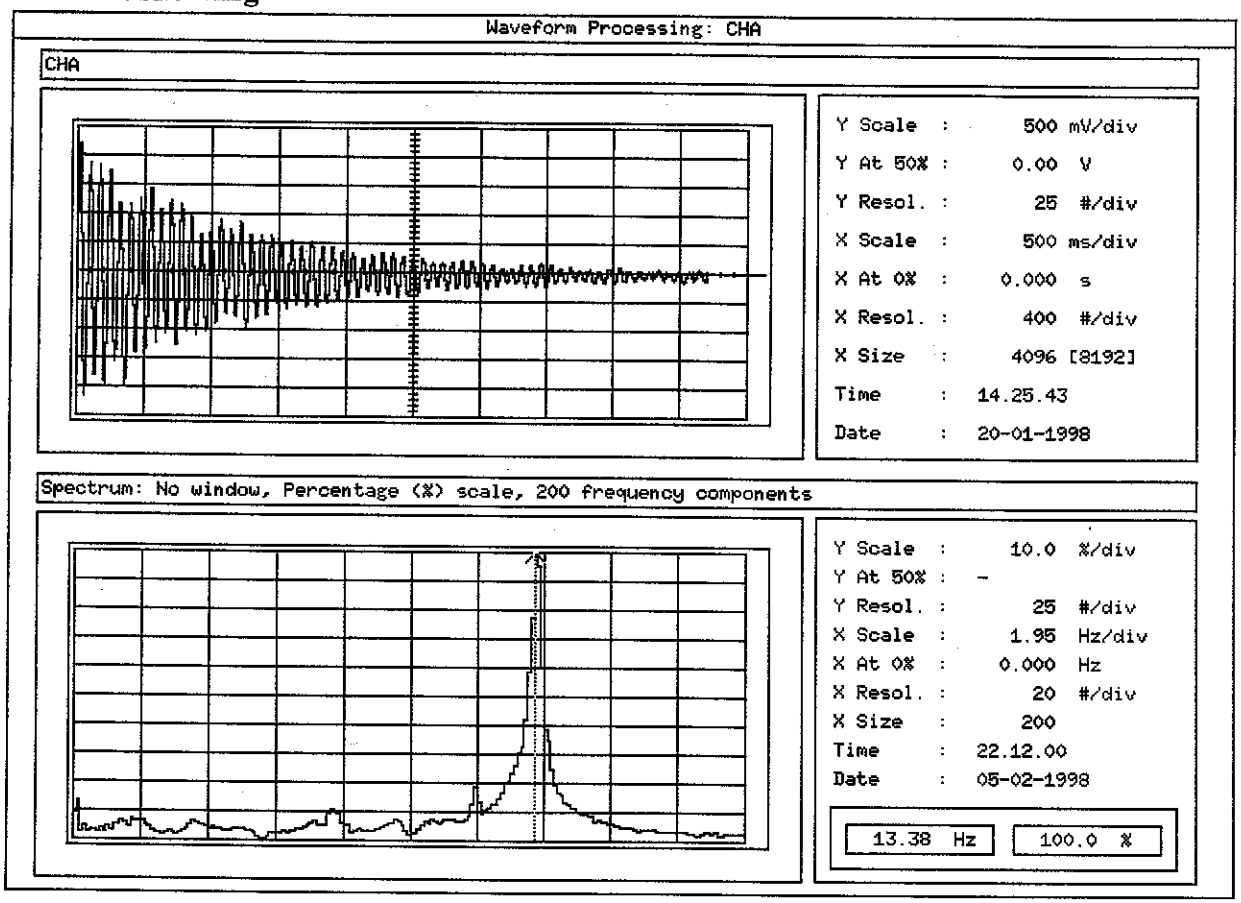


Wind excitation

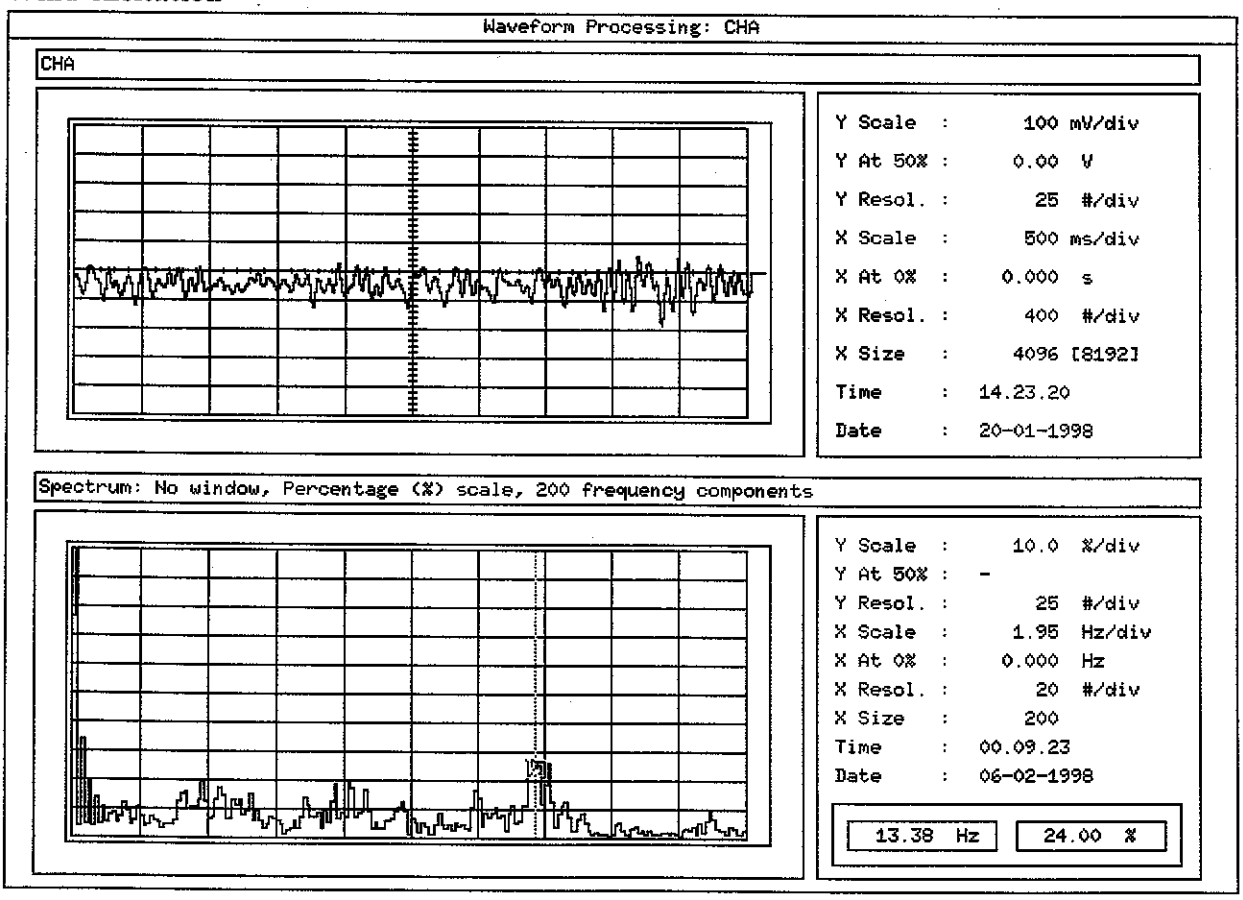


Rotor - chordwise blade motion

Random shocking

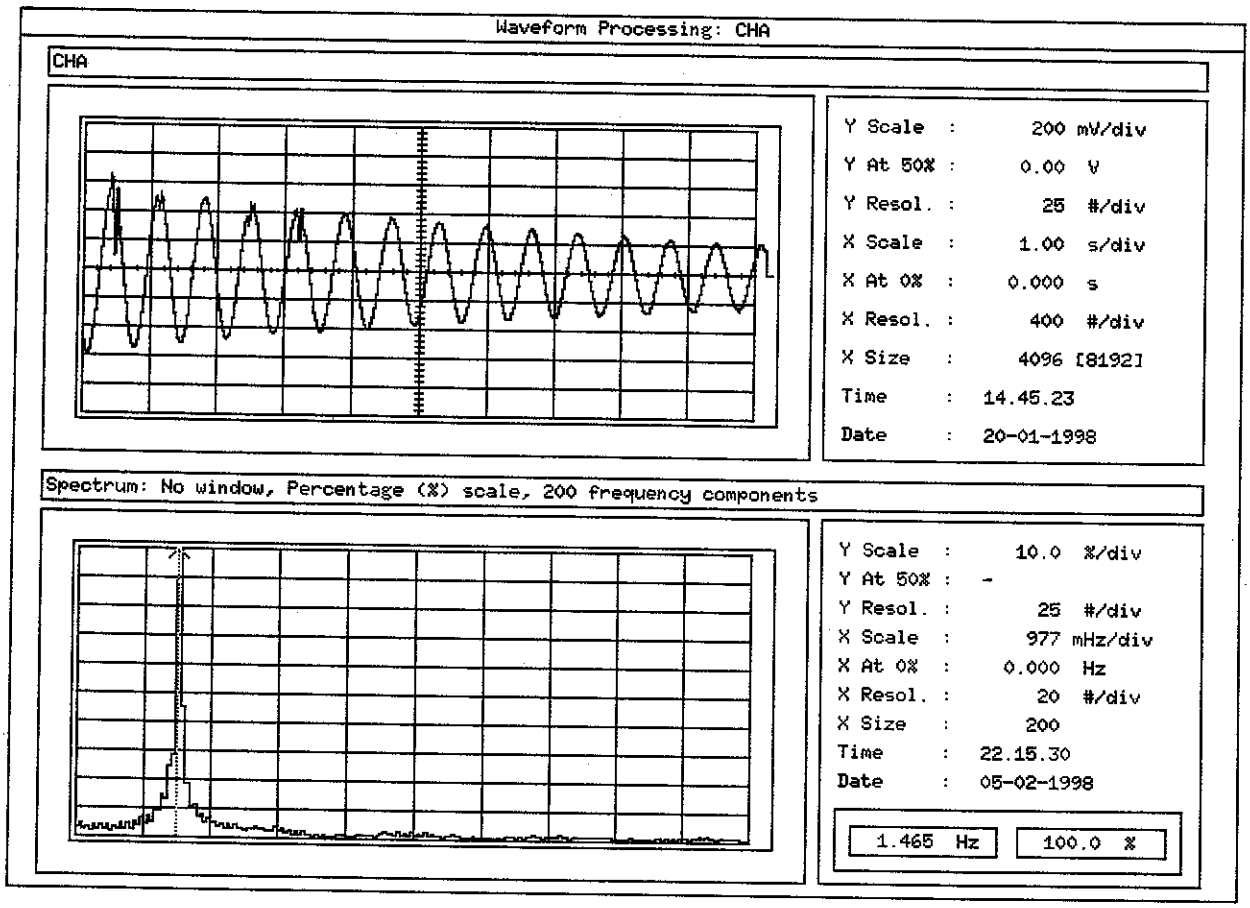


Wind excitation

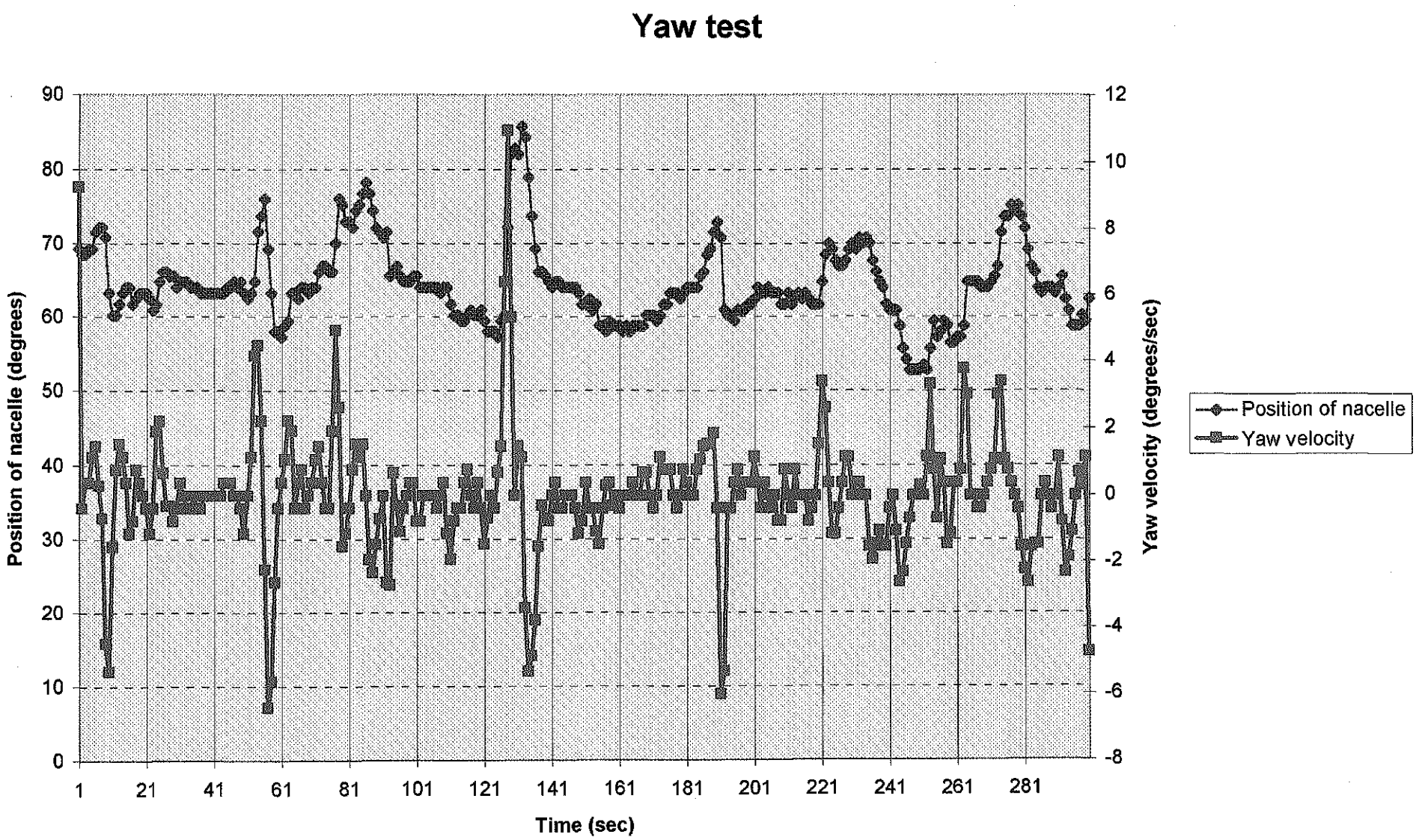


Tower - tower motion

Pull



Appendix I


Yaw test
Position of nacelle (degrees)
Yaw velocity (degrees/sec)
Time (sec)
Position of nacelle
Yaw velocity
0
10
20
30
40
50
60
70
80
90
-8
-6
-4
-2
0
2
4
6
8
10
12
1
21
41
61
81
101
121
141
161
181
201
221
241
261
281