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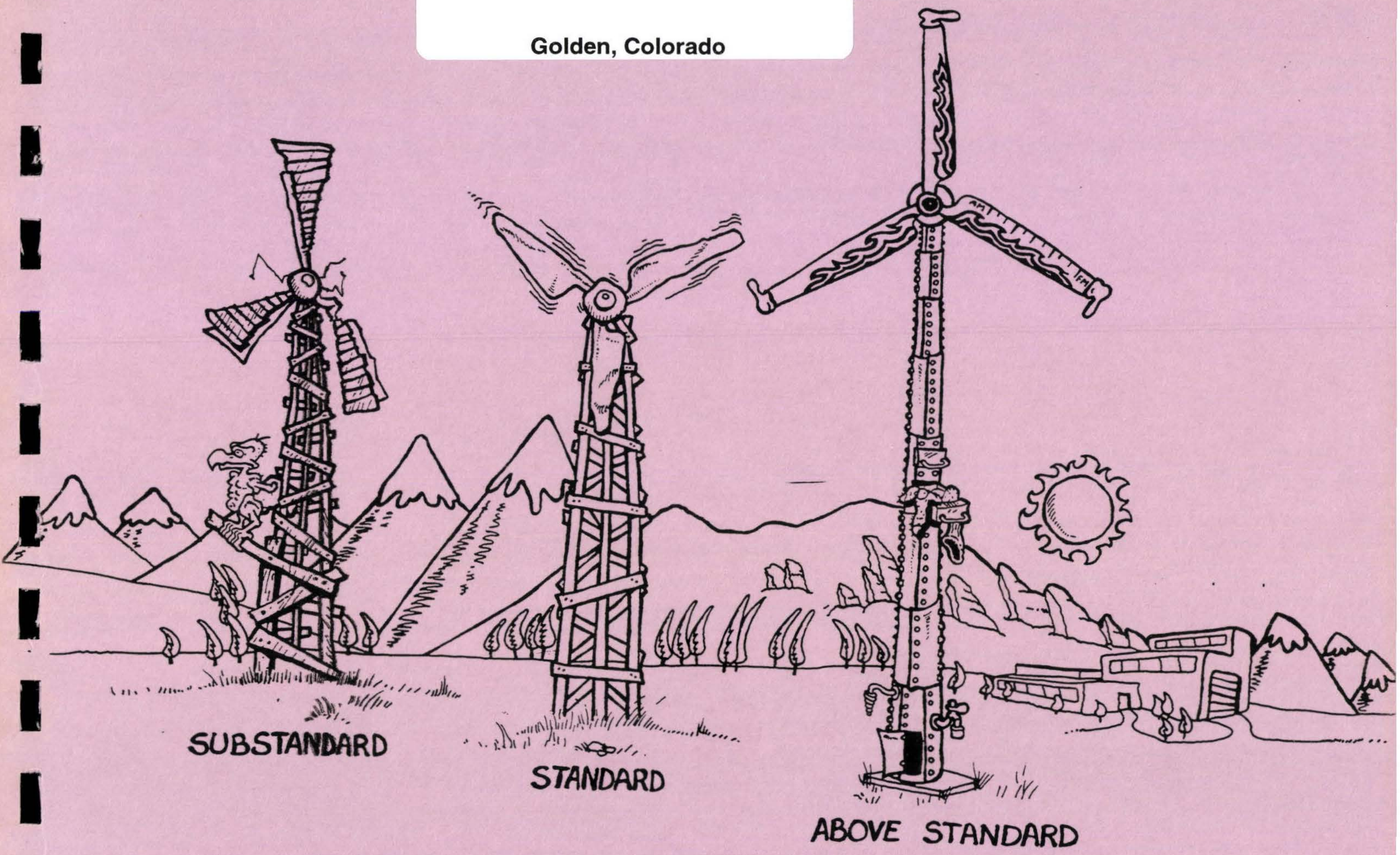
IMTS

14th Annual International Meeting of Wind Turbine Test Stations

September 12-13, 1994
Boulder, Colorado, USA

NREL Library
Golden, Colorado



Original drawings of wind turbines by Caprice Lawless

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NREL/CP-442-6877
DE95000222

14th Annual International Meeting of Wind Turbine Test Stations
(IMTS)

September 12 - 13, 1994

Hosted by:
National Renewable Energy Laboratory
National Wind Technology Center
Golden, Colorado 80401
USA
and the
Department of Energy

Held at the:

Boulderado Hotel
Boulder, Colorado
USA

International Meeting of Test Stations
September 12-13, 1994

Book of Proceedings

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National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393
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NREL

International Meeting of Test Stations
September 12-13, 1994
Hosted by National Renewable Energy Laboratory
and the
US Department of Energy
Held in Boulder Colorado

Introduction:

This marks the 14th Annual International Meeting of Test Stations. As the original charter states these meetings are intended to be an international forum for sharing wind turbine testing experiences. By sharing our experiences we can improve our testing skills and techniques. As with all new industries the quality of the products is marked by how well we learn from our experiences and incorporate this learning into the next generation of products.

Our role in this process is to provide accurate information to the companies we serve. This information is used by designers to confirm and improve their designs. It is also used by certification agencies for confirming the quality of these designs. By sharing our experiences we are able to accomplish these goals, serve these customers better and ultimately improve the international wind energy industry.

I hope that the friendships that are established during this meeting form the basis for open exchanges throughout the year, until the next IMTS.

Sandy Butterfield

STICHTING

ENERGIEONDERZOEK CENTRUM NEDERLAND Petten, 15 September 1982.

Proposal

Informal Working Group Wind Turbine Test Stations

suggested rules of the game.

- The working group is open to co-workers in national test stations, where a variety of different wind turbines are investigated.
- The working group will normally meet once a year.
- Presentations and discussions in the meetings will be informal. Written papers are not obligatory. There will be no offical proceedings. Only minutes will be made to cover the mutual agreements on technical matters. These minutes will be prepared by the host organisation and distributed among the members of the working group.
- One of the test station organisations will be the host for each meeting.
- It will be decided during each meeting which organisation is to be the host for the next meeting. Also a tentative agreement will be made for the overnext meeting.
- Each meeting will also have a short discussion on the aims and desirable topics of the next meeting.
- The host organisation is in charge of the secretariat of the working group. This task includes:
  . to prepare and organise a working group meeting;
  . to take care of invitations;
  . to fix the programme and agenda of the meeting;
  . to hold the chairmanship of the meeting;
  . to prepare and distribute minutes after the meeting.
- The secretarial task will finish with the distribution of the minutes, preferably within a month after the meeting. Then the relevant files (lists of addresses of organisations and members, results of previous meetings) will be forwarded to the next host.
- All organisational costs are to be borne by each host organisation. Travel and accommodation expenses are for the account of each participant.

14th International Meeting of (Wind Turbine) Test Stations (IMTS)
Boulderado Hotel, Boulder, Colorado, USA
September 12-13, 1994
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Left-Right: Wim Stam, Dale Berg, Dan Ancona, Mark Rumsey, Helmut Klug, Troels Friis Pedersen, Valeri Minin, Carsten Skamris, Grigori Dmitriev, Walt Musial, Sandy Butterfield, Magnus Ellsén, Stephan Glocker, Apostolos Fragoulis, Allan Johnston, Ray Hunter

Left-Right Back Row: Darrell Dodge, Dale Berg, Allan Johnston, Carsten Skamris, Neil Kelley, Magnus Ellsén, Warren Bollmeier, Nolan Clark, Grigori Dmitriev, Valeri Minin, Stephan Glocker, Mark Rumsey, Wim Stam, Troels Friis Pedersen, Apostolos Fragoulis
Left-Right Front Row: Dan Ancona, Bob Thresher, Sue Hock, Walt Musial, Bob Sherwin, Ray Hunter, Peter Hjuler Jensen, Helmut Klug

IMTS AGENDA

Monday, September 12, 1994

8:30	Welcome and opening discussion		
8:45	Introductions		
9:00	Test station descriptions and status presentations		
	A. Fragoulis (CRES)	-	Testing at CRES
	S. Glocker (KWK)	-	Power Curve Parameter Sensitivity Wind Energy Converters in Western Europe-Technologies and Experiences at the German Test Station
	H. Klug (DEWI)	-	Noise Testing
	A. Johnston (NEL)	-	IEC TC88 Noise and Performance Testing
	M. Ellsén (Chalmers U.)	-	Hönö Test Site Activity
11:30	Lunch (Walk to Boulder Mall restaurant of your choice)		
1:00	P. Jensen (Risø)	-	Certification Activity at Risø
	W. Stam (ECN)	-	ECN Certification Activity
	T. Friis Pederson	-	Risø Testing Activity
	V. Minin (IN)	-	Weibul Wind Distribution
	G. Dmitriev (IEN)	-	Wind Energy North of Russia
	N. Clark (USDA)	-	Testing Activities at the USDA
	D. Berg (SNL)	-	34-m VAWT Testing
	W. Musial (NREL)	-	NREL Blade Fatigue Testing
	N. Kelley (NREL)	-	NREL Anemometer Field Calibration
5:30	Vehicles leave for NREL sponsored dinner at Gold Hill Inn		

CERTIFICATION ISSUES

Tuesday, September 13, 1994

8:30	C. Butterfield (NREL)	-	NREL Certification Program
	C. Skamris (Risø)	-	Certification
	R. Hunter (NWTC)	-	Lloyd's Certification Assessment
	B. Sherwin (AOC	-	Certification
	W. Stam (ECN)	-	ECN Certification Activity
11:30	Discussion and adjourn meeting		
12:00	Lunch (Restaurant of your choice)		
1:30	Tour of NREL National Wind Technology Center (NWTC) Vehicles leave Boulderado Hotel at 1:30 for tour		
4:30	Vehicles return from tour at NWTC		

Testing at CRES

Apostolos Fragoulis
CRES

14th IMTS Meeting

- CRES' WT Test Station Presentation

Dr Apostolos N. Fragoulis
Head Wind Energy Program
12-13 Sept. 1994, NREL, CO

C.R.E.S.

WIND ENERGY PROGRAM

OBJECTIVES

- Transfer and Development of New Technology
- Wind Industry Support and Development
- Dissemination and Effective Use of Technology
- Certification of Wind Energy Systems
- Wind Potential Assessment

C.R.E.S.

WIND ENERGY PROGRAM

Research

R&D Facilities - Certification

Project Development

Project Management

WIND ENERGY PROGRAM

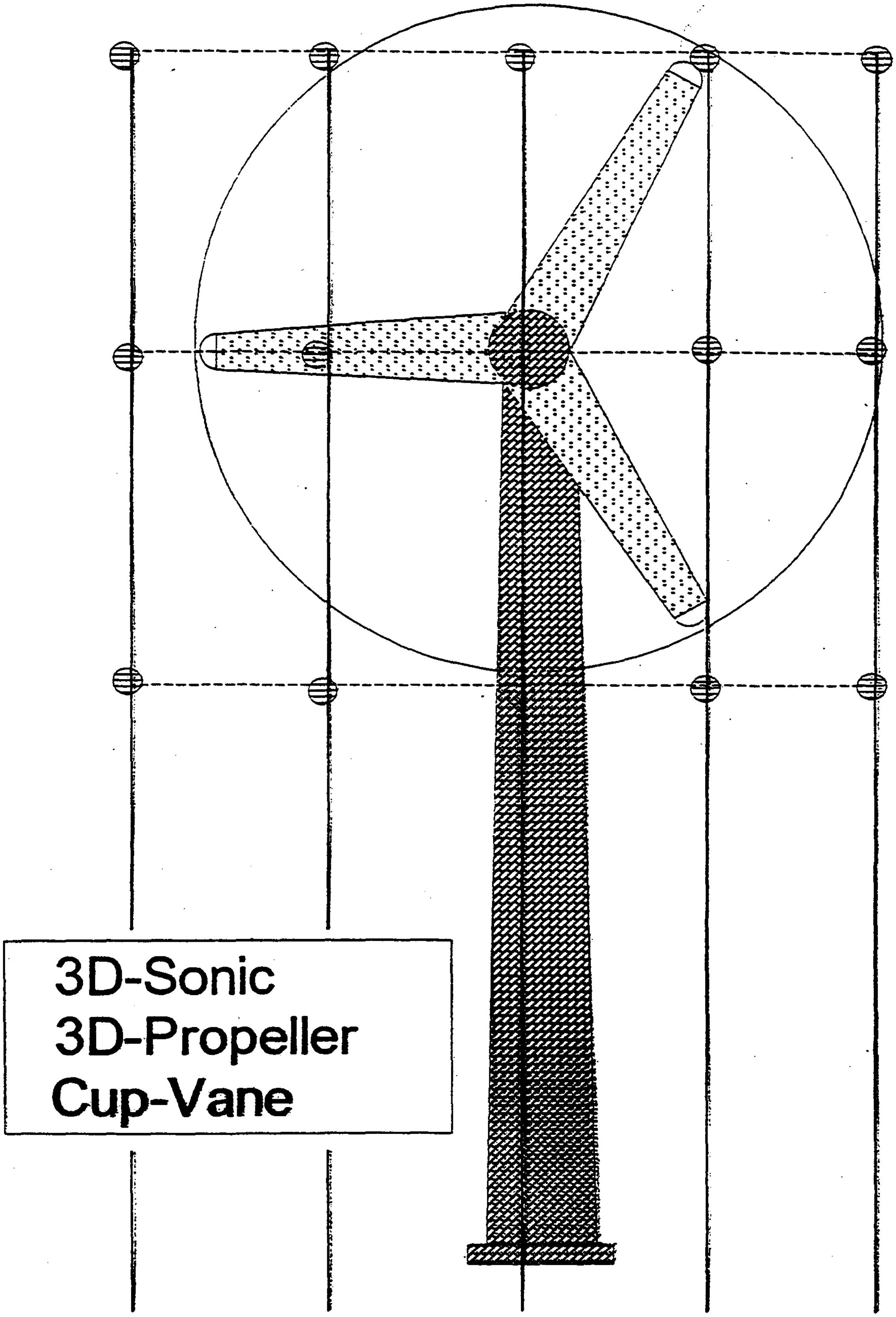
RESEARCH

1. Atmospheric Boundary Layer
   Wind Turbine / Wind Park Siting - Turbulence

2. WT Analysis - Design - Optimization
   (Blades, Transmission - Production System, Tower)

3. System Analysis
   - Wind Diesel, Hybrid Systems
   - Penetration Optimization-Maximization
   - New utilizations for Wind Energy

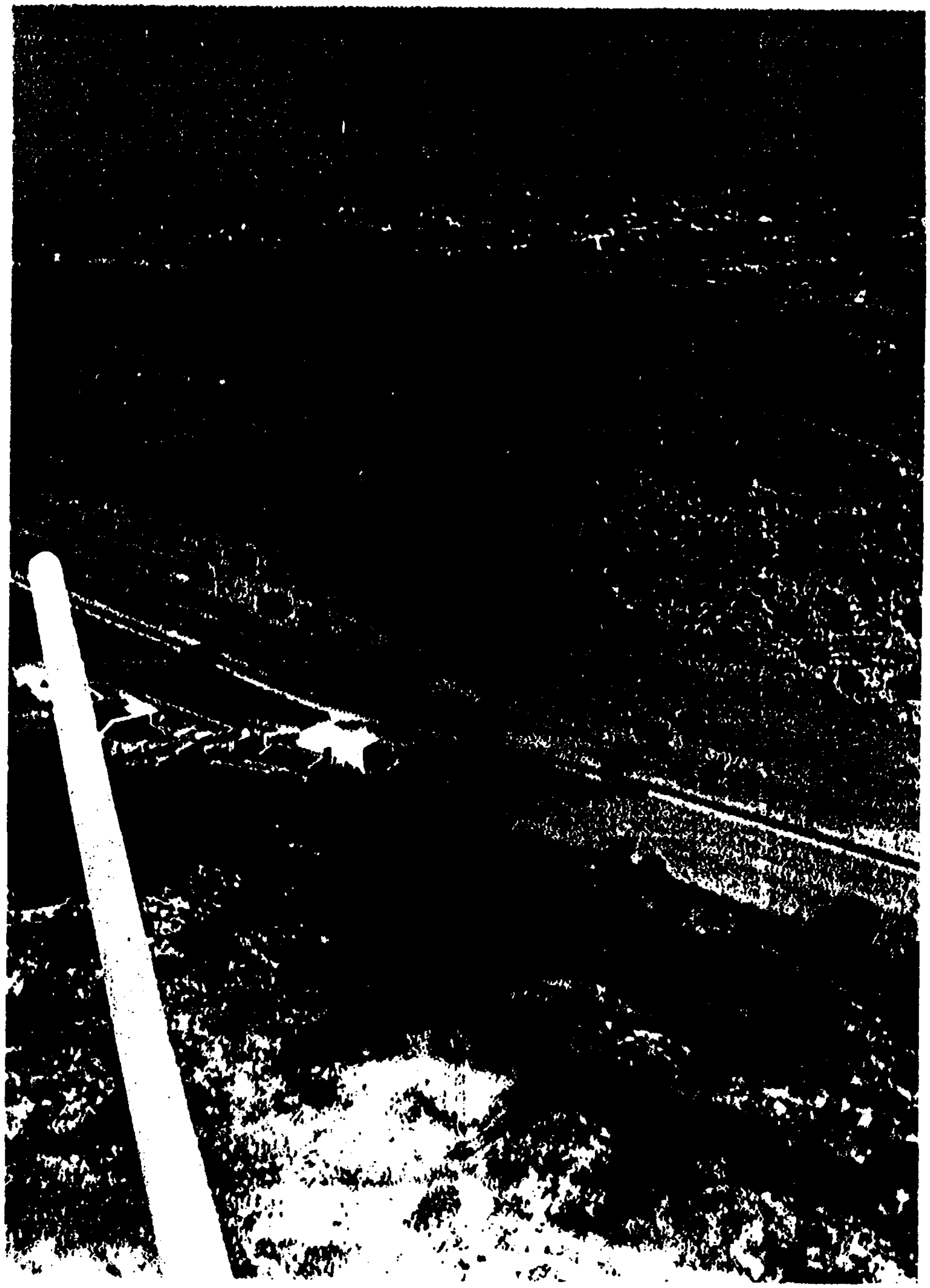
Measurement System for the Wind Structure on Rotor Disk



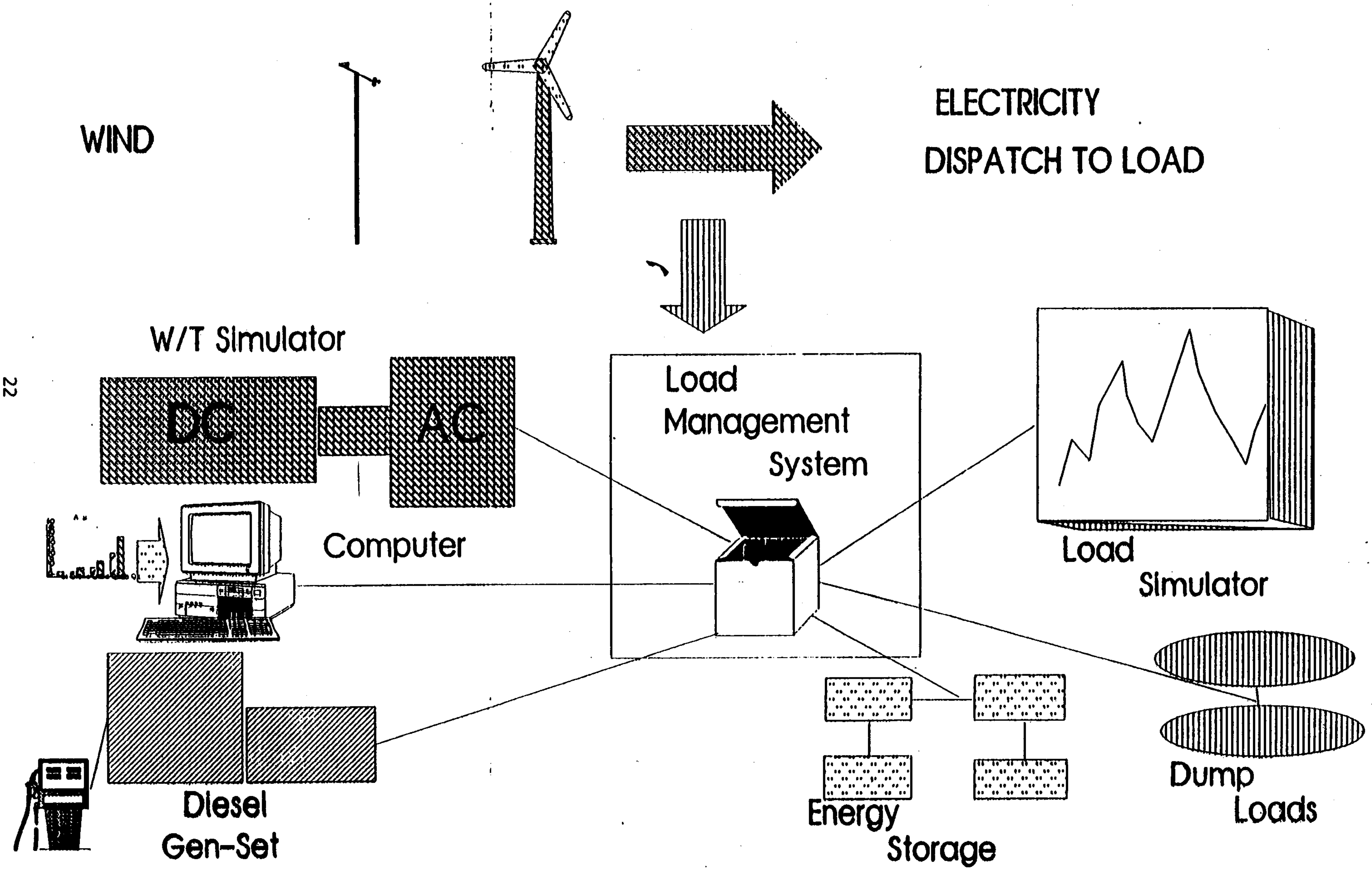
WIND ENERGY PROGRAM

R&D FACILITIES - CERTIFICATION

1. Wind Turbine Test Station
2. Mobile Test Units
3. R&D Laboratories
   - Wind Diesel - Hybrid System Simulator
   - Blade Testing Facility
     (Static - Dynamic -Fatigue)

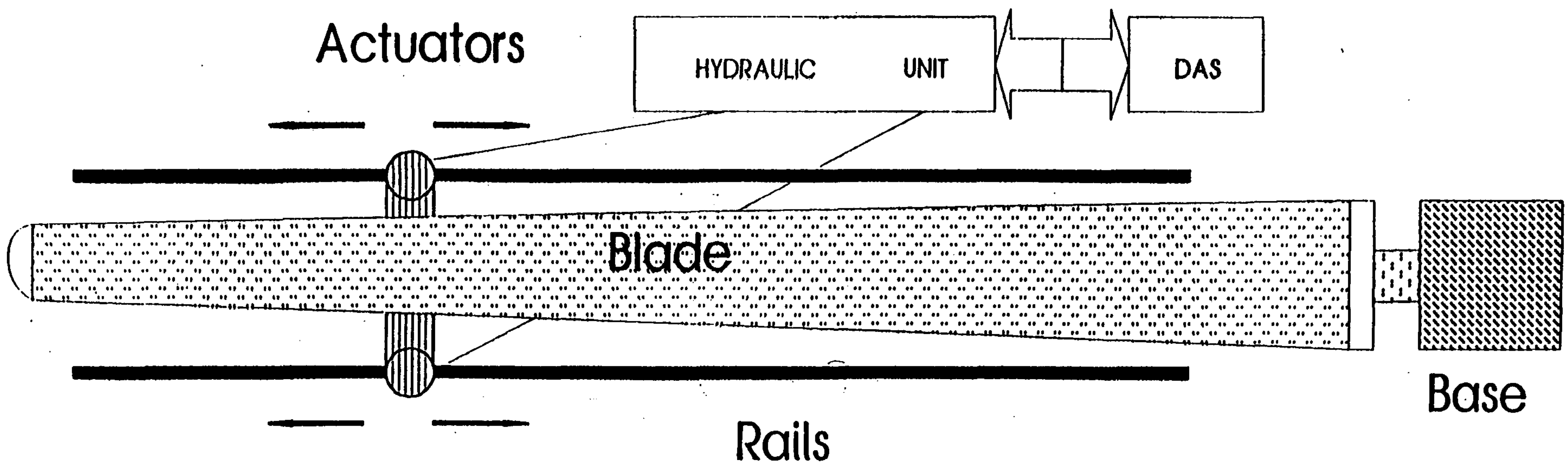


CRES' HYBRID WIND - DIESEL LABORATORY SYSTEM



CRES – WIND ENERGY DEPARTMENT

Capability of up tp 25m blade testing



Actuators capable of -60kN to 25kN loads at 750mm displacements. (1Hz at 400mm displacement)

STATIC - DYNAMIC - FATIGUE

BLADE TESTING FACILITY

WIND ENERGY PROGRAM

PROJECT DEVELOPMENT
PROJECT MANAGEMENT

NATIONAL

- Private
- Local Authorities
- Ministry for Energy

INTERNATIONAL

- DG XII
- DG XIII
- DG XVII

SOME FIELD PROJECTS

- Turbulence Measurements in Complex Terrain - Wind Flow
  (JOULEI Project) Location: ANDROS & CRETE
- 90 kw HAWT Performance Evaluation
  (PRIVATE Project) Location: AKARNANIKA
- 150 kw VAWT Performance Evaluation
  (DEMONSTRATION Project) Location: MILESI
- 100kW Hybrid W/D System Development
  (DEMONSTRATION Project) Location: AGIOS EFSTRATIOS
- Test Station Development, 110kW HAWT - Infrastructure
  (VALOREN Project) Location: AGIA MARINA, LAVRIO
- Dynamic & Fatigue Load Measurements (JOULEII Projects)

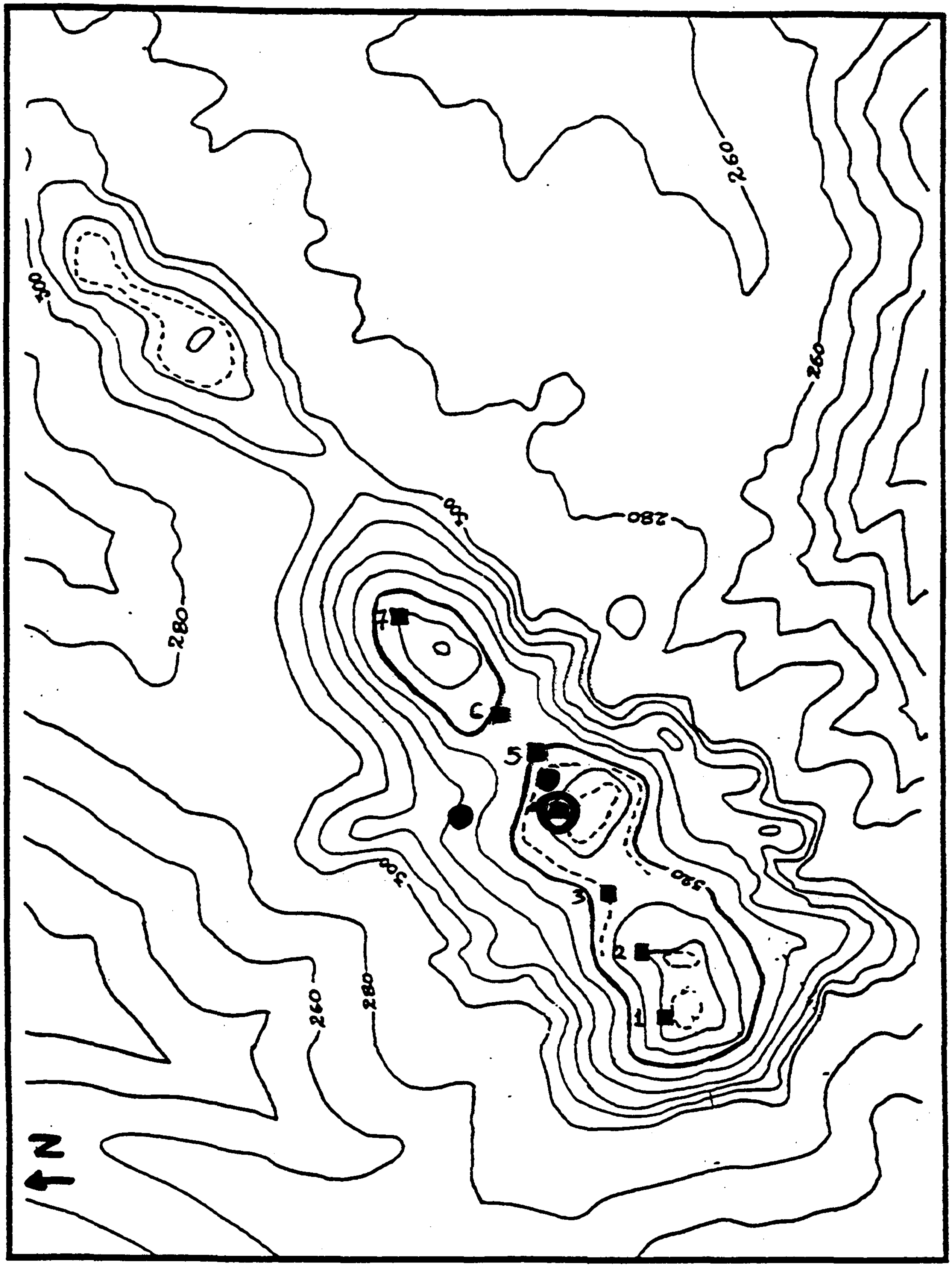
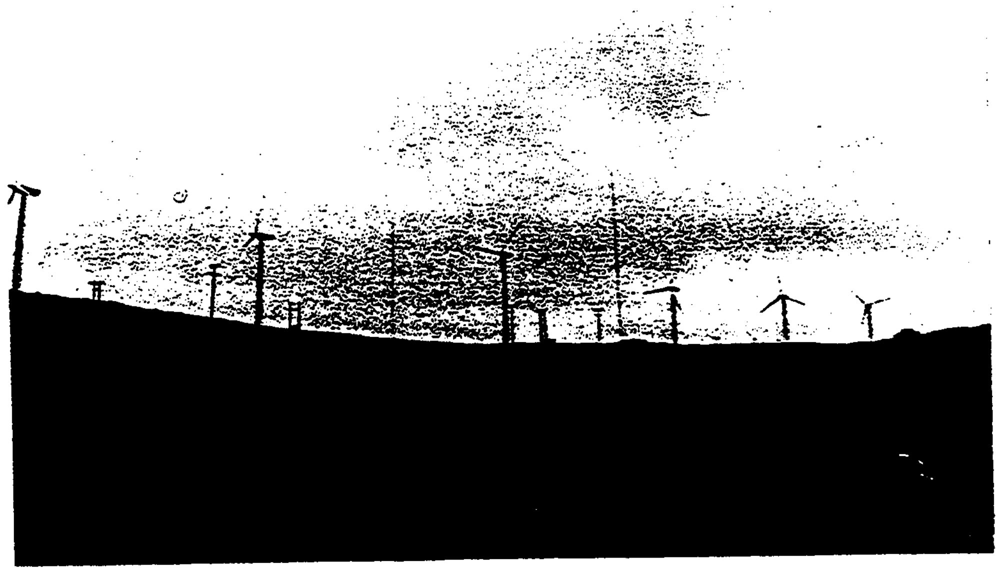


Figure 1.3 Detailed map of the Wind Park of Andros

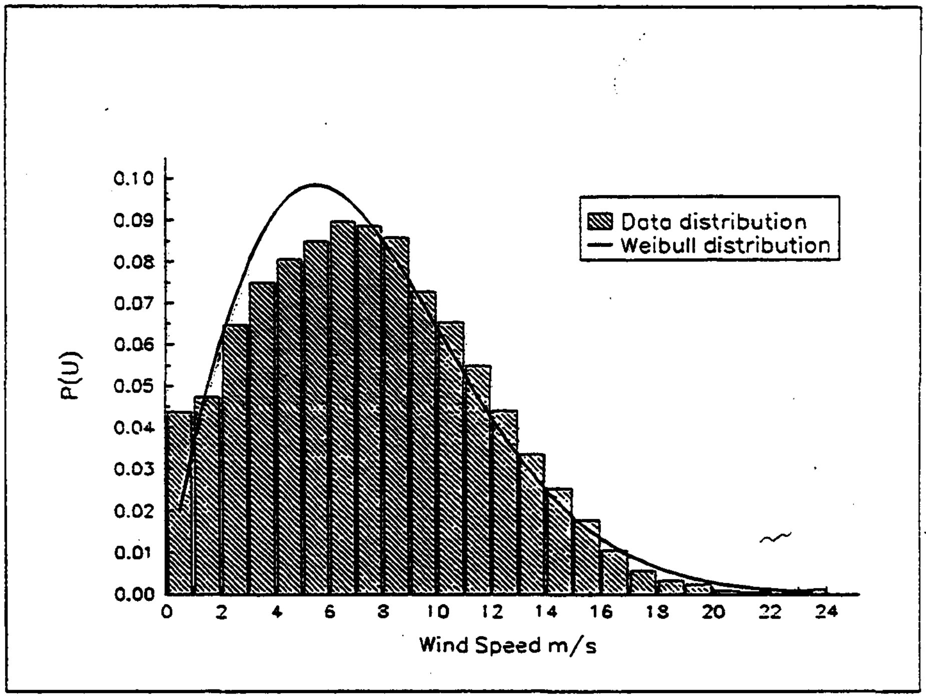
● : Mast's locations, ■ : WT's locations

instrumented WT no 4.



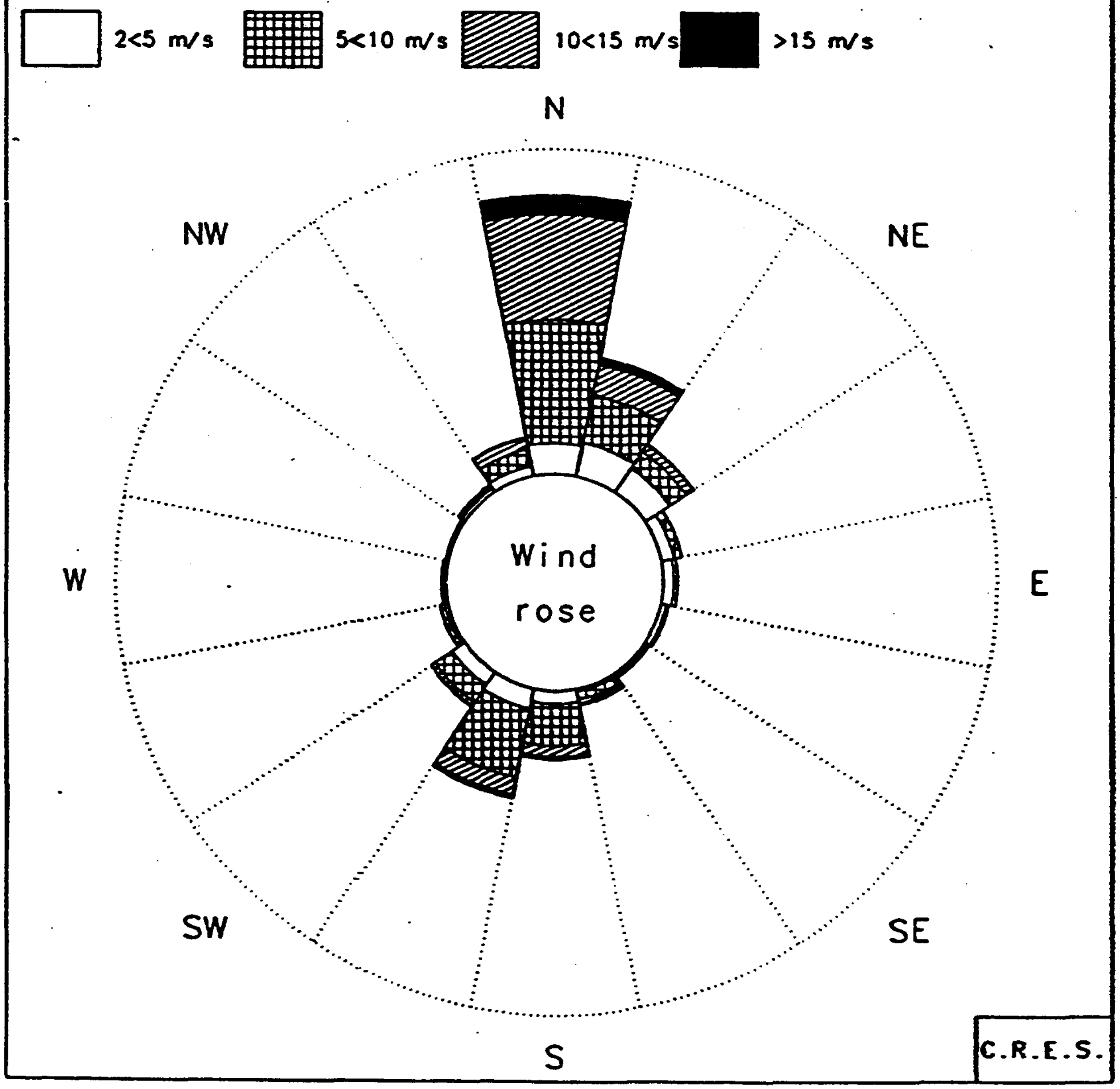
Station : 021 , ANDROS ISLAND

Measurements period: from 04/07/91 to 13/02/94

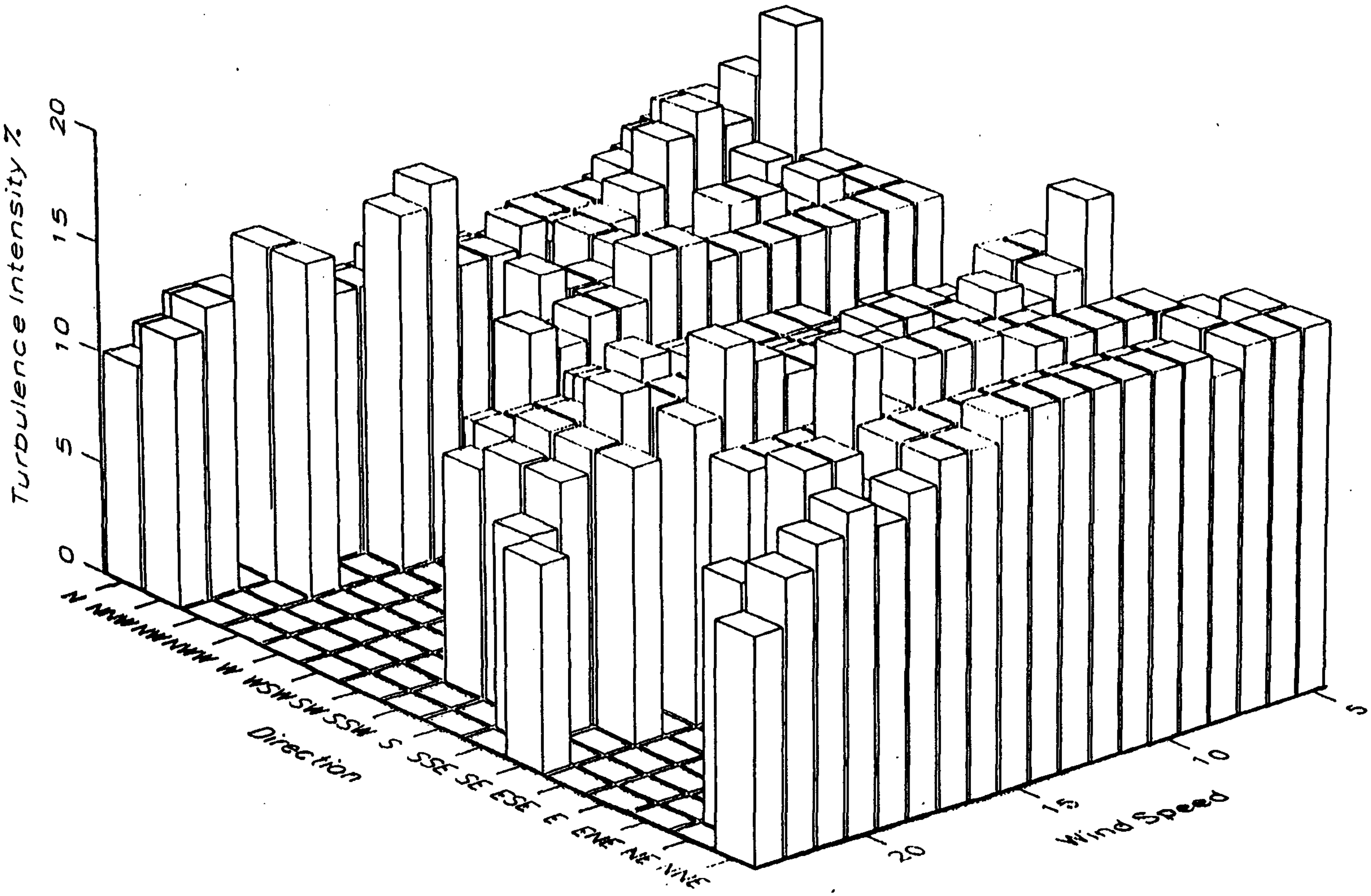


Station : 021, ANDROS ISLAND , project : JOUR 0067
Height: 10m AGL, 151m ASL
Measurements period: from 04/07/91 to 13/02/94

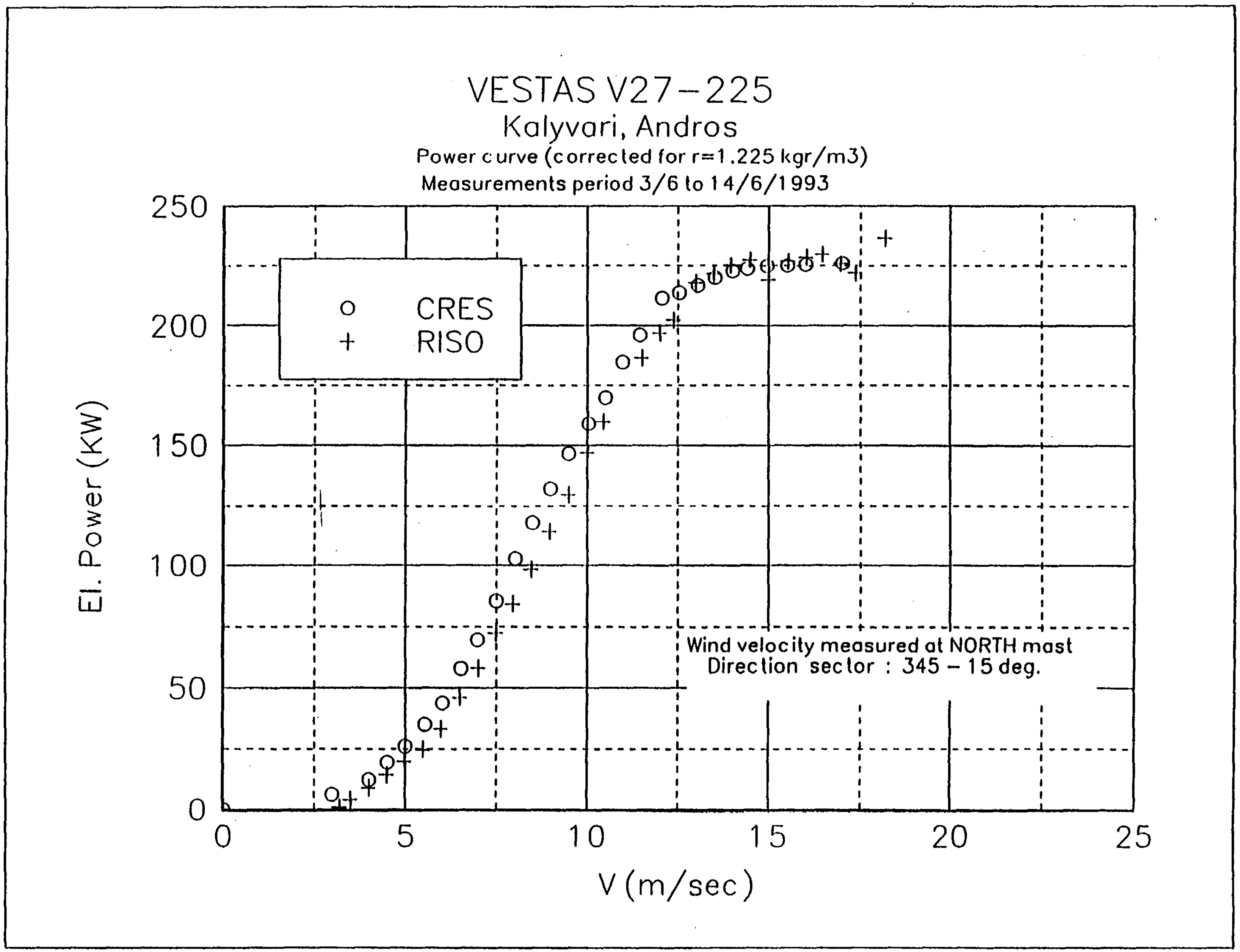
Mean Wind speed	7.4	m/s
Standard Deviation	4.2	m/s
Mean Power	493.1	Watt/m2
Total Wind Energy	10029.6	kWh/m2
Weibull Distribution		
Shape factor k	1.86	
Scale factor C	8.3	m/s
Data information		
collected data	122051	
calms included (<2.0 m/s)	11111	
missing data	15613	(11.3 %)
Circles percentage of the total Time		
Outer	40.0	%
Inner	0.0	%

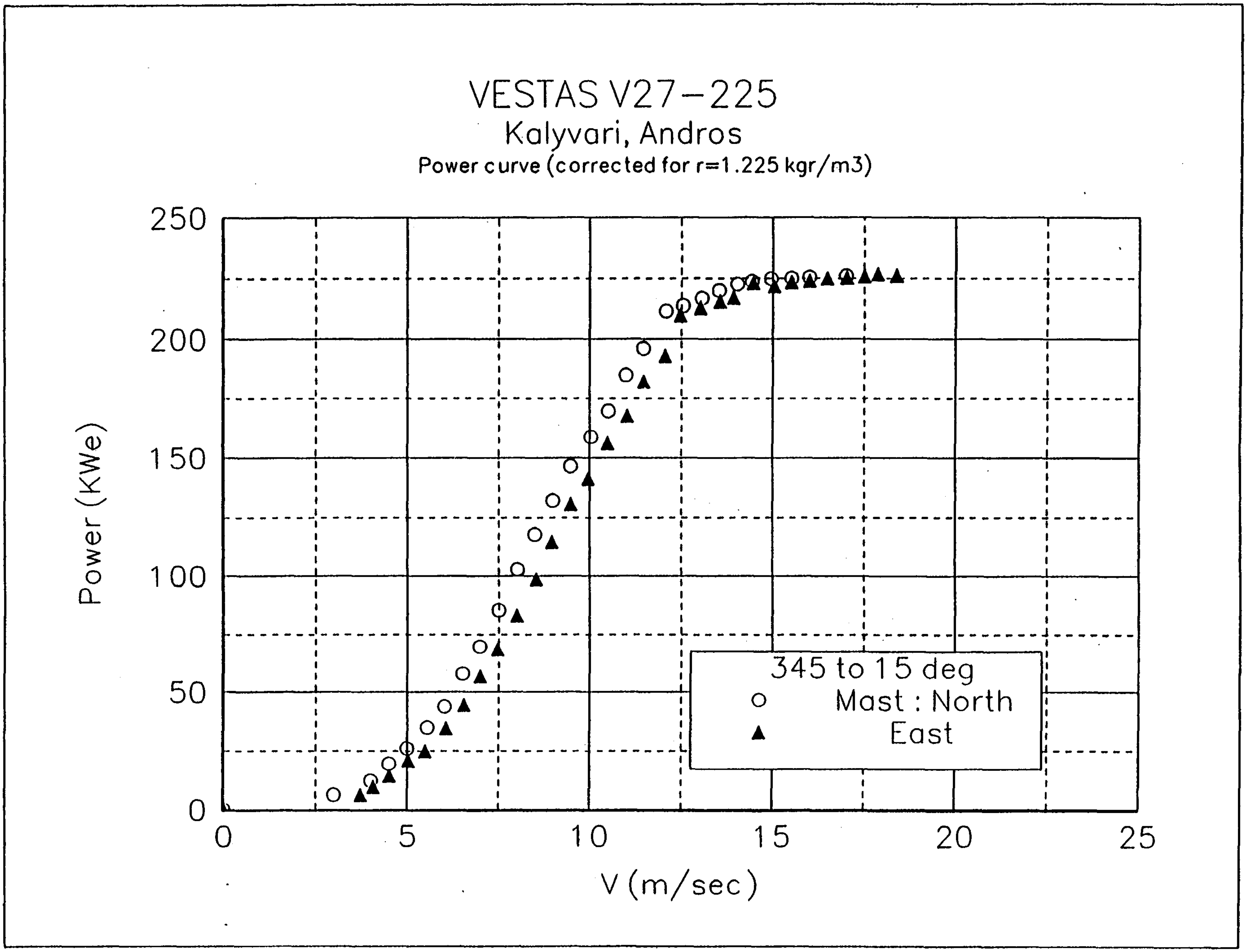


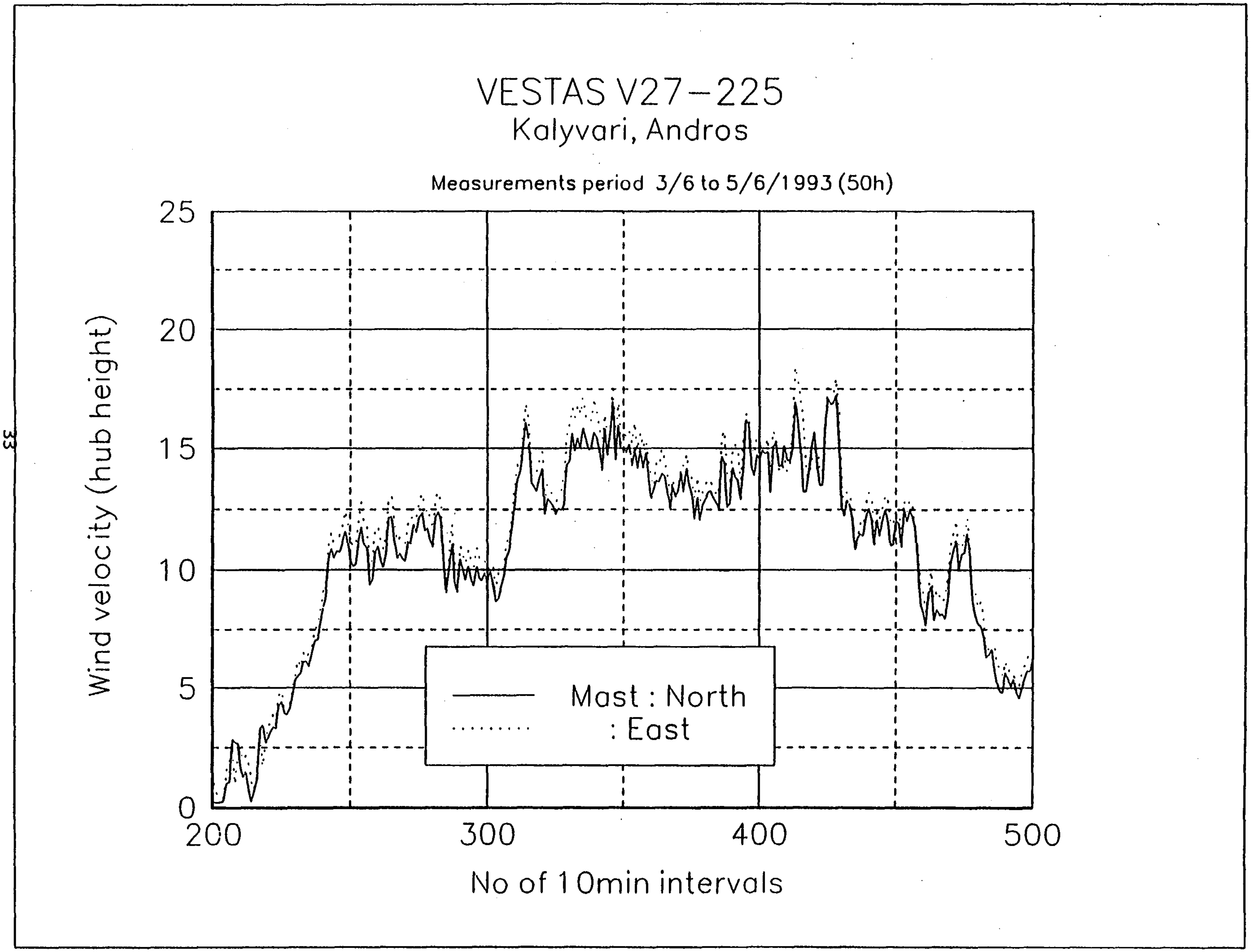
Station : 021 , ANDROS ISLAND
Measurements period: from 04/07/91 to 13/02/94



B.1

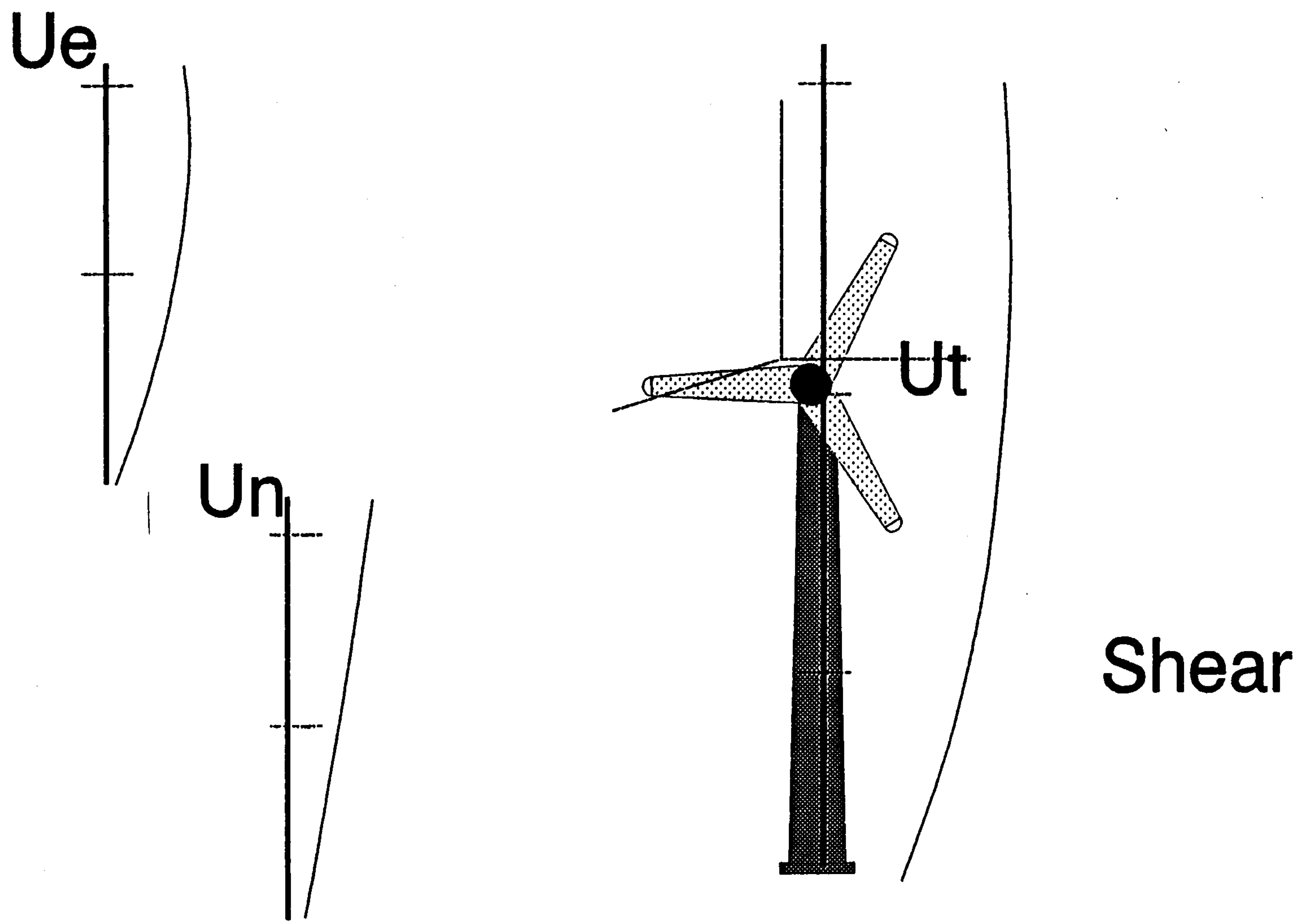

VESTAS V27-225
Kalyvari, Andros
Power curve (corrected for r=1.225 kgr/m3)
Measurements period 3/6 to 14/6/1993
CRES
RISO
El. Power (KW)
V (m/sec)
Wind velocity measured at NORTH mast
Direction sector : 345 - 15 deg.
0
50
100
150
200
250
0
5
10
15
20
25

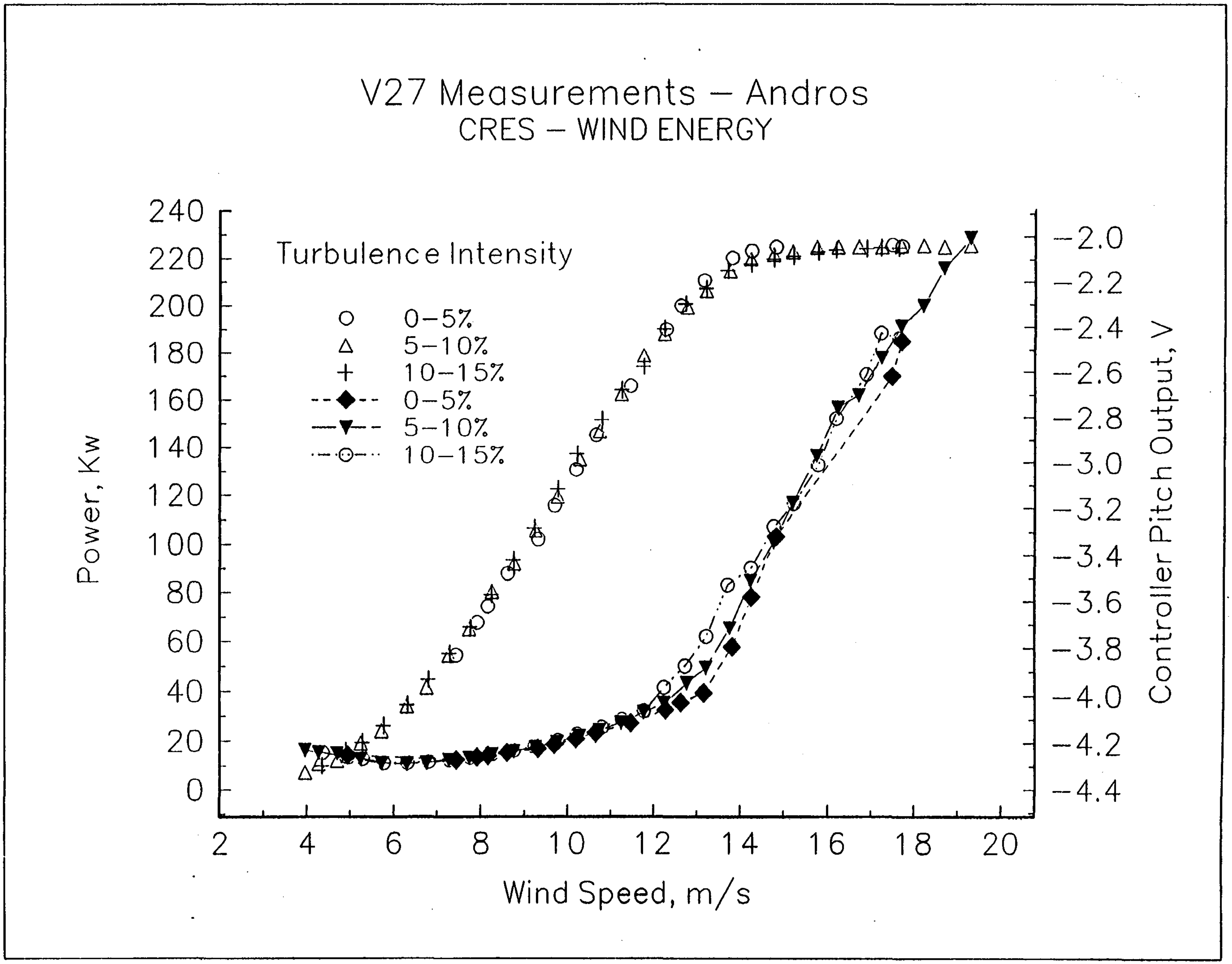

VESTAS V27-225
Kalyvari, Andros
Power curve (corrected for r=1.225 kgr/m3)
Power (KWe)
V (m/sec)
345 to 15 deg
Mast : North
East
0
50
100
150
200
250
0
5
10
15
20
25

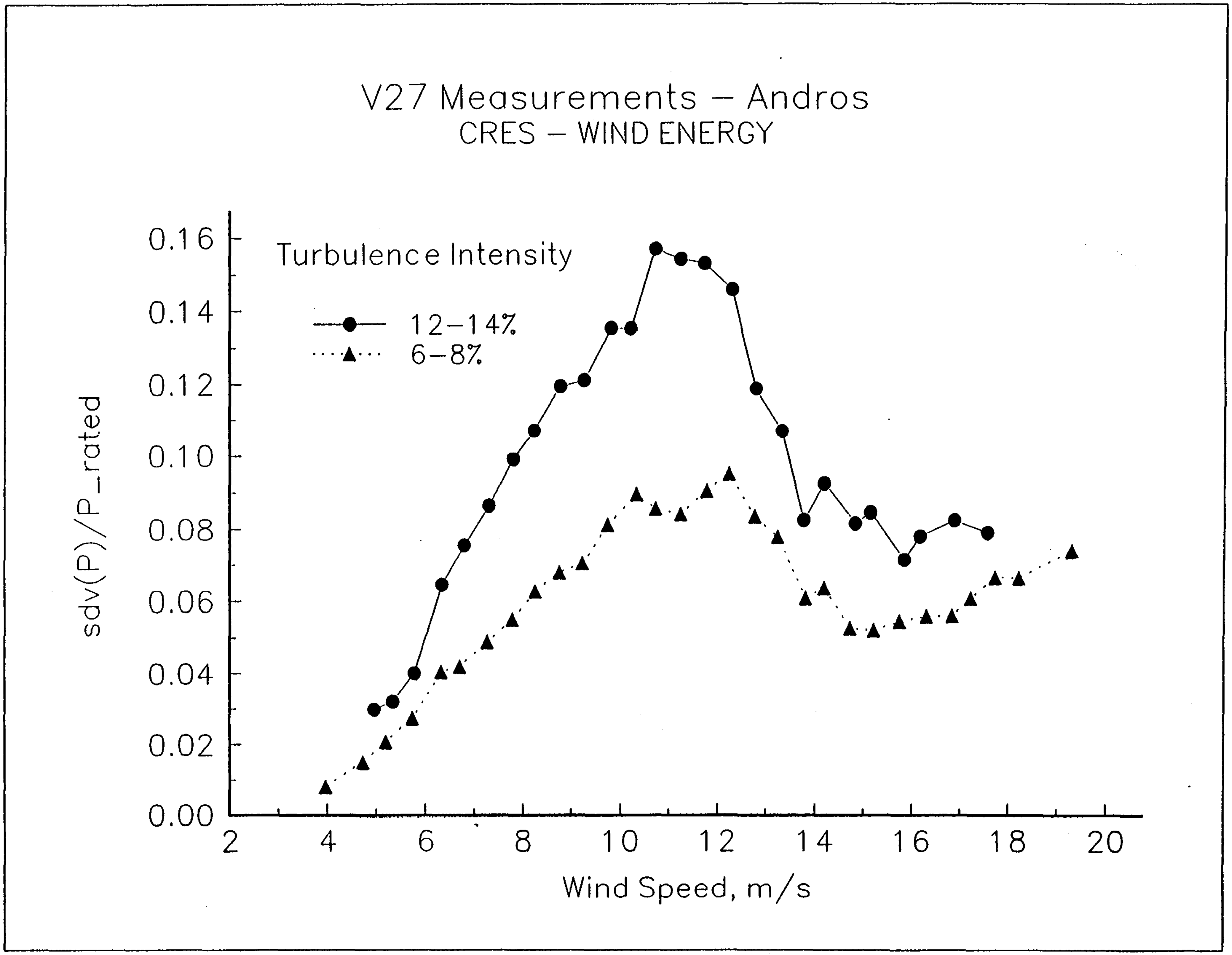


VESTAS V27-225
Kalyvari, Andros
Measurements period 3/6 to 5/6/1993 (50h)
Wind velocity (hub height)
25
20
15
10
5
0
200
300
400
500
No of 10min intervals
Mast : North
: East

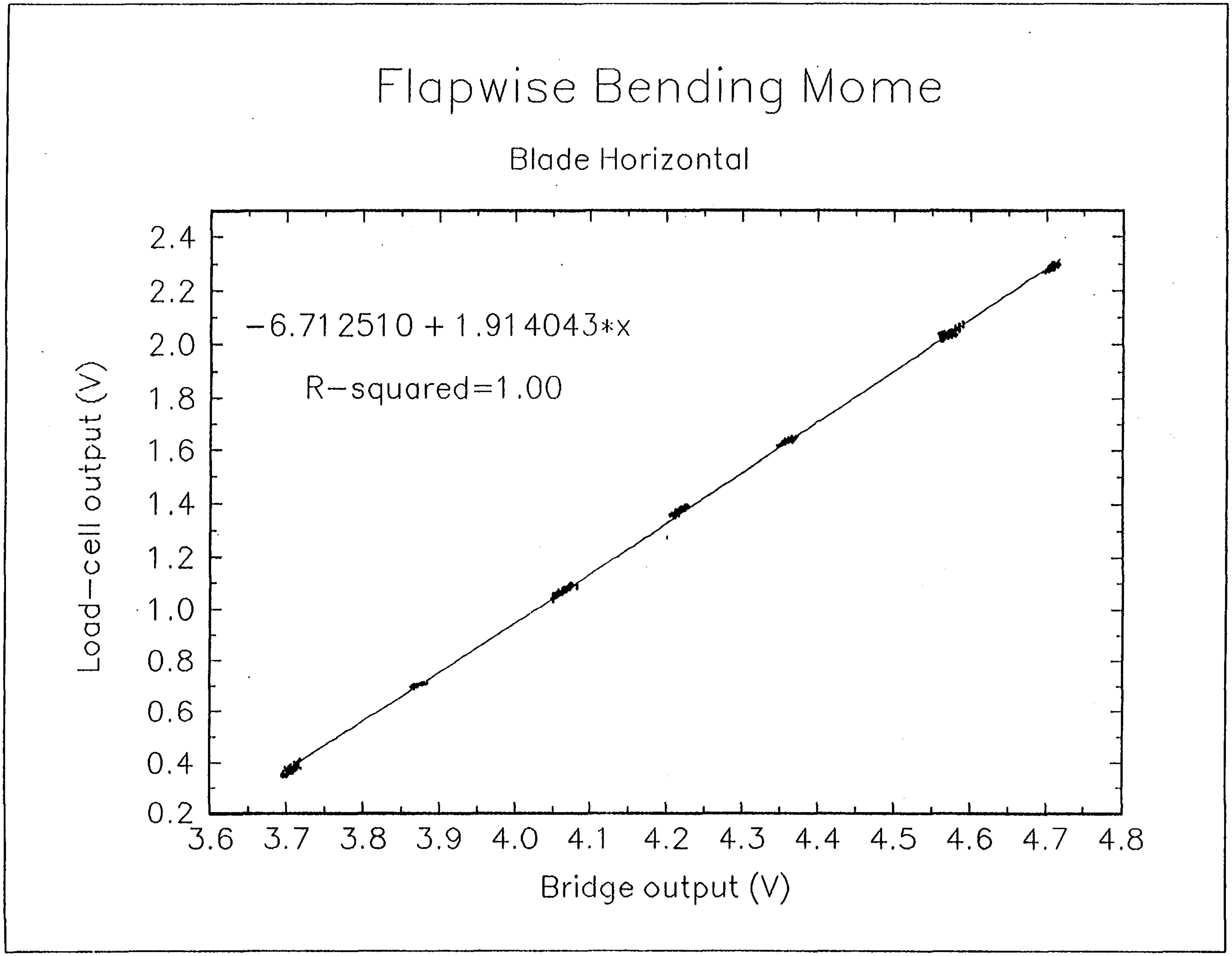
Site "Correction" Method

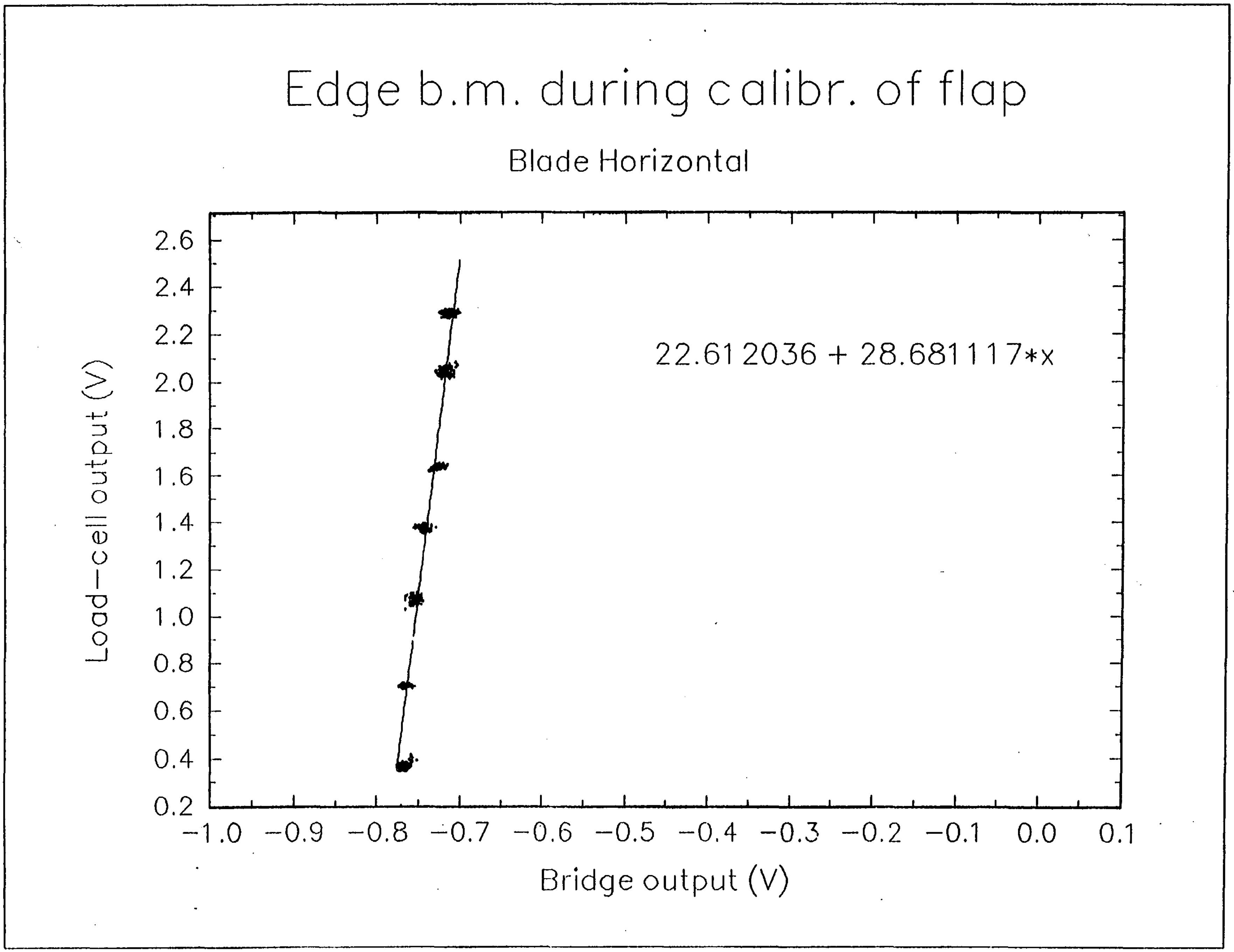



V27 Measurements — Andros
CRES — WIND ENERGY
Turbulence Intensity
0–5%
5–10%
10–15%
0–5%
5–10%
10–15%
Power, Kw
0
20
40
60
80
100
120
140
160
180
200
220
240
Controller Pitch Output, V
-2.0
-2.2
-2.4
-2.6
-2.8
-3.0
-3.2
-3.4
-3.6
-3.8
-4.0
-4.2
-4.4
Wind Speed, m/s
2
4
6
8
10
12
14
16
18
20



V27 Measurements – Andros
CRES – WIND ENERGY
Turbulence Intensity
12–14%
6–8%
sdv(P)/P_rated
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
2
4
6
8
10
12
14
16
18
20
Wind Speed, m/s

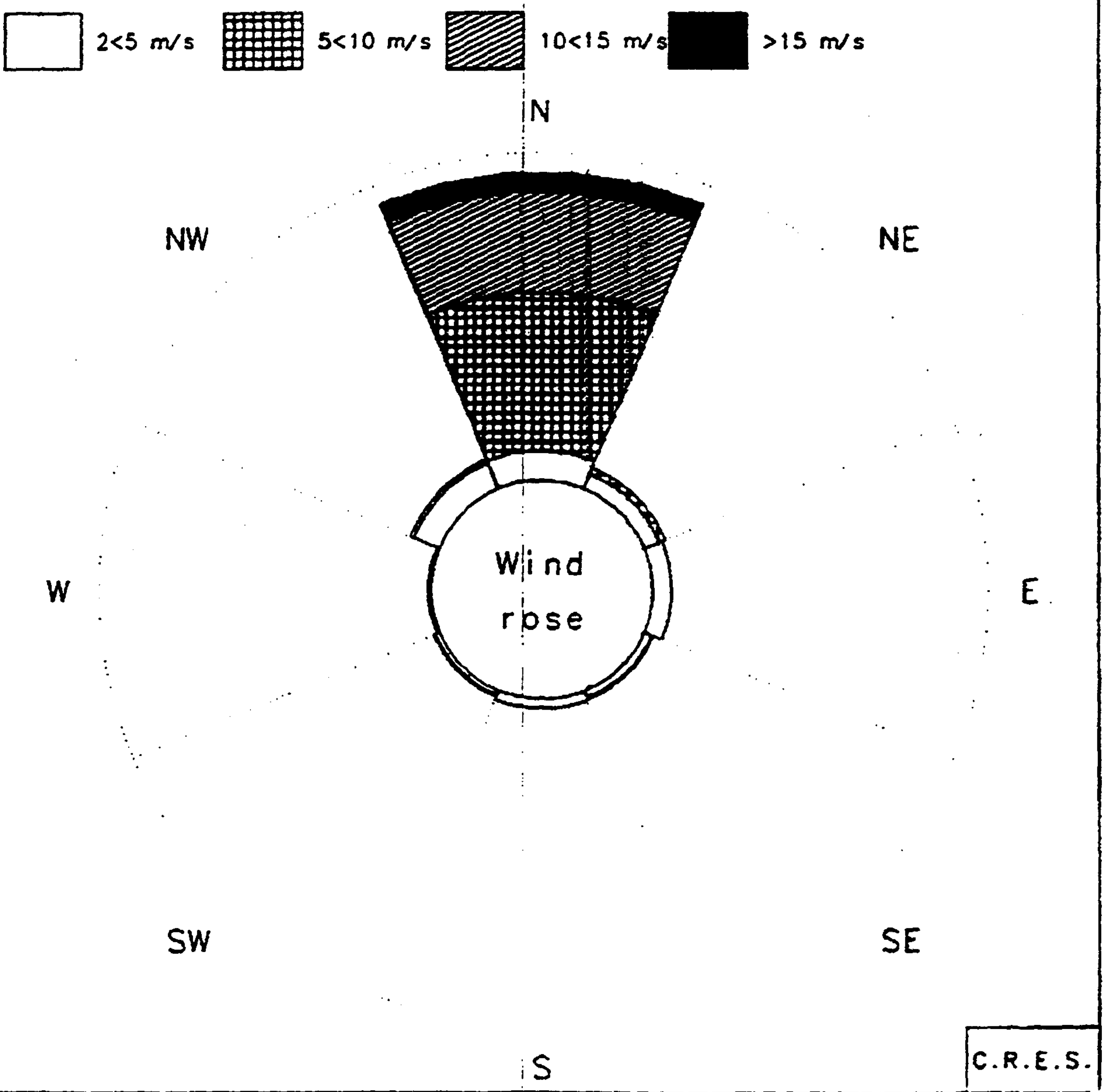

Flapwise Bending Mome
Blade Horizontal
-6.712510 + 1.914043*x
R-squared=1.00
Load-cell output (V)
Bridge output (V)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8


Edge b.m. during calibr. of flap
Blade Horizontal
22.612036 + 28.681117*x
Load-cell output (V)
Bridge output (V)
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
−1.0
−0.9
−0.8
−0.7
−0.6
−0.5
−0.4
−0.3
−0.2
−0.1
0.0
0.1

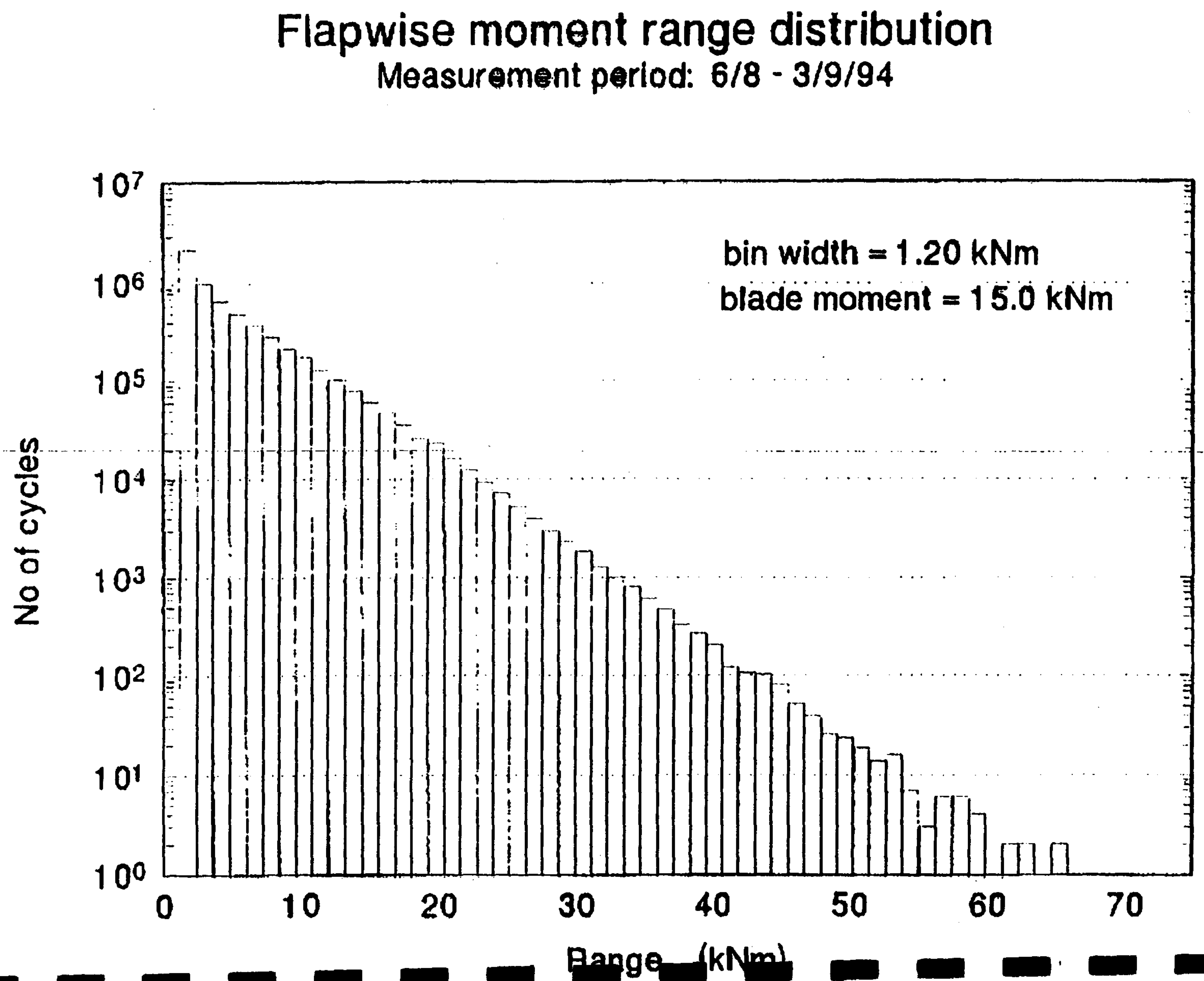
results from AV.BAS (8/94) cup/vane

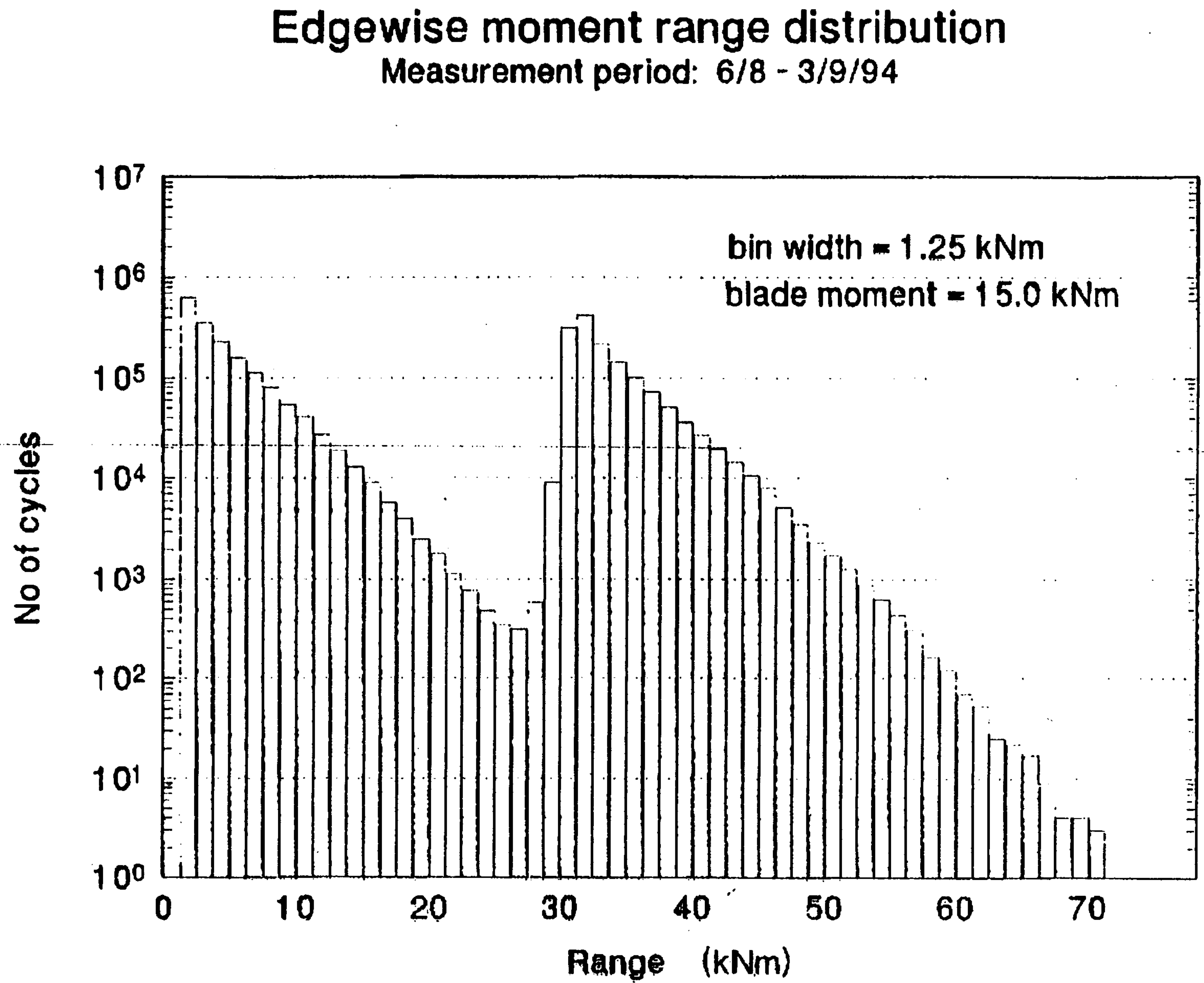
Station : 003, AG. MARINA LAVRIO, project : YBET - VALOREN
Height: 20m AGL, 116m ASL
Measurements period: from 06/08/94 to 03/09/94

Mean Wind speed	7.2	m/s
Standard Deviation	4.2	m/s
Mean Power	464.9	Watt/m2
Total Wind Energy	308.8	kWh/m2
Weibull Distribution		
Shape factor k	1.80	
Scale factor C	8.1	m/s
Data information		
collected data	3985	
calms included (<2.0 m/s)	388	
missing data	191	(4.6 %)
Circles percentage of the total Time		
Outer	80.0	%
Inner	0.0	%



C.R.E.S.


Flapwise moment range distribution
Measurement period: 6/8 - 3/9/94
bin width = 1.20 kNm
blade moment = 15.0 kNm
No of cycles
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
0
10
20
30
40
50
60
70
Range (kNm)



Edgewise moment range distribution
Measurement period: 6/8 - 3/9/94
bin width = 1.25 kNm
blade moment = 15.0 kNm
No of cycles
Range (kNm)

Meas. No.	1	2	3	4	5
Date	20/8/94	22/8/94	22/8/94	3/9/94	
Time	16	11	16	20	
Cloudness	-	-	-	-	
Temperature (°C)	27	31	30	24	
Average wind speed (m/s)	8	8	8.1	7.7	
Range of 1min. mean values of wind speeds (m/s)	6.5 - 9.7	6.2 - 9.4	5.2 - 9.9	5.5 - 9.6	
Relative humidity (%)	42	29	33	59	
Barometric pressure (mbar)	1,001	1003	1,003	1,006	
Sensitivity $\Delta L_{WA}/\Delta V$ dB per m/s	0.93	0.87	0.75	1.08	
Correlation coefficient	0.57	0.59	0.69	0.81	
L_{WA}= (dBA)	86.92+0.93 x	86.78+0.87 x	88.54+0.75 x	85.55+1.08 x	
Sound power level (dBA), at wind speed of 8 m/s	94.4	93.7	94.6	94.2	

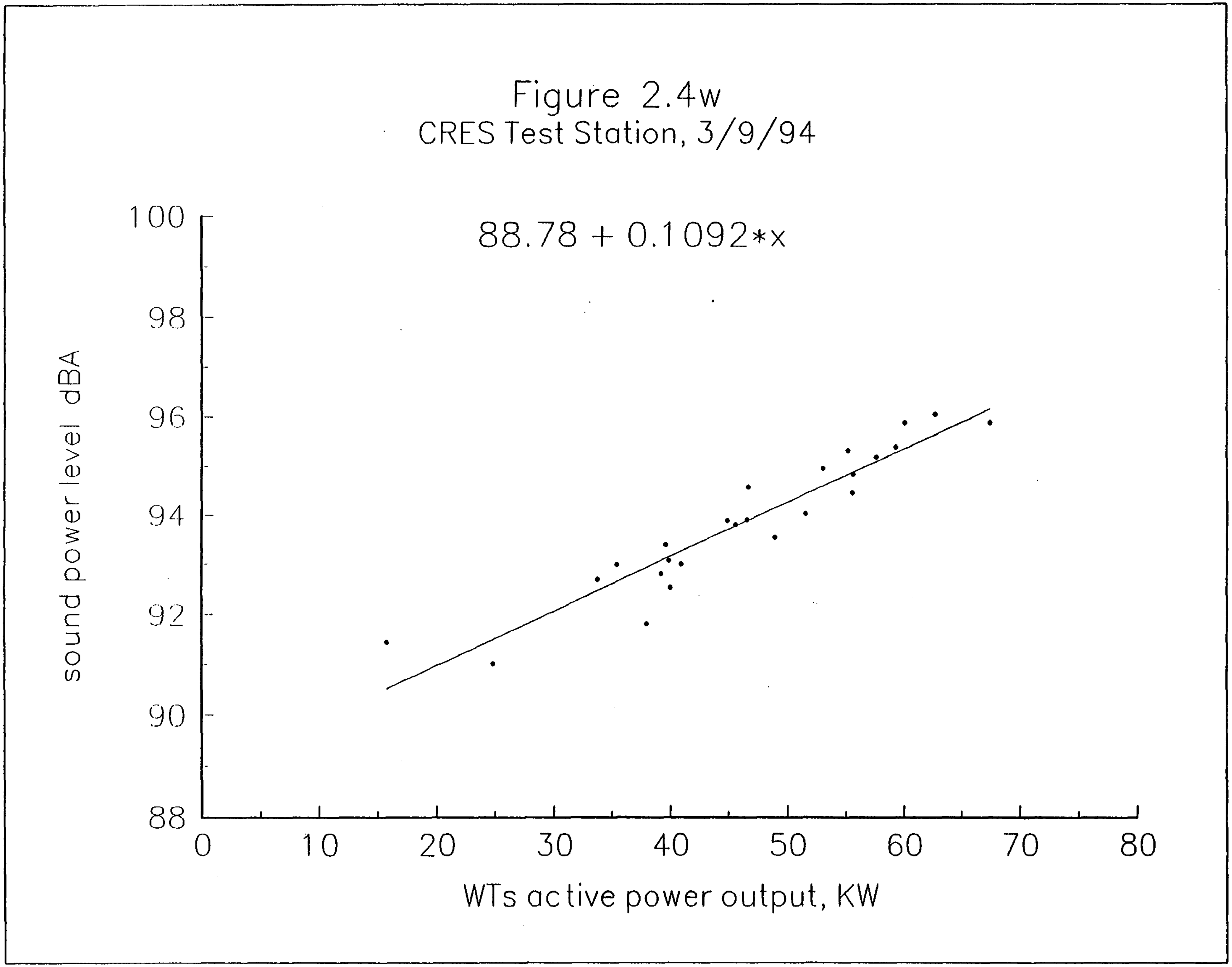
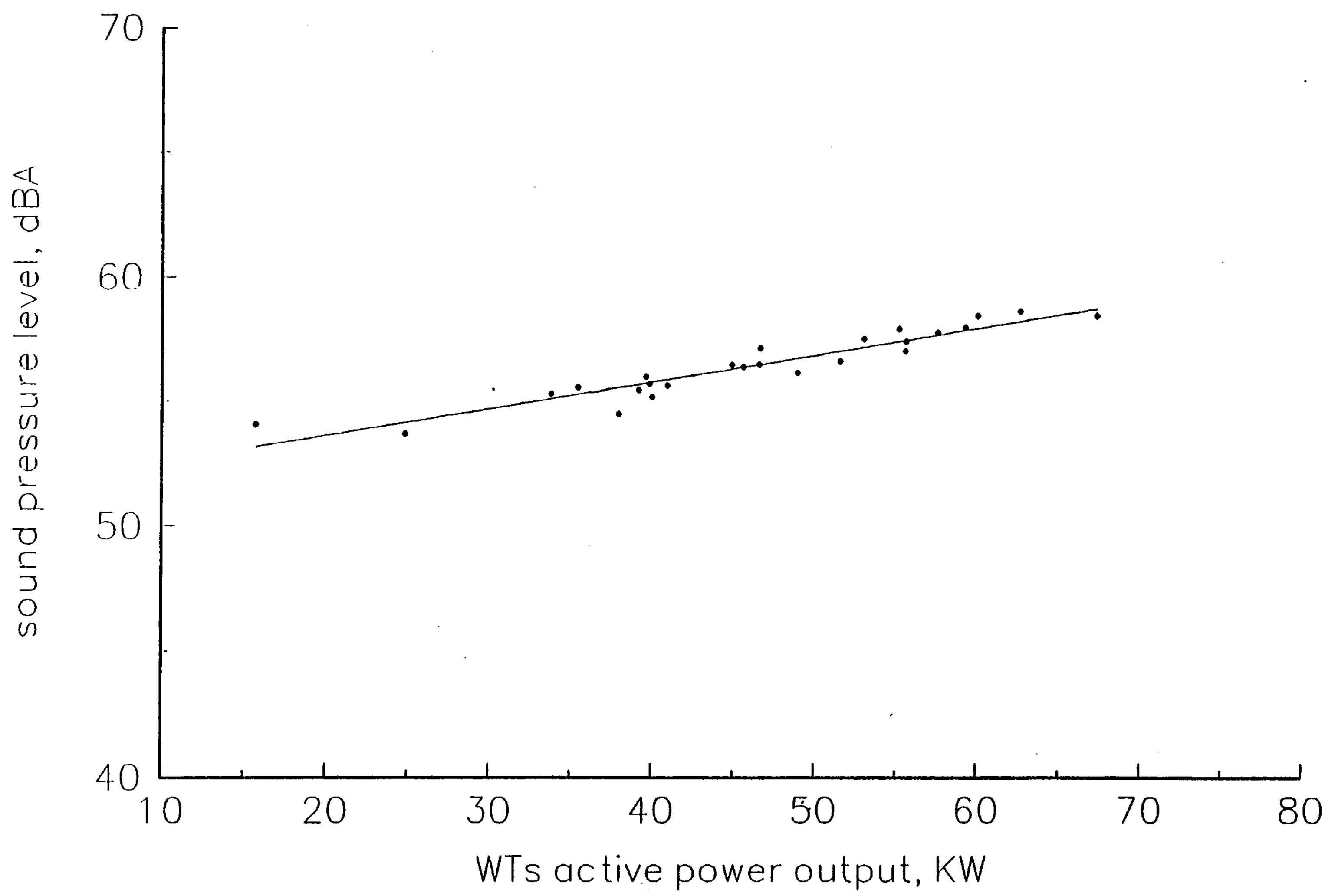


Figure 2.4w
CRES Test Station, 3/9/94
88.78 + 0.1092*x
sound power level dBA
100
98
96
94
92
90
88
0
10
20
30
40
50
60
70
80
WTs active power output, KW

Figure 6.4w
CRES Test Station 3/9/94



Power Curve Parameter Sensitivity

Stephan Glocker
WINDTEST

Shareholders: State Schleswig-Holstein
District Dithmarschen
Community Kaiser-Wilhelm-Koog
Schleswag AG (25%)
Germanischer Lloyd (25%)

Tasks: Operation of the **Test Station** for WEC at former GROWIAN-site
Measurements on WEC due to efficiency, noise, grid quality and loads
Consulting of utilities, planers, gouvernment and manufacturers
Site measurements and evaluations
Short time forecasting for **load management** for utilities

Founded: 13. September 1989

Size (04'94): 9 Engineers
4 Workers and Sekretaries
about 5 Students

WINDTEST KWK | **WEA 114**

Building permit procedure

Prüfung im Rahmen des Baugenehmigungsverfahrens

→ Nachweis der Genehmigungsfähigkeit

Prüfung des baulichen Teils:
- Turmstatik
- Fundamentsta…

Prüfung des maschinenbaulichen Teils: *Expertises*
- WKA
- Lasten

Sachverständigen-organisation

Untere Bauaufsichtsbehörde

Responsible: Permit Authorities

Approval

Einzelprüfung

Prüfung des baulichen Teils:
- Turmstatik
- Fundamentstati…
(evtl. Prüfstatiker)

Prüfung des maschinenbaulichen Teils:
- WKA
- Lasten

Sachverständigen-organisation

Untere Bauaufsichtsbehörde

Type approval

Typenprüfung

Prüfung des baulichen Teils:
- Turmstatik
- Fundamentstati…

Prüfung des maschinenbaulichen Teils:
- Lastannahmen
- Sicherheitssystem
- Dokumentation
- Rotorblätter
- Komponenten

Sachverständigen-organisation

Oberste Ba…

Certification

Zertifizierung

→ Nachweis der Qualität gegenüber Käufern, Finanzierungsgesellschaften und Versicherern

Prüfung der Qualität des Produkts (Leistungsfähigkeit, Zuverlässigkeit, Verfügbarkeit)
- Prüfung der Unterlagen
- Fertigungsüberwachung
- Transportüberwachung
- Montageüberwachung
- Inbetriebnahme
- Prototyptest ←

Sachverständigen-organisation

Design approval
Survey of construction
transport
installation

prototype test

Measurements!

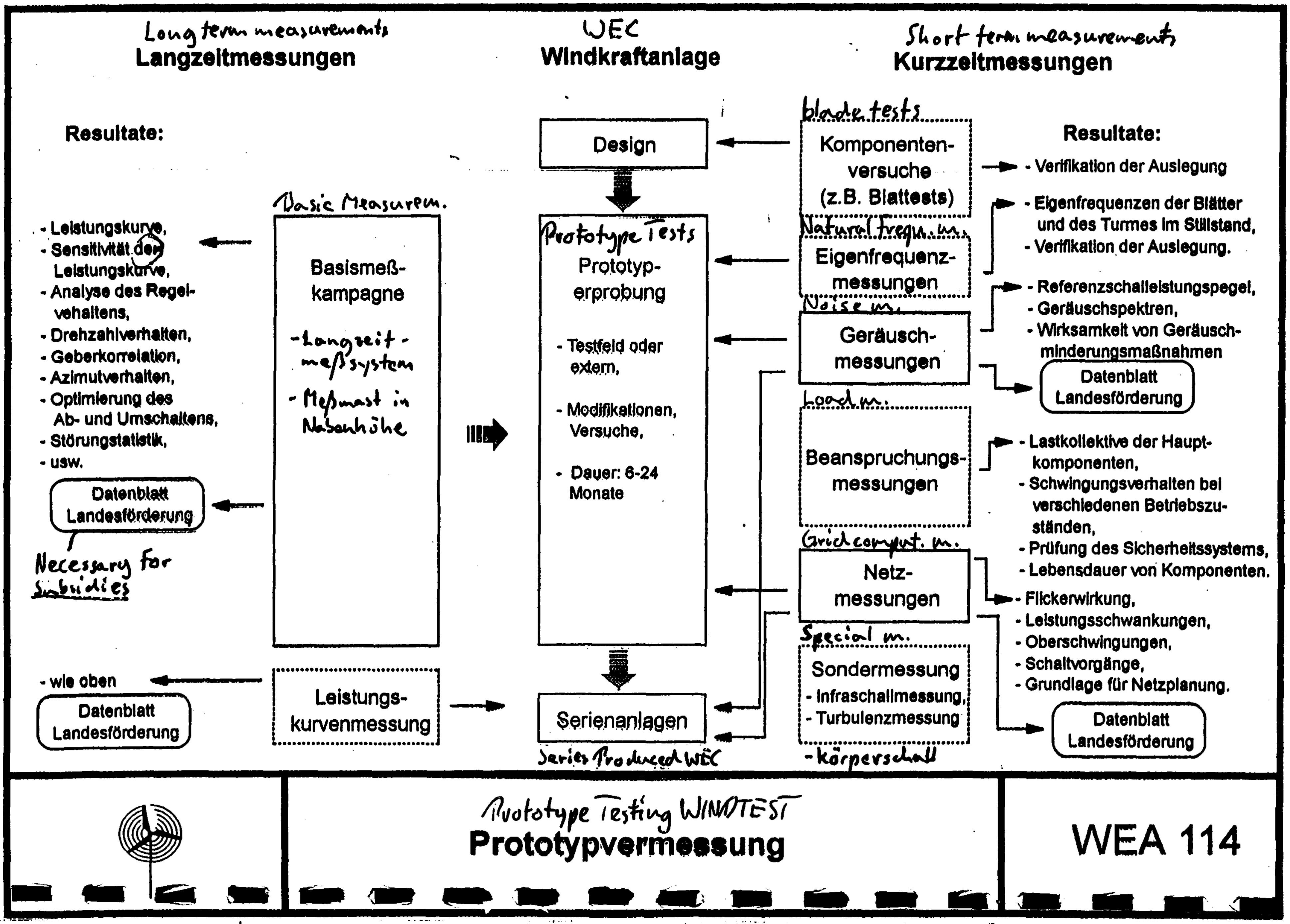
Messungen
- der Leistungskurve
- der Schallemission
- ggf. der Beanspruchungen
- nach IEA

Typenprüfung, Einzelprüfung und Zertifizierung in der BRD

WEA 113

1.	Land	Deutschland "Prototypmessungen" (Entwurf) Prototype-Measurements (Draft)
2.	Ziel	Prototypen, die gefördert werden oder als Serienanlagen gefördert werden sollen, werden auf ihre fundamentalen Eigenschaften hin untersucht. Optional werden zusätzlich die Lastannahmen der Anlagen nachgewiesen. Condition for subsidies
3.	wo beschrieben	Richtlinie noch zu erstellen?
4.	Besonderheiten	1. Standort soll windbegünstigt sein (besser als 5,0 m/s in 10 m Höhe) 2. Alle Messungen an einer WKA-Einstellung
5.	untersuchte Bereiche	Prototypmessungen: Identification 1. Abnahme der WKA, Identifikation aller Komponenten und Einstellungen 2. Funktionsprüfung des Überwachungssystems und des Sicherheitssystems mit Messungen Functional Test (controll and safety system) 3. Regelung Measurement of controll effectifity 4. Wirksamkeit der Windnachführung ... of the yaw system 5. Geräuschverhalten ... sound characteristics 6. Leistungskurve ... power curve 7. Netzqualität ... grid compatibility 8. Zu- und Abschaltvorgang der Anlage mit Belastungsmessungen ... loads in cut in and cut out 9. Eigenfrequenzen im Stillstand ... natural frequencies zusätzlich Stukturmessungen (z.B. bei neuen Konzepten und Anlagen >500 kW): additional for WEC > 500 kW: load measurements 9. Rechnerische Ermittlung der Dynamik der Anlage (in Betrieb und im Stillstand) 10. Blatt- und Rotorbelastungen Blade and main shaft
6.	erforderliche Meßkampagnen	1. **Leistungskurvenermittlung** nach Länderrichtlinie mit Azimutabweichung und Korrelation des Gondelanemometers 2. **Eigenfrequenzenmessung** im Stillstand 3. **Geräuschmessungen** nach Länderrichtlinien 4. **Netzmessungen** nach Länderrichtlinie (dreiphasig) 5. **Messungen zur Beurteilung der Regelung, der Betriebsführung und des Sicherheitssystems** ((Registrierung von Leistung, Drehzahl, Wind im Regelbetrieb, beim Zu- und Abschaltvorgang, bei Notstop, Aktivierung der Sicherheitssysteme, evtl einfache Belastungsmessungen an Hauptwelle und einem Blatt, Abfolge der Sicherheitskette mit 0,05 sec-Auflösung, evtl in 1 oder 6 integrierbar)) -> **mit einfache Belastungsmessungen** zusätzlich: 6. **Belastungsmessungen** und Vergleich mit der Auslegung : Wind, Azimutabweichung, Blattbelastung in Schlag- und Schwenkrichtung, Rotorbelastungen (Biegemomente, Torsionsmoment der Hauptwelle, Rotorschub)

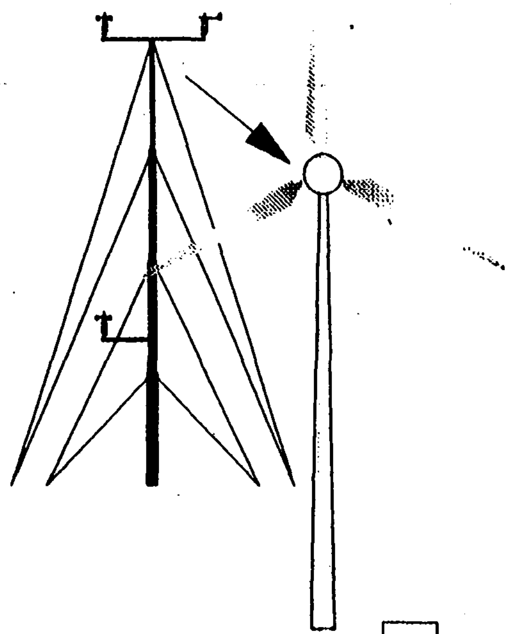
C:\GLOCKER\TEXTE\PROTOTY.DOC



Long term measurements
Langzeitmessungen
WEC
Windkraftanlage
Short term measurements
Kurzzeitmessungen
Resultate:
- Leistungskurve,
- Sensitivität der Leistungskurve,
- Analyse des Regelverhaltens,
- Drehzahlverhalten,
- Geberkorrelation,
- Azimutverhalten,
- Optimierung des Ab- und Umschaltens,
- Störungsstatistik,
- usw.
Datenblatt Landesförderung
Necessary for subsidies
Basic Measurem.
Basismeß-kampagne
-Langzeit-meßsystem
-Meßmast in Nabenhöhe
- wie oben
Datenblatt Landesförderung
Leistungs-kurvenmessung
Design
Prototype Tests
Prototyp-erprobung
- Testfeld oder extern,
- Modifikationen, Versuche,
- Dauer: 6-24 Monate
Serienanlagen
Series Produced WEC
blade tests
Komponenten-versuche (z.B. Blattests)
Natural frequ. m.
Eigenfrequenz-messungen
Noise m.
Geräusch-messungen
Load m.
Beanspruchungs-messungen
Grid comput. m.
Netz-messungen
Special m.
Sondermessung
- Infraschallmessung,
- Turbulenzmessung
-körperschall
Resultate:
- Verifikation der Auslegung
- Eigenfrequenzen der Blätter und des Turmes im Stillstand,
- Verifikation der Auslegung.
- Referenzschalleistungspegel,
- Geräuschspektren,
- Wirksamkeit von Geräuschminderungsmaßnahmen
Datenblatt Landesförderung
- Lastkollektive der Hauptkomponenten,
- Schwingungsverhalten bei verschiedenen Betriebszuständen,
- Prüfung des Sicherheitssystems,
- Lebensdauer von Komponenten.
- Flickerwirkung,
- Leistungsschwankungen,
- Oberschwingungen,
- Schaltvorgänge,
- Grundlage für Netzplanung.
Datenblatt Landesförderung
Prototype Testing WINDTEST
Prototypvermessung
WEA 114

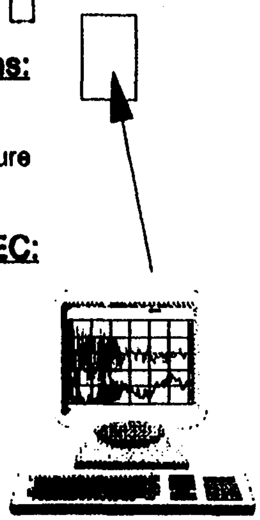
50

Measurements



Atmospheric conditions:
- wind speed at hub height
- wind direction
- air pressure and temperature
- (humidity)

Parameters of the WEC:
- power output
- rotor speed and other relevant parameters
- digital signals (e. g. grid connection)



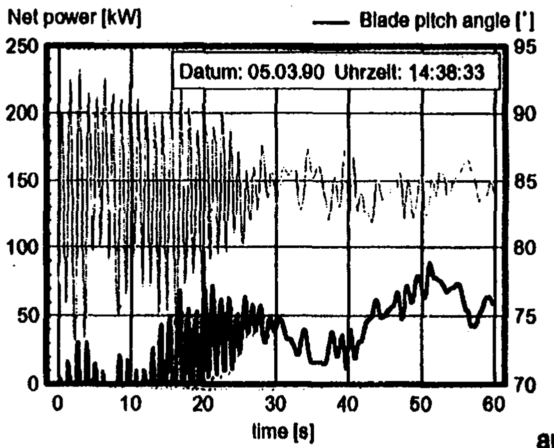
Data Acquisition system

Data collection

Raw data

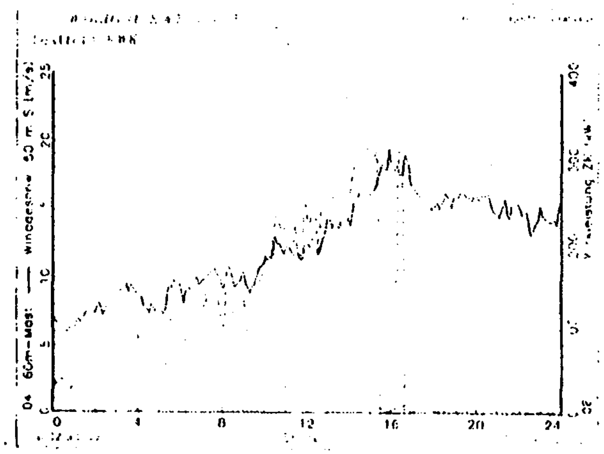
Site data

Raw data time series (e. g. from 5 Hz data)
triggered by events, by power downs or manuel



Picture 1: Power output and blade pitch angle

Time series of averages (1 or 10-min)



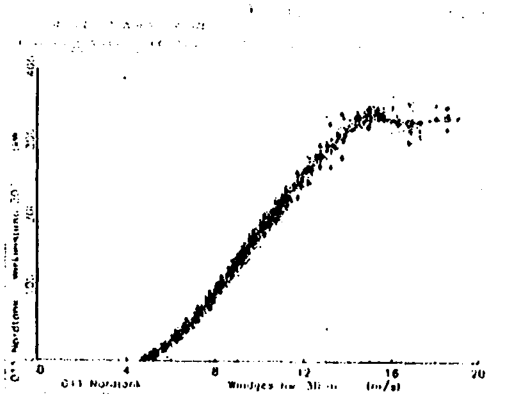
Picture 2: Power output and wind speed of a WEC

Data analysis

Results

Energy output prediction for special sites

Power curve analysis
- standardized power curves e. g. according to IEA or ECN-217
- sensitivity of power curve on different parameters(e. g. turbulence, converting conditions...)



Picture 3: Power curve of Nordtank NTK 300/31

Evaluation of the parameters required to apply for subsidies of northern German States (Schleswig-Holstein, Lower Saxony, Mecklenburg-Vorpommern)
- Power curve according to IEA
- standardized energy output at a 10m/s site

Statistics
- failure statistics and analysis
- operation statistics

Verification of design and modelling methods

Review of control behaviour (simple dynamic analysis according to sampling rate: turbulence interaction, start and stop, high wind speeds ...)

Figure 2: Power performance testing

WINDTEST
Kaiser-Wilhelm-Koog GmbH

Durch das DAP Deutsches Akkreditierungssystem Prüfwesen akkreditiertes Prüflaboratorium
Die Akkreditierung gilt für die in der Urkunde aufgeführten Prüfverfahren
BAM-Begutachtungs-Stelle (BBS)
Deutscher Akkreditierungsrat
DAR
DAP-P-01.556-00-91-01

Prüfbericht "Messung der Leistungskurve der VESTAS V-39/500 (Auszug)"

Bericht Nr.: WT198/94

Windkraftanlage: VESTAS V-39/500

Rotordurchmesser: .... 39,0 m
Installierte Generatorleistung: .... 500 kW
Rotordrehzahl: .... 30 min^{-1}
Nabenhöhe: .... 40,5 m
Blatteinstellwinkel: .... entfällt
Blattyp: .... VESTAS 702005, 702000

Meßprogramm:

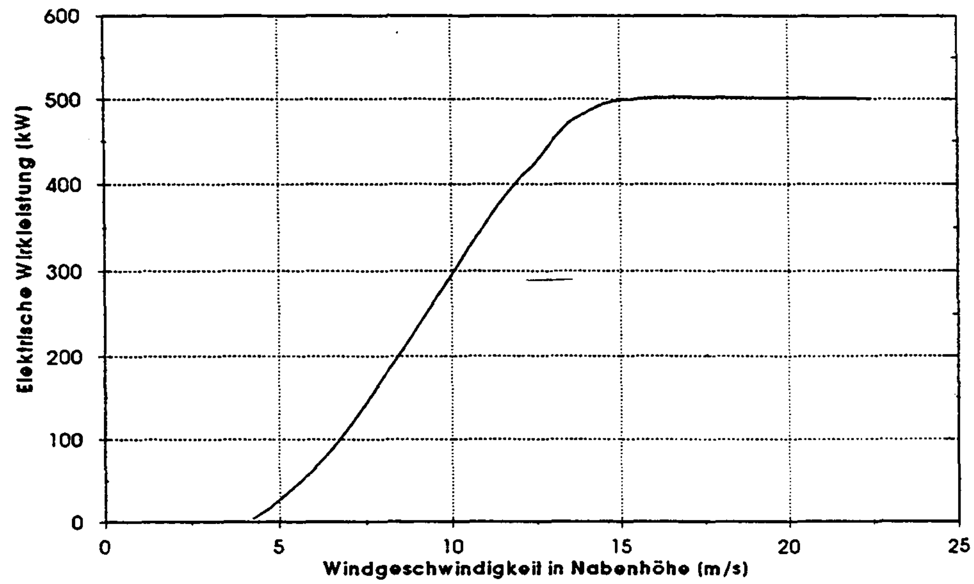
Messungen nach IEA Empfehlungen "Recommended practices for wind turbine testing and evaluation",
1. power performance testing, 2. edition 1990

- Meßzeitraum: 11.01.1994 bis 03.02.1994,
- Messung des Windes in Nabenhöhe,
- abgeschattete Windrichtungen wurden nicht berücksichtigt,
- Korrektur auf Normbedingungen (Luftdichte r_{Luft} =1,225 kg/m^3) nach IEA,
- Genauigkeit der Windgeschwindigkeitsgeber durch Kalibrierung: +/- 0,2 m/s im Bereich zwischen 4 und 20 m/s,
- Genauigkeit des Wirkleistungsmeßumformers +/-0,5% bezogen auf 750 kW,
- Genauigkeit der Luftdichtebestimmung: +/- 0,25 %.

Der Meßumfang ist dem Bericht WT 176/94 zu entnehmen.

BIN von	bis	Anzahl Sätze	v_{Wind}	P_{Wirk}	c_{pAnl}
[m/s]	[m/s]	[]	[m/s]	[kW]	[]
3,75	4,25	1	4,23	4,0	0,072
4,25	4,75	9	4,66	16,1	0,218
4,75	5,25	32	5,06	28,8	0,304
5,25	5,75	36	5,57	47,0	0,372
5,75	6,25	81	6,00	64,8	0,409
6,25	6,75	94	6,47	85,9	0,434
6,75	7,25	71	7,01	114,9	0,455
7,25	7,75	89	7,50	142,9	0,462
7,75	8,25	65	7,98	172,4	0,464
8,25	8,75	94	8,52	205,2	0,453
8,75	9,25	107	9,01	235,8	0,441
9,25	9,75	90	9,51	265,9	0,423
9,75	10,25	103	10,00	295,2	0,404
10,25	10,75	85	10,48	325,8	0,386
10,75	11,25	69	11,02	357,6	0,365
11,25	11,75	60	11,51	382,9	0,344
11,75	12,25	81	12,00	406,3	0,321
12,25	12,75	78	12,48	425,2	0,299
12,75	13,25	86	13,03	453,1	0,280
13,25	13,75	85	13,51	472,9	0,262
13,75	14,25	64	13,98	483,3	0,242
14,25	14,75	41	14,52	494,6	0,221
14,75	15,25	56	15,01	498,7	0,201
15,25	15,75	53	15,48	499,4	0,184
15,75	16,25	66	15,99	502,1	0,168
16,25	16,75	41	16,48	503,0	0,154
16,75	17,25	33	17,00	502,7	0,140
17,25	17,75	26	17,44	503,2	0,130
17,75	19,75	50	18,57	502,2	0,107
19,75	21,75	44	20,58	501,4	0,079
21,75	23,75	15	22,47	500,3	0,060

Nach IEA gemessene Leistungskennlinie: VESTAS V-39/500



11. Februar 1994

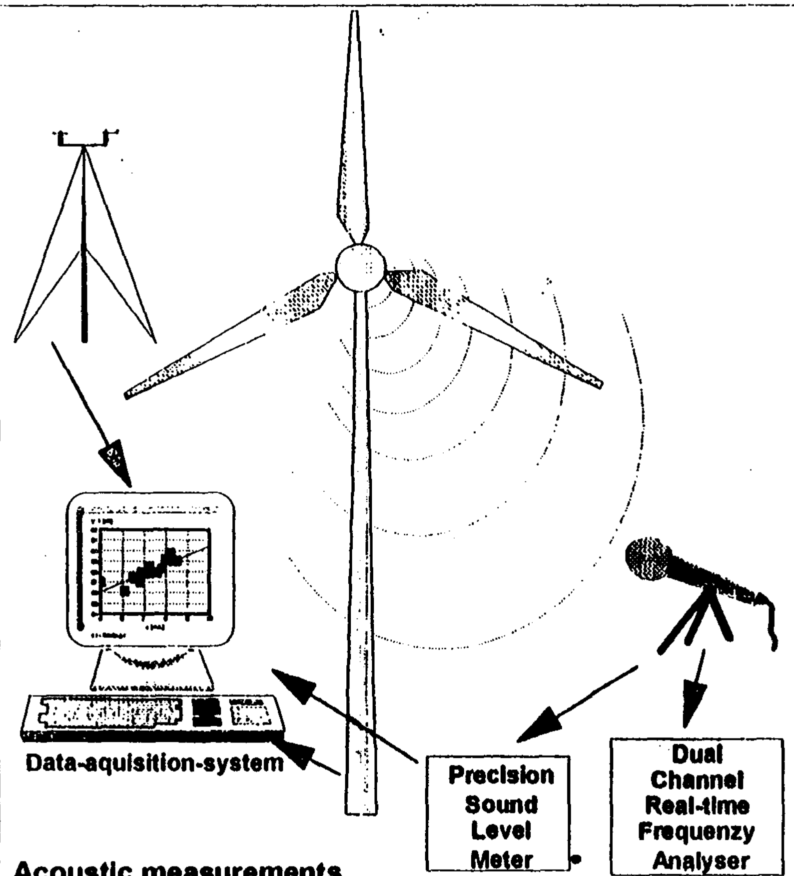
WINDTEST KWK GmbH

Gemessen durch: WINDTEST KWK GmbH
Sommerdeich 14b
25709 Kaiser-Wilhelm-Koog
Tel.: 04856/901-0

Datum: 15. März 1994
Unterschrift:

WINDTEST KAISER-WILHELM-KOOG GMBH

Measurements



Acoustic measurements

- equivalent continuous A-weighted sound pressure level measured with a flush - mounted microphone upon a hard board on the ground.
- equivalent continuous sound pressure level in third - octave bands
- narrow band spectrum

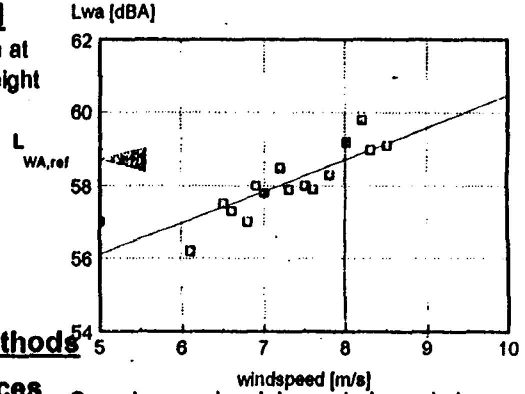
Non - acoustic measurements

- wind speed measured in 10 meters height
- wind direction
- power output
- rotor speed
- metereological conditions

Results

Calculation of sound power level

from the wind turbine relevant to immission at a reference wind speed of 8 m/s in 10m height



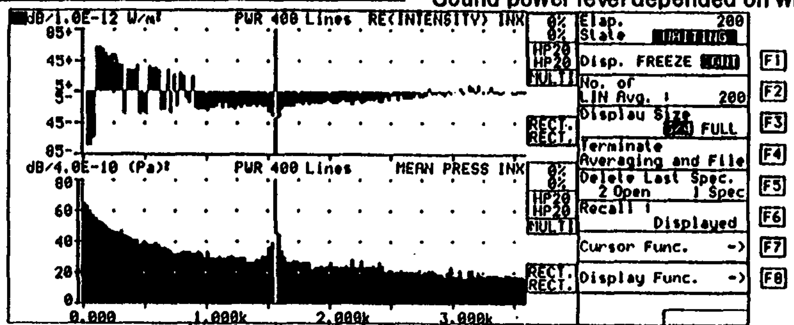
Sound power level depended on wind speed

Evaluation of the parameters used for subsidizing by the northern German states

- Noise measurements according to IEA
- Sound power level per area at limited immision levels

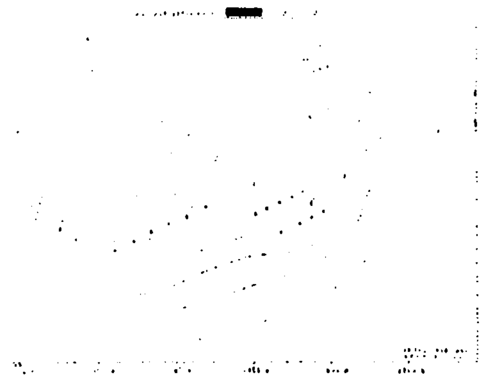
Effectivity of noise reduction methods

Analysis of noise emission sources



Bipolar display of intensity and mean pressure

Environmental noise prediction according to VDI 2714

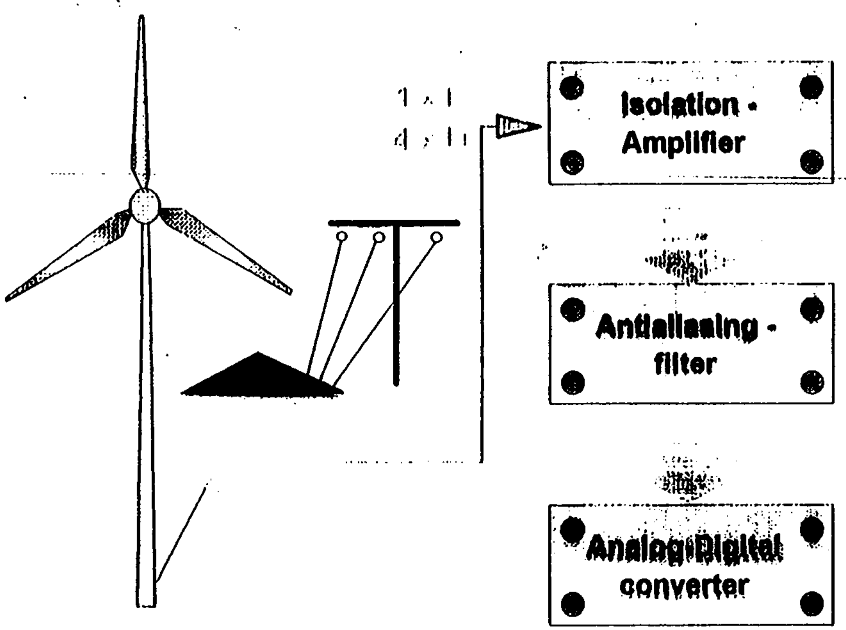


Lines of equal sound pressure levels around a wind farm

Site data

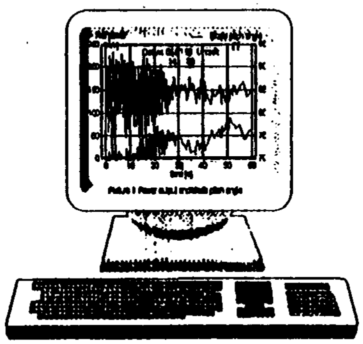
Figure 4: Acoustic measurements

Measurement



Measurement of:

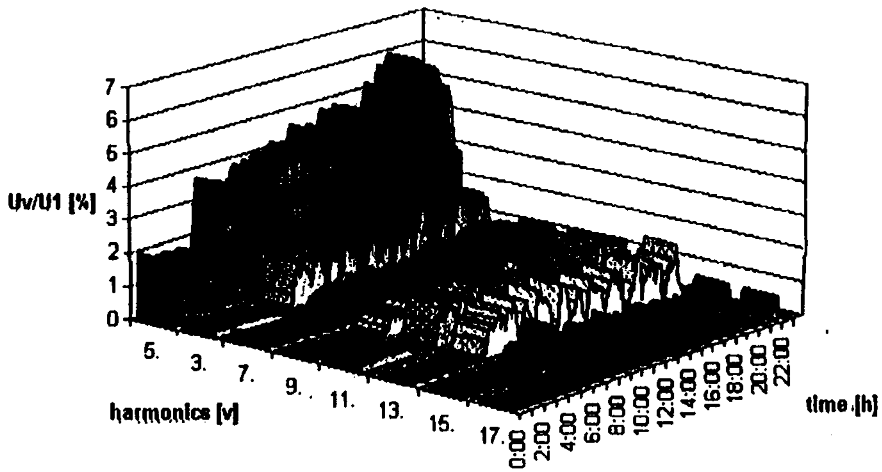
- current and voltage
- 8 channels parallel
- up to 10 kHz each channel
- long terms
- startup shutdown
- harmonics and interharmonics
- flicker effects



Data - acquisition - system

Results

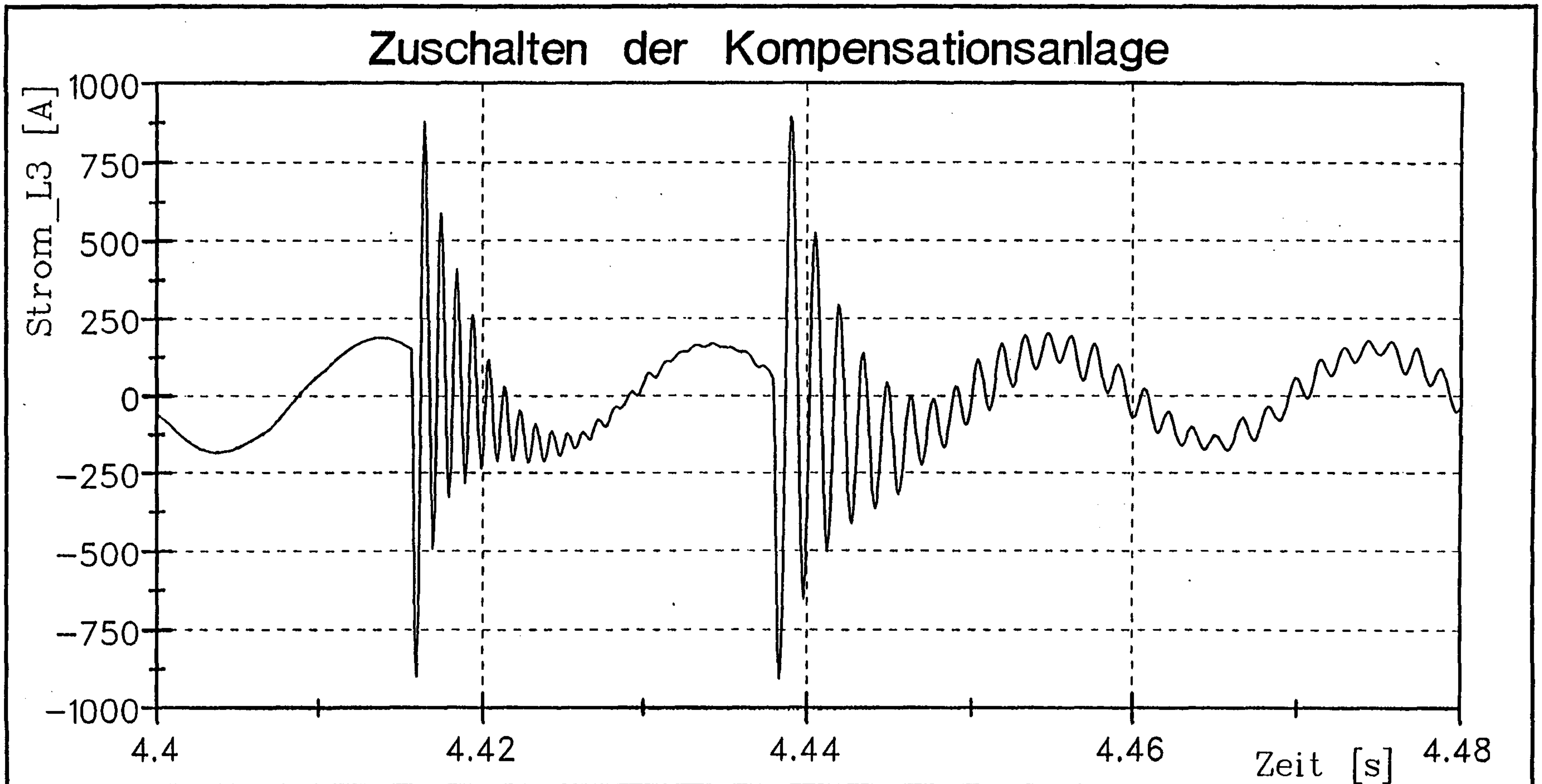
- flicker effects caused by the WEC at various operating conditions
- Analyse for harmonics and interharmonics up to 2500 Hz
- power peaks
- power factor of various operating conditions
- power fluctuations
- elapse of current and voltage at startup and shutdown
- voltage variations
- total harmonic distorsion
- analysing of single cycle and multicycle events



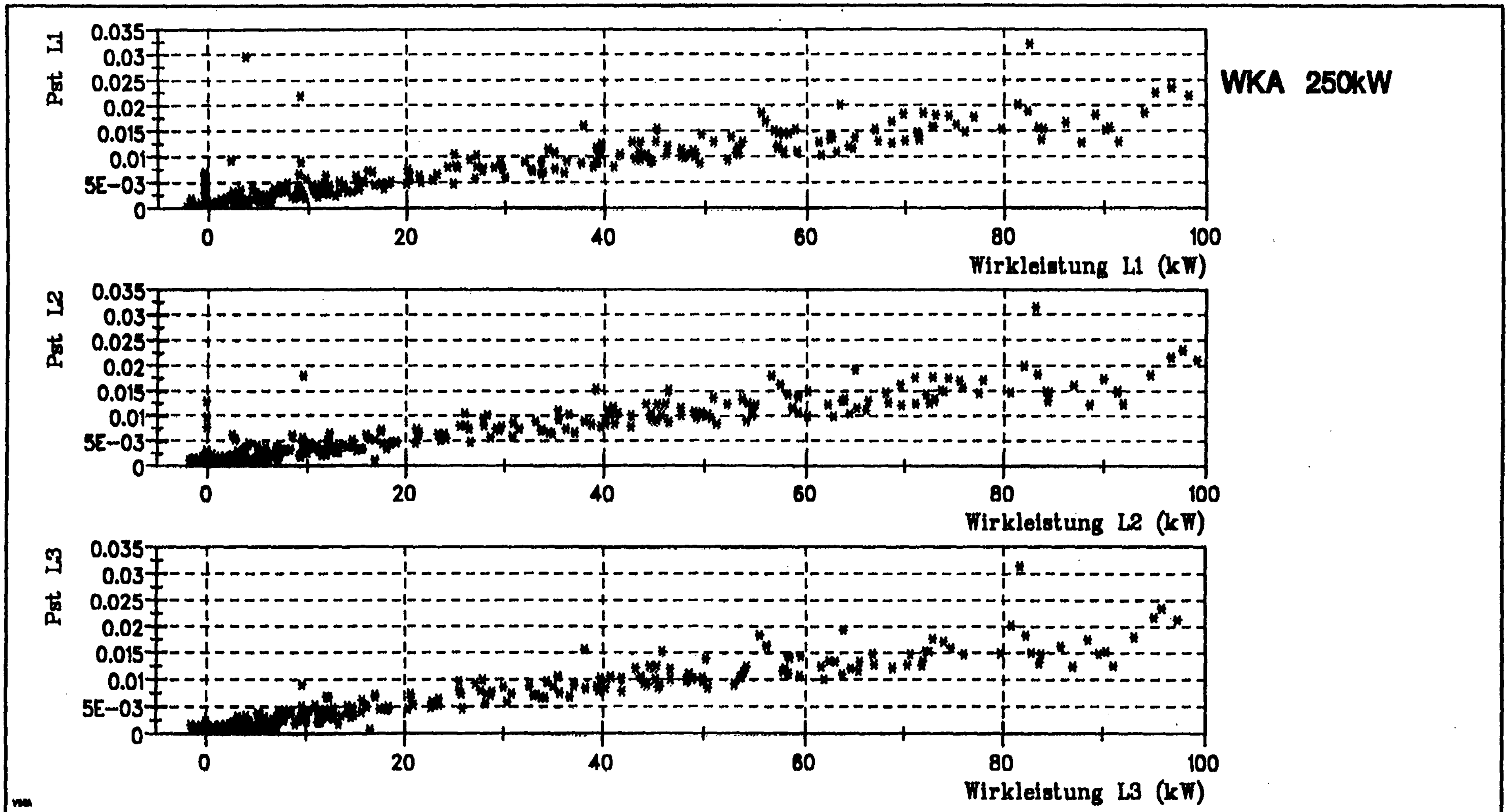
harmonics in a industial power system over 24 hours

Measurements of the effects upon the grid will be a condition for the subsidizing of the northern German states.

Figure 5 : Measurements of effects upon electrical grid



WINDTEST KWK GmbH	Anlagentyp:	XXXXXXXXXXX	Bearbeiter/Datum:	Köhne, 01.12.1993, 15:28:41
	Standort:	XXXXXXXXXXX	Quelldaten:	da93_f03.xxx
	Messart:	10 kHz, 3-phasig	Zieldaten:	da93_f03.xxx
	Messdatum:	13.10.1993	Name der Grafik:	

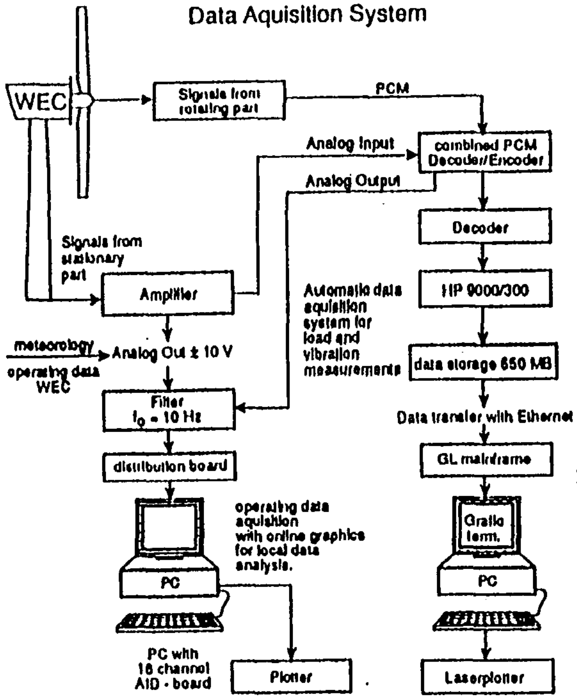


WINDTEST
Kaiser-Wilhelm-Koog GmbH

Flickerbewertung des Stromes durch DIFlim
Bemerkung: Strommeßfaktor 200, Spannungsmeßfaktor 70
Messung: 3xAußenleiter, MS SSf
Bearbeiter: J. Möller

Messzeitraum: 17.03 bis 28.03.94
Datenbasis: 527Hz
Originaldatei: sichern3
Werteanzahl: 418 Pst-Werte pro Außenleiter 08.04.1994 22:3

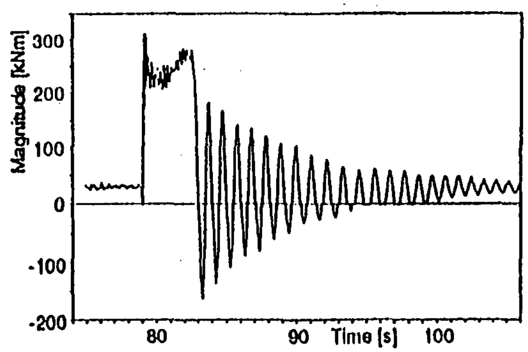
Data Aquisition System



Data to be measured:

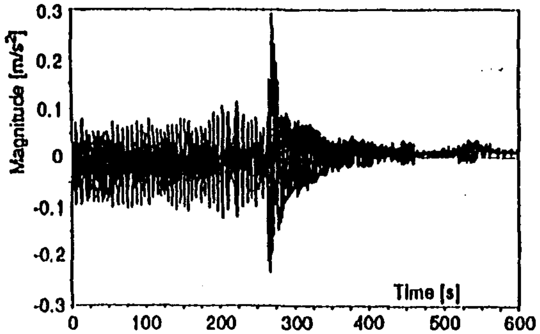
- Stresses, accelerations, displacements of the main parts e. g. rotor blades, hub, tower
- Meteorology
- Operating data WEC

Realtime data for different operating conditions of the WEC according to IEA.
Sampling rate: e. g. 350 Hz
Duration of each measurement: 600 sec
Number of channels recorded simultaneously: e. g. 60



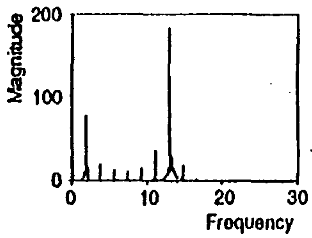
Torque in the rotor shaft of a WEC during emergency stop

⇒

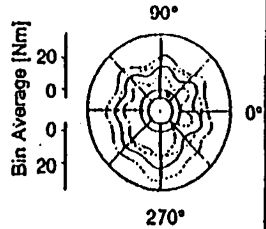


Accelerations of the nacelle during emergency stop

Results of load and vibration measurements
- Determination of the load spectrum for the main parts,
- Evaluation of the vibration behaviour of the WEC at different operating conditions,
- Monitoring of the system behaviour using realtime plots,
- Determination of maximum loads, e. g. at emergency stop,
- Check of the safety system.

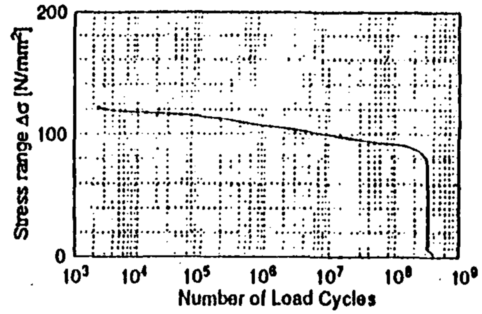


Frequency Analysis



Bending moments of a rotorblade over bladeposition

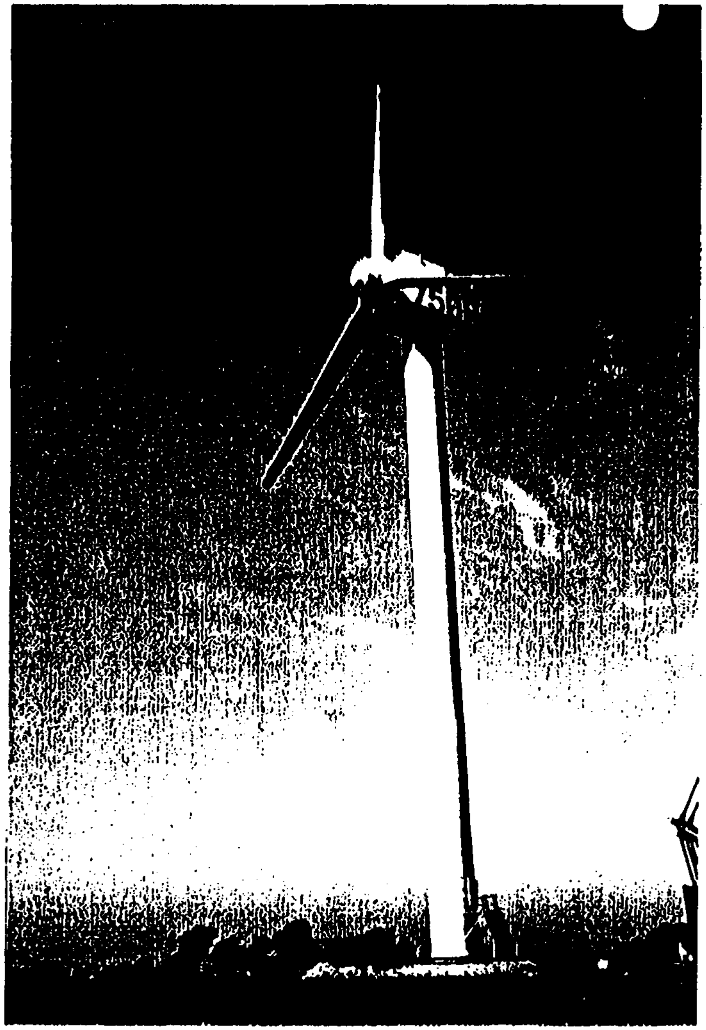
⇒



Load spectrum of a rotorshaft calculated from measurements, average windspeed 6.5 m/s, life time 20 years

Load and Vibration Measurements

R. Rohden



HSW 750

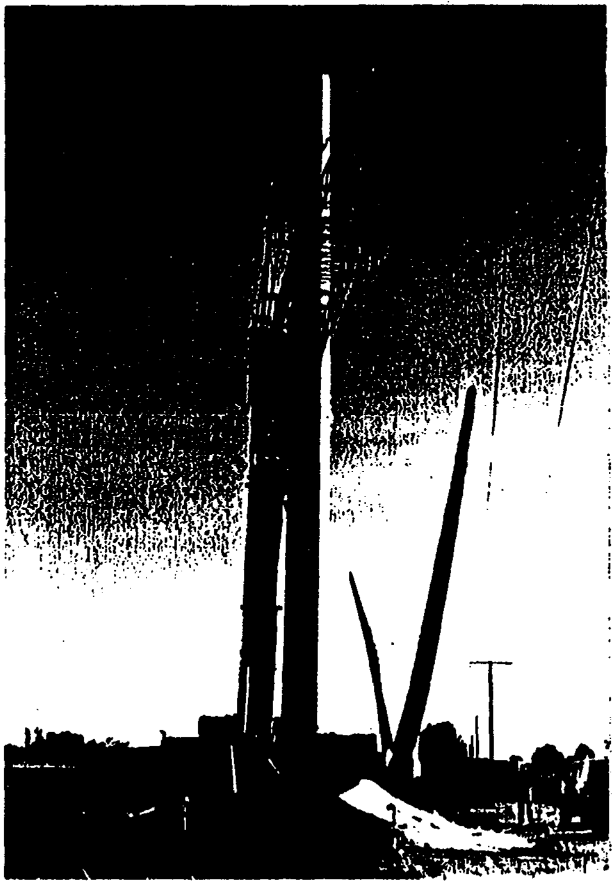
Technische Daten:

- Bauart: Dreiblättriger Luvläufer
- Betriebsweise: Blattverstellung
- Nennleistung: 750kW
- Rotordurchmesser: 46 m
- Nabenhöhe: 55 m
- Anlaufwindgeschwindigkeit: 5 m/s
- Abschaltwindgeschwindigkeit: 24 m/s

Testumfang:

- Betriebs- und Leistungscharakteristik
- Prototypentest

	Anlagenbeschreibung HSW 750	WEA 104



TACKE TW 600

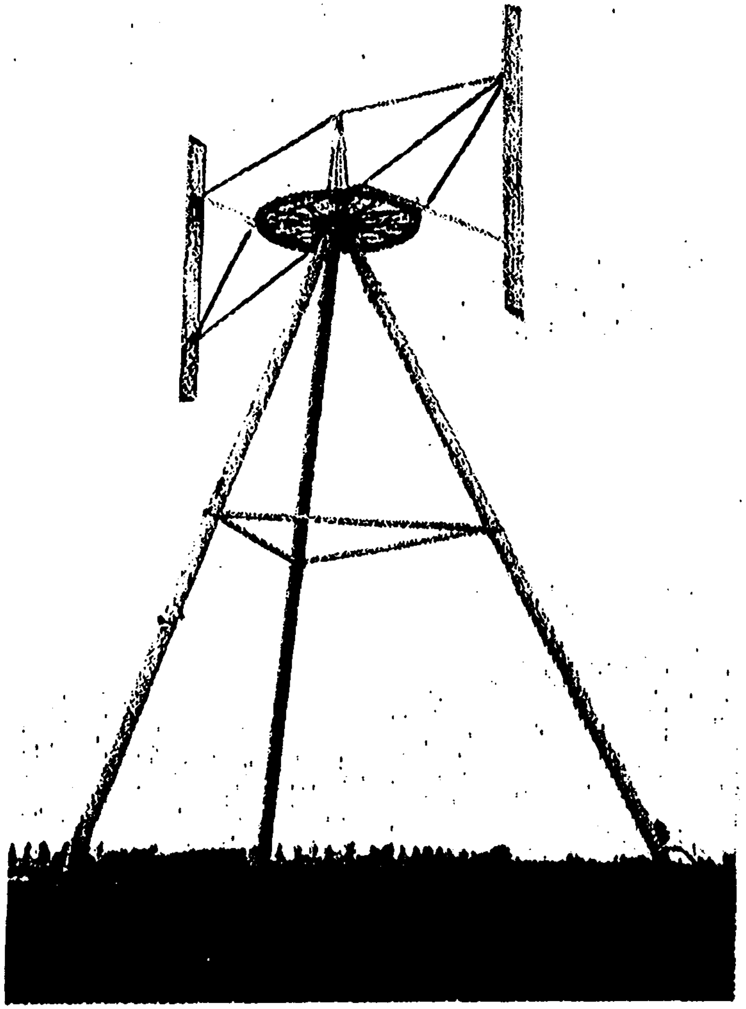
Technische Daten:

- Bauart: Dreiblättriger Luvläufer
- Betriebsweise: stall, polumschaltbar
- Nennleistung: 600/150 kW
- Rotordurchmesser: 43 m
- Nabenhöhe: 50 m
- Anlaufwindgeschwindigkeit: 3 m/s
- Abschaltwindgeschwindigkeit: 25 m/s

Testumfang:

- Betriebs- und Leistungscharakteristik

	Anlagenbeschreibung TACKE TW 600	WEA 108



Heidelberg H - Rotor 300

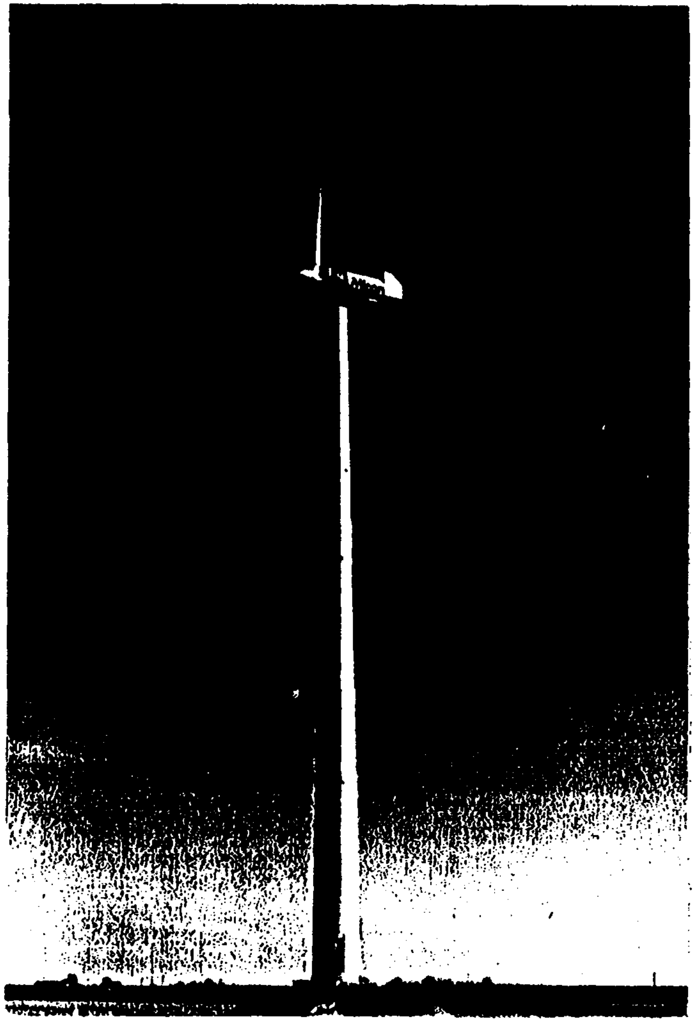
Technische Daten:

- Bauart:	Zweiblatt Vertikalachs - Rotor
- Betriebsweise:	Drehzahlvariabel, Gleichstrom-Zwischenkreis
- Nennleistung:	300 kW
- Rotordurchmesser:	32m (672 m² Rotorfläche)
- Nabenhöhe:	50 m
- Anlaufwindgeschwindigkeit:	3,5 m/s
- Abschaltwindgeschwindigkeit:	28 m/s

Testumfang:

- Betriebs- und Leistungscharakteristik
- Prototypentest

	Anlagenbeschreibung Heidelberg H-Rotor 300	WEA 109



MICON M1300-600/150 kW

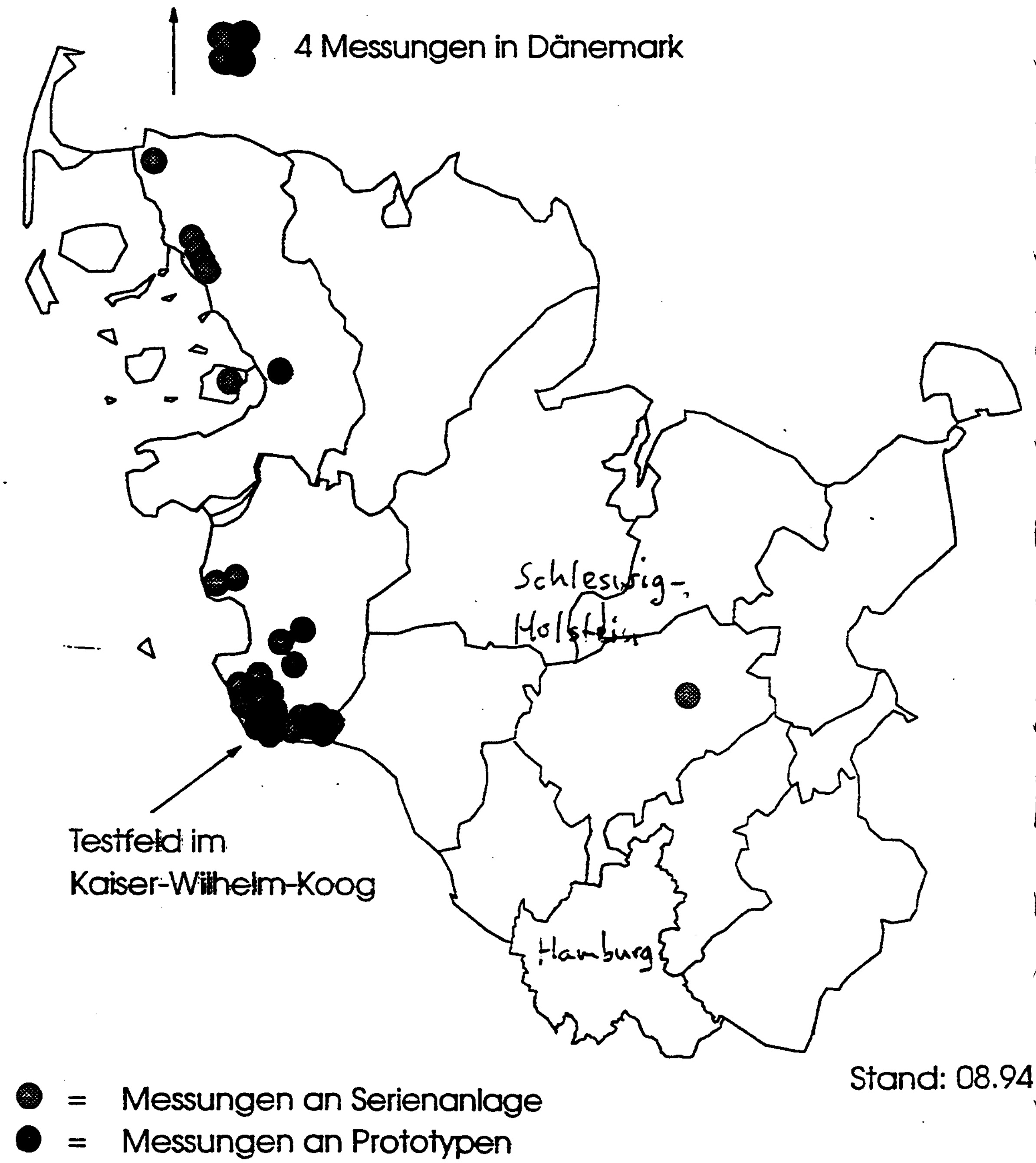
Technische Daten:

- Bauart: Dreiblättriger Luvläufer
- Betriebsweise: stall, polumschaltbar
- Nennleistung: 600/150 kW
- Rotordurchmesser: 41 m
- Nabenhöhe: 45 m
- Anlaufwindgeschwindigkeit: 3 m/s
- Abschaltwindgeschwindigkeit: 25 m/s

Testumfang:

- Betriebs- und Leistungscharakteristik

Anlagenbeschreibung MICON M1300-600/150 kW	WEA 107



Bearbeiter:
J. Clausen

Leistungskurvenvermessung bei WINDTEST

WEA 1[illegible]5

Wind Energy Converters in Western Europe
Technologies and Experiences at the German Test Station

Stephan Glocker
WINDTEST

Seminar on Wind Energy for Russia

EC-Energy Centre Moskow, 28th - 29th April 1994

Wind Energy Converters in Western Europe
Technologies and experiences at the German Test Station

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Tel: 04856/901-0, Fax: 04856/901-49

ABSTRACT:

Tests and experiments are of fundamental significance for Wind Energy Converters (WEC). This technology is still in the developmental stage, further essential progress is expected as a result of practical research. Appropriate test procedures and measurement campaigns are important for prototypes as well as for series produced WEC. The range of tests is including measurements of power performance, loads and vibrations, noise and grid effects. For Prototypes the tests can be carried out at the test station for WEC of WINDTEST at Kaiser-Wilhelm-Koog. Machines in a range between 0,8 and 750 kW with different concepts are installed at the most important German test station actually. The test procedures and the different concepts are shortly discribed in the following.

1. INTRODUCTION

During recent years wind energy has become an increasing commercial factor in Germany. In Schleswig-Holstein, where half of the German WEC-capacity (330 MW in 12'93) is installed, wind energy supplies the regional electrical consumption with about 3% overall. All WEC are connected to the grid. The main reasons for competitive production of electricity out of wind energy in the windy coastal areas are the promotion subsidies by the governments and the legal situation in Germany. Feeding into the grid is regulated by two important laws, which force the utilities at first to take electricity of private power plants to their grid and secondly to pay a good price for the energy out of renewable power plants (0,17 DM/kWh).

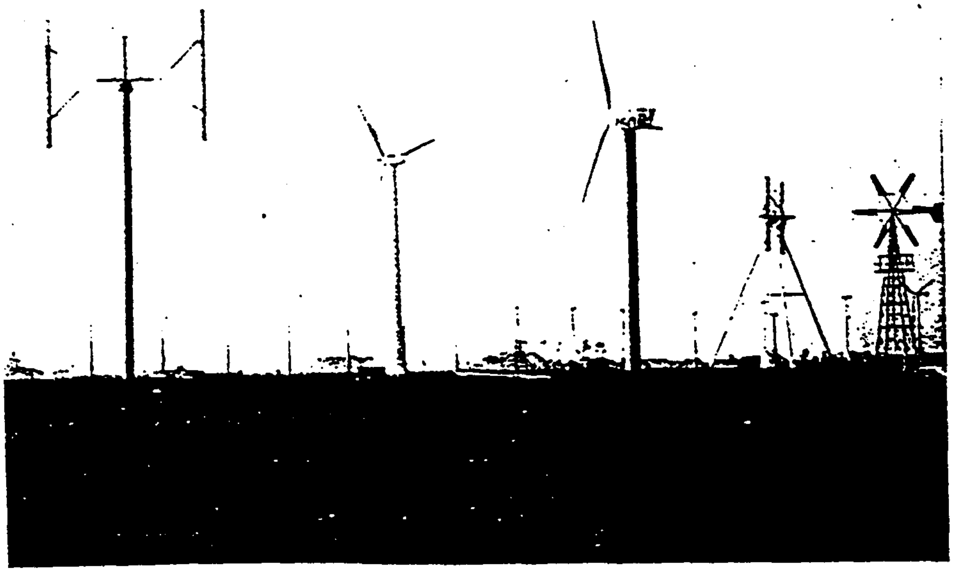
Therefore the significance of measurement campaigns on research and development has increased. On request of manufacturers and operators Germanischer Lloyd (GL) and WINDTEST Kaiser-Wilhelm-Koog GmbH (WINDTEST) carry out measurements on WEC with regard to effeciency, safety, static and dynamic strength, as well as noise emission and electrical characteristics. The results either confirm with the assumptions being made in the design calculations or lead to a modification of the design. This in turn has effects upon the costs and the quality of the product (e. g. service life, efficiency).

Some of these measurement campaigns are required for the application for subsidies from the governments of the coastal states of northern Germany. Power characteristics and sound pressure levels have a direct effect on the total amount of the financial support [4].

GL examines and certifies WEC according to the Society rules and/or standards and regulations at the site of operation. The Society supervises the manufacture, transport and construction commissioning of WEC as well as the testing of materials and components and operational testing. The complete certification procedure includes tests of WEC and periodical surveys [9][10].

A further application of measurements is to serve as an instrument for damage analysis for manufacturers and insurance companies. Measurements are not only used for verification, but do also furnish a proof of quality thereby serving as a sales argument.

Most of the tests are carried out on the test station at Kaiser-Wilhelm-Koog, which is operated by WINDTEST (see Picture 1).



Picture 1: Test station at Kaiser-Wilhelm-Koog, Germany

2. SCOPE OF TESTING FOR PROTOTYPES AND COMMERCIAL WEC

A usefull scope of testing covers the following individual measurement campaigns:

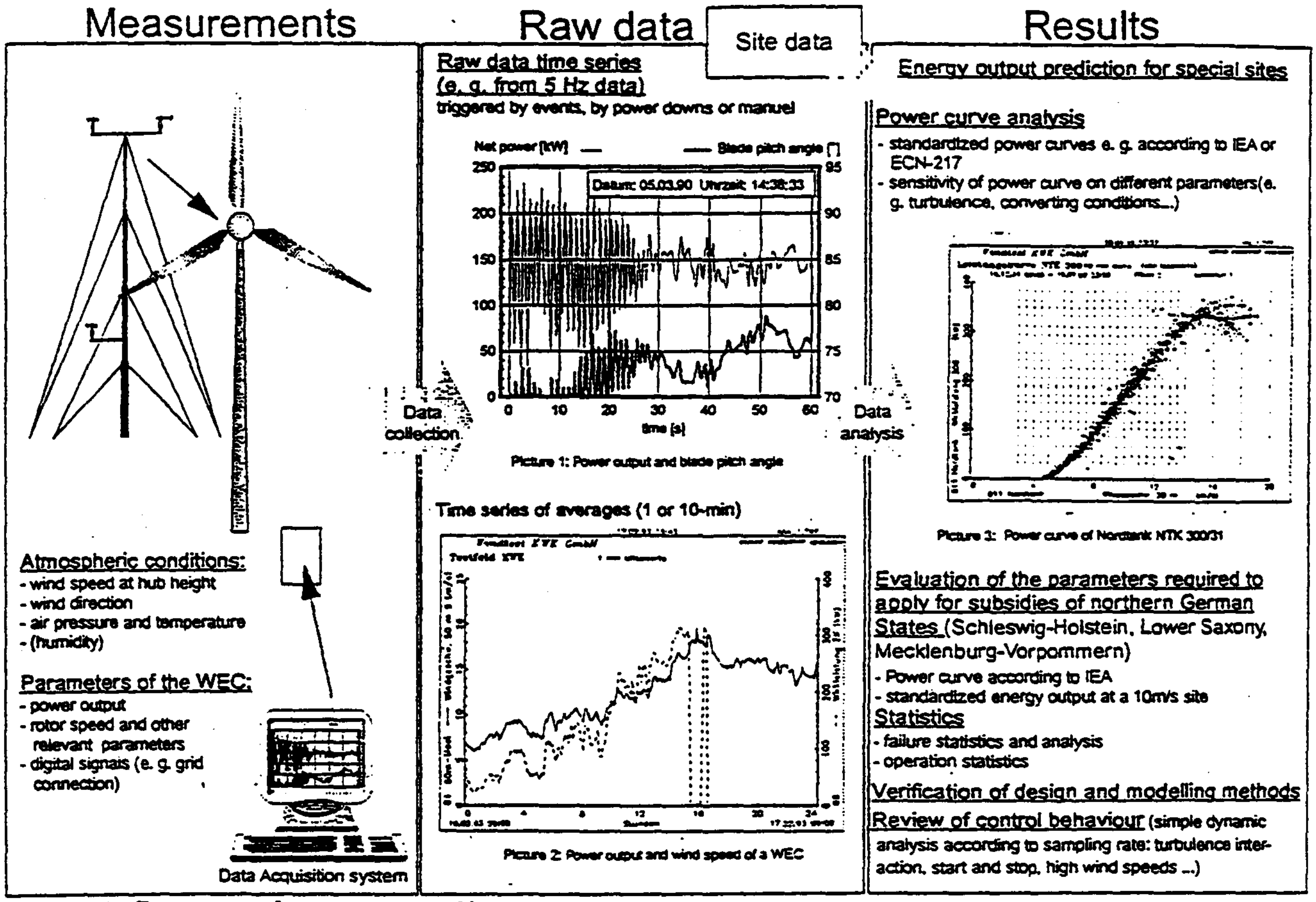


Figure 2: Power performance measurement procedure

- Power measurements including recording of service data
- Measurements of loads and vibrations
- Noise measurements
- Measurements of grid effects

During the period of concept realisation and design material and component tests are an important instrument for the verification of the design parameters. New concepts often are based on newly developed components such as rotor blades, generator systems or gearbox concepts. Some of the component tests can be carried out on test beds, but it is not guaranteed that the test conditions are realistic in all details. As a consequence component tests should be verified by measurements on prototypes.

During prototype testing one of the most important tasks is testing and evaluation of fatigue loads to confirm design assumptions. The optimization of noise emission and power performance is a main subject of WEC-tests and special measurement campaigns are required. Noise and grid effect measurements are carried out after all revisions and improvements of the prototype have been made.

For commercial and series produced WEC it is recommanded to perform the complete test procedure, because each certification, subsidizing and authorisation require parts of the measurements. In most cases changes of the WEC's concept or design lead to new examinations and approvals.

In Germany the northern coastal states Schleswig-Holstein, Lower Saxony and Mecklenburg-Vorpommern have defined special test procedures to be fulfilled before granting subsidies [4]. Power performance and noise measurements according to IEA-recommendations [1], [6] including measurements of effects upon grid are necessary. The subsidies directly depend on the quality of the

- power characteristics represented by the calculated energy output at a standardized site (5,5 m/s in 10 m height) and the
- noise emission represented by the area taken by the WEC where a sound pressure level of 55 dBA is being exceeded.

In addition to that measurements of the effects upon the grid will be obligatory in future, but these will not have any influence on the subsidies.

3. SPECIFIC MEASUREMENT CAMPAIGNS

3.1 Power performance measurements

Figure 2 is the overall view of the power performance measurement procedure including data collection, averaging and data analysis.

The procedure aims at measurement and evaluation of power curves for energy production calculation. The power curve is a graph which despicts the net power of a WEC as a function of the wind speed. The wind speed, measured at hub height, and other meteorological parameters are refered to the centre of the WEC-rotor assuming they were not disturbed by the presence of the turbine. This reference can only be taken at reasonable homogenious terrains having a minimum of influence on the wind sheer. Site calibration by flow modelling or experimental investigations should be used with care, because the required accuracy of the measurements hardly can be achived. All sensors should be of high accuracy. Especially anemometers have to be calibrated before and after the measurement campaign.

Depending on the sampling rate the time histories of the data can include informations about dynamic effects such as start and stop or effectiveness of the power controll system. Time histories can be triggered by different events. Data are reduced to minutes or 10 min-values and stored as pre-averaged times series.

The collected data have to be processed using using particular methods, e.g. the determination of the power curve according to different recommendations [1, 2, 3]. In case of sensor or system failures, grid variations and special meteorological conditions (e.g. wake effects on measurement tower or WEC, icing, high turbulence intensities and in some cases precipitation) the respective data sets can not be used for the determination of the power curve. The selected data shall be corrected to standard air density of 1.225 kg/m³ according to the recommendations. They are sorted using the "method of Bins". Depending on the recommendations a minimum of data sets for each bin is required. The data around cut-in and cut-out suffer from high uncertainties because of dynamic effects (e. g. hysteresis). These have a high impact upon the statistical determination of the power curve.

The time for the measurements required for a power curve depends largly on the environmental conditions of the site. Different campaigns have shown that it usually takes about three to eight weeks to complete a power curve e.g. at Kaiser-Wilhelm-Koog.

It is important to present the results immediately, preferably during data collection. WINDTEST is working on a new measurement system which will show specific evaluations online.

The power performance measurement procedure of WINDTEST is accredited according to DIN EN 45 001 since 1992.

3.2 Load and vibration measurements

In cooperation with WINDTEST GL carries out load and vibration measurements on the test station at Kaiser-Wilhelm-Koog during prototype testing.

As it is shown on the flow chart of the data aquisition system (see figure 3) the PCM (Pulse Code Modulation) method is used within these measurements. This method enables a safe data transfer from the rotating part of the WEC as well as a simultaneous data aquisition of many channels with high sampling rates.

For the data aquisition a software was developed by GL, which carries out measurements according to the IEA-Recommendations [5] in automatic operation.

The measured data are transfered to the GL-mainframe computer, where software for an efficient evaluation of extensive data files is available.

The reasons for and results of the load and vibration measurements (short term measurements) can be summarized as follows:

- Determination of the load spectrum for the main components in order to carry out calculation of expected lifetime, check of the design and comparison with the calculations
- Vibrational behaviour of the WEC at different operating conditions in order to find resonant frequencies if present
- Monitoring of the system behaviour using realtime plots e. g. to optimize the control system
- Determination of the maximum loads for the main components, e. g. at emergency stop
- Check of the safety system

3.3 Noise measurements

Noise emission of WEC is an essential topic for the introduction of wind energy. The noise emission of WEC is determined according to the IEA method [6]. The continues A-weighted sound pressure level (L_{Aeq}) has to be measured in five positions around the WEC.

All measurements have to be carried out with a microphone which is flush-mounted on a hard board upon the ground

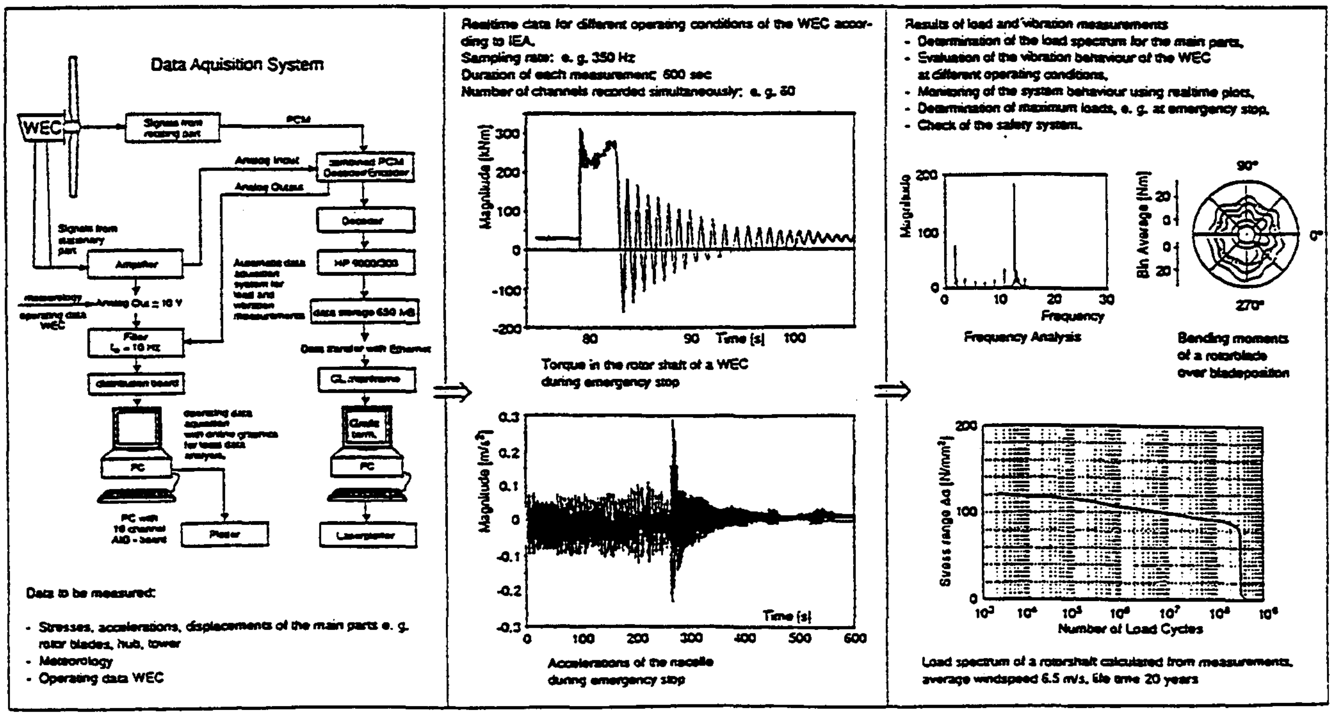


Figure 3: Load and vibration measurements

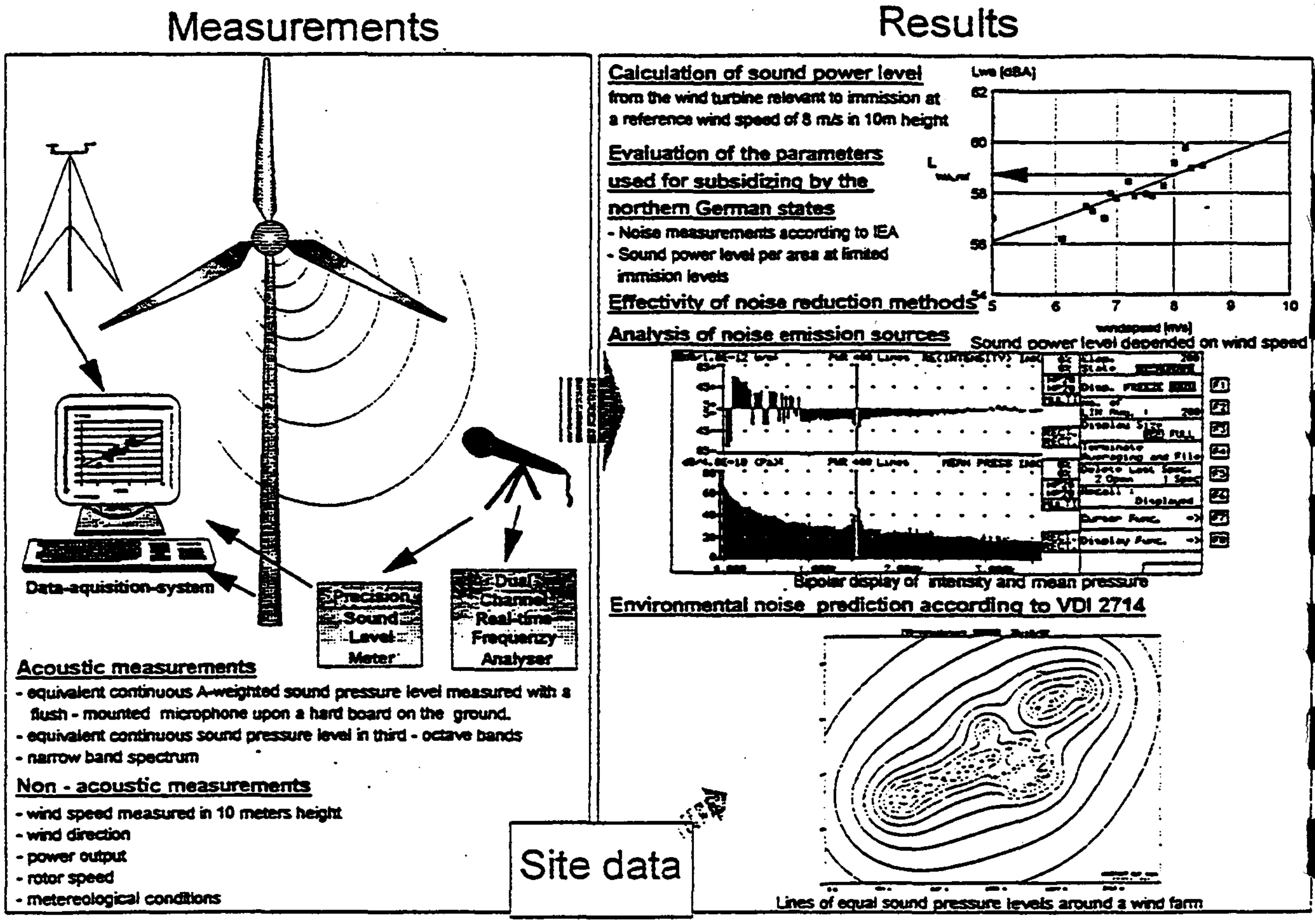


Figure 4: Acoustic measurements

(see figure 4). The wind speed during the measurements should be in the interval of 5 to 10 m/s in a height of 10 m. The results in downwind direction are used for determining the relevant sound pressure level. A picture in Figure 4 shows the relation between the noise emission and the wind speed measured 10 m above ground together with a narrow-band frequency spectrum.

Based on measured sound pressure levels at different WEC, WINDTEST evaluates predictions of the environmental noise for locations and compares those to the limitations in the surrounding. After the erection, measurements are carried out to verify the predictions.

3.4 Measurements of effects upon electrical grid

Usually WEC are connected to the grid of the local utility. In some circumstances this can affect applications connected to the grid.

The main affects are flicker, harmonics and disturbances caused by start up and shut down. To examine a WEC with respect to this, measurements will be set up at the connection point to the grid. With these measurements information will be obtained to decide whether a WEC has neglectable effects upon the grid or not.

Currents and voltages at the power connection point have to be measured. Depending on the signals the different effects can be analysed. The evaluation of harmonic distorsion and flicker effects demands long-time measurements, while the measurement of start up and shutdown requires short-time measurements with a high sampling rate. An overview about the measuring procedure is shown in figure 5.

4. TEST STATION AT KAISER-WILHELM-KOOG

The test station at Kaiser-Wilhelm-Koog is operated by WINDTEST. At that place the manufacturers have the opportunity to operate their prototypes under good conditions and to get them tested and measured by an specialised and independent authority. At excellent wind regime the permission procedure is very easy in comparison to commercial sites. The placements are prepared with universal foundations, grid connection and measurement system for easy installation. The infrastructure of the test station is shown in picture 6. The electricity feeds into the grid of SCHLESWAG, the electrical utility of Schleswig-Holstein.

The work at the test station started in 1989 with smaller WEC, using former GROWIAN-infrastructure. In 1990 8 machines were installed with a rated power between 1,5 and 100 kW, most of them have been tested in not grid connected versions e.g. for underdeveloped countries. As the size of the WEC increased, the test station expanded to machines up to 750 kW. At the moment 7 machines with 2000 kW in all are in test.

The Atlantis WB15 is the smallest test machine. A photovoltaic panel and a wind generator charge a batterie which can supply small consumers such as measurement or relais stations.

Sterne 60 from GERB with a rated power of 60 kW is a pitch-regulated two bladed downwind operating WEC. The blades are mase from wood, the hub is teedered.

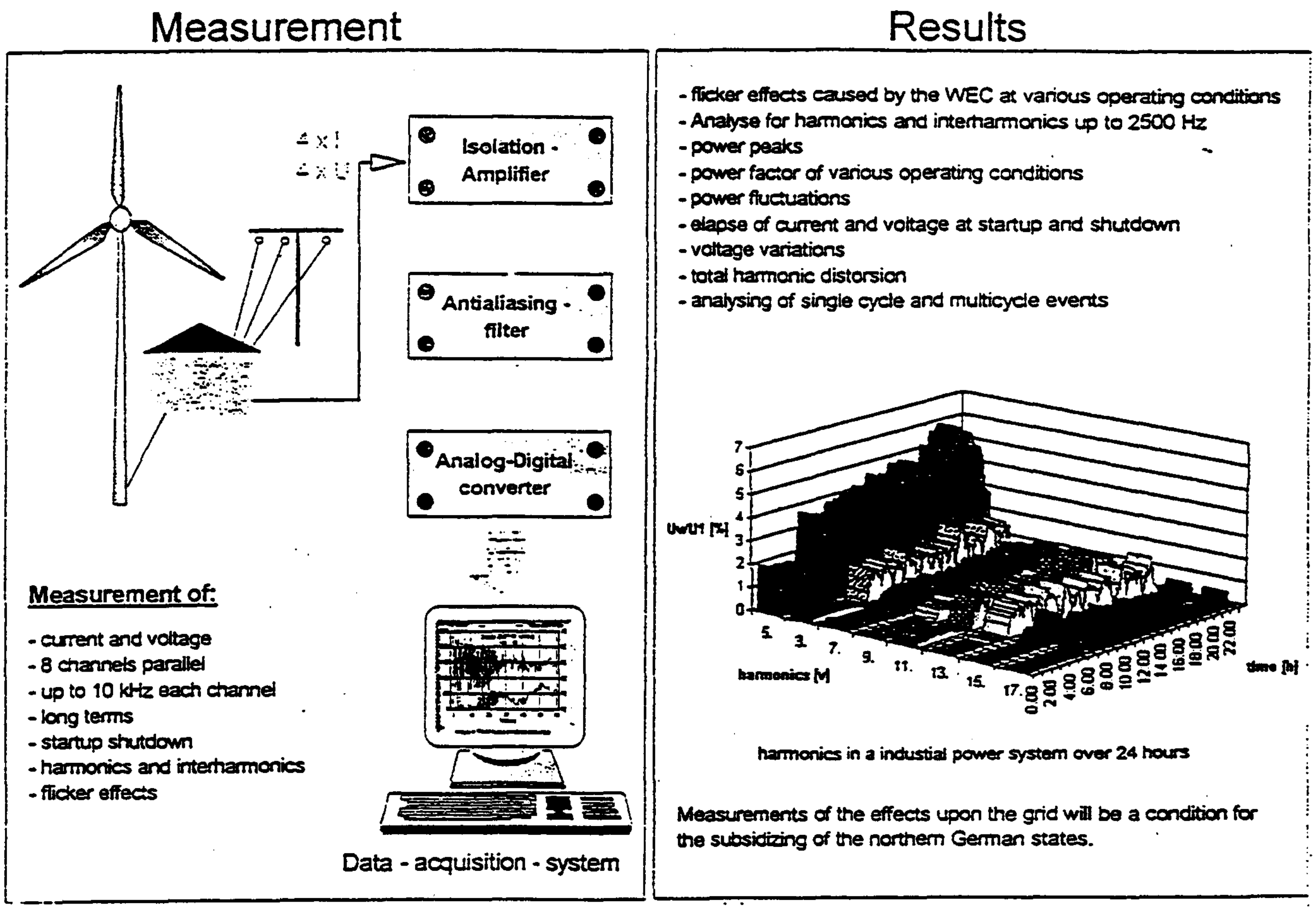


Figure 5: Measurements of the effects upon the electrical

The HMW670 from Heidelberg Motor is a gearless vertical axis construction (H-Darrieus). It has a rated power of 300 kW, a hub height of 50 m and a rotor area of 670 m². The generator system is a walking field generator in combination with a grid induced AC-DC-AC converter system. The first series produced machines are now installed near the test station at the moment.

The AEV 41/500 is a stall regulated WEC with a gearbox integrated into the hub. With a hub height of 40 m, a diameter of 41 m the turbine can operate in two rotational numbers (150 and 500 kW).

Since 1993 the prototype of the HSW 750 of Husumer Schiffswerft is installed. With 46 m diameter and 750 kW this is the biggest machine before series production at the moment. The generator is connected to the gear box by a fluid coupling system.

As test sites are all occupied at the moment other sites have been found near the test station. A Danish made Micon 600 prototype with 600 kW and 43 m diameter and a German Tacke TW600 with similar dimensions are under test outside the test station. Both are from the commercial view very interesting concepts, at a good site as Kaiser-Wilhelm-Koog is they produce more than 1 500 000 kWh a year.

The adresses of the manufacturers of test machines are:

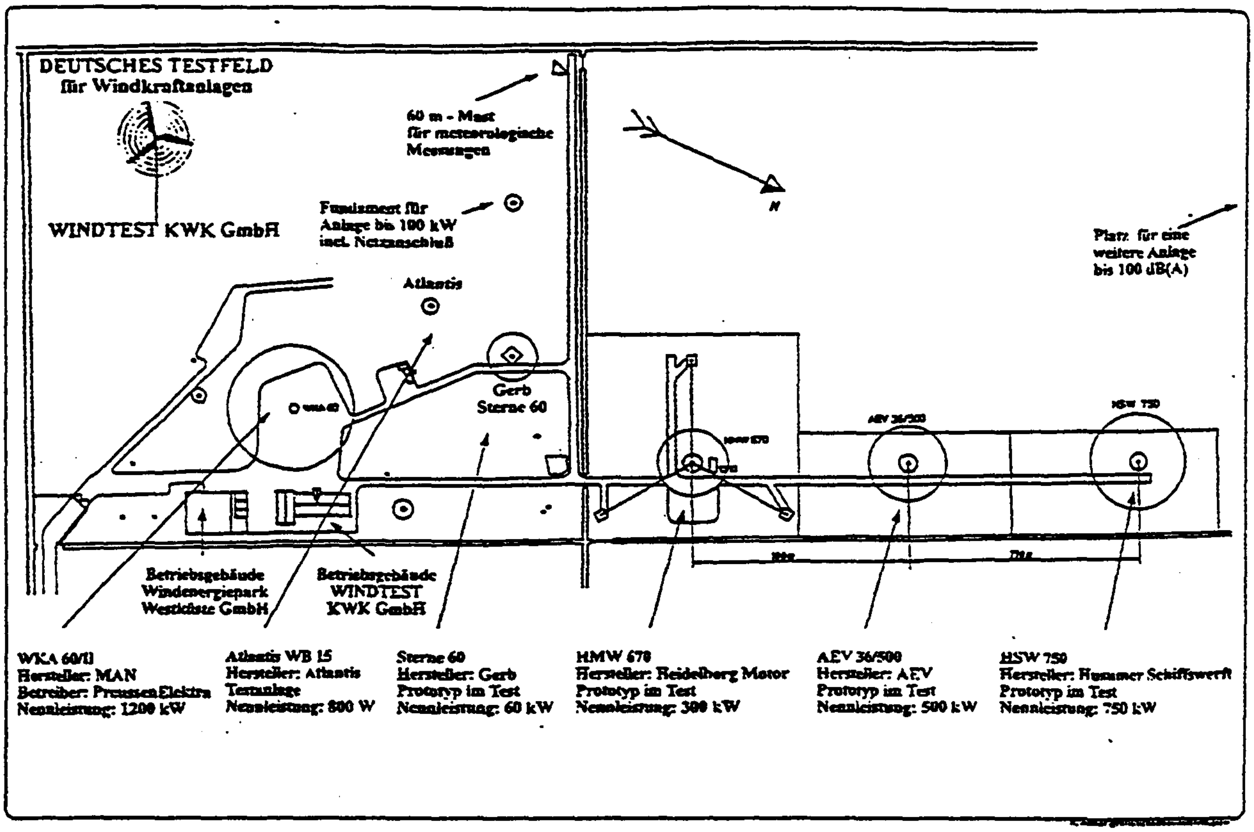
- AEV Windkraftanlagenbau GmbH, Westerbreite 7, 49084 Osnabrück, Germany.
- Atlantis gGmbH, Glogauer Str. 19-21, 10999 Berlin, Germany.
- GERB Gesellschaft für Isolierungen mbH & Co.KG, Postfach 510230, 13362 Berlin, Germany.
- Heidelberg Motor GmbH, Petersbrunner Str. 2, 82319 Starnberg, Germany.
- Husumer Schiffswerft GmbH, Postfach 1320, 25803 Husum, Germany.
- Micon, Milkovvej 8, DK-8900 Randers Helstrup, Denmark.
- Tacke Windtechnik GmbH&Co. KG, Postfach 1261, 48497 Salzbergen, Germany.

5. CONCLUSION

WEC are from the technical point of view very complicated machines. Due to of commercial and reliable production of electrical energy a lot of efforts in research and development have been done and still remain essential.

Therefore a test station is an important factor for the development of WEC. A test station should be located in a windy region, so that the tests can be worked out quickly and the operation of the prototypes is realistic in any way. The infrastructure must obtain grid connection, measurement systems, meteorological towers and foundations which can be adapted to the WEC.

The measurement campaigns have to be worked out in detail for each machine, the measurement procedures should be conform with international standards. A usefull scope of testing procedures for prototypes includes measurements of loads, vibrations, power performance, noise and the effects upon electrical grid. Series produced WEC can profit from tests carried out on the prototype, if they have not been modified.



Picture 6: Ground-plan of the test station at Kaiser-Wilhelm-Koog (04'94)

The most economical size of WEC is at the moment between 450 and 750 kW rated power. Therefore the rotor-diameter is between 36 and 46 m, the hub height is between 40 and 55 m.

New concepts of WEC tested at Kaiser-Wilhelm-Koog with good chances of effort are:

- Vertical axis wind turbines with a direct driven walking field generator
- using AC-DC-AC-converter systems for grid connection, preverable with grid feeding by pulse-width-modulated converter
- vibrational isolation of components or the complete nacelle for noise reduction
- gearless generating systems
- more flexible rotational speed of asynchronious generator systems by using of fluid coupling
- combination of wind and solar energy for small consumers without grid connection
- combination of WEC and diesel generator (e.g. H-Rotor 20 by Heidelberg Motor GmbH tested for Antarctic)

Other tasks of WINDTEST outside the tests are consulting of utilities, government, planers and manufacturers due to wind regimes, noise impact, park efficiency and economy.

6. REFERENCES

[1] IEA Recommended Practices for Wind Turbine Testing and Evaluation, 1. Power Performance Testing, 2. Edition 1990.

[2] Recommendation for Wind Turbine Power Curve Measurements, Technical Requirements for Type Approval and Certification of Wind Turbines in Denmark.

[3] ECN-Recommendations for a European Wind Turbine Standard on Performance Determination (ECN-217).

[4] Technische Richtlinien zur Bestimmung der Leistungskurve, des Schalleistungspegels und der Netzverträglichkeit von Windkraftanlagen, Deutsches Windenergieinstitut GmbH, WINDTEST Kaiser-Wilhelm-Koog GmbH, Rev. 4 from 03.12.93.

[5] IEA Recommended Practices for Wind Turbine Testing and Evaluation, 3. Fatigue Loads, 2. Edition 1990.

[6] IEA Recommended Practices for Wind Turbine Testing and Evaluation, 4. Acoustic Measurement of Noise Emission from Wind Turbines, 2. Edition 1988.

[7] S. Glocker u. a., Test Procedures for Prototypes and Machineries of Wind Energy Converters produced in Series, ECWEC Lübeck-Travemünde 1993.

[8] S. Glocker, B. Richter, Testfeld für Windkraftanlagen in Kaiser-Wilhelm-Koog, Windenergietage Husum 1993.

[9] Germanischer Lloyd, Regulation for the Certification of Wind Energy Conversion Systems, 1993 Edition.

[10] B. Richter, Germanischer Lloyd, Prüfung und Zertifizierung von Windkraftanlagen (paper in Russian language)

Noise Testing

Helmut Klug
DEWI

IMTS '94

DEWI-Measurement-Activities

— Power-Performance

— -Anemometry-

— SODAR-Meteorology

Load Spectra

— Acoustics

Power Quality

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DEWI-Measurement-Activities

Power-Performance

-Anemometry-

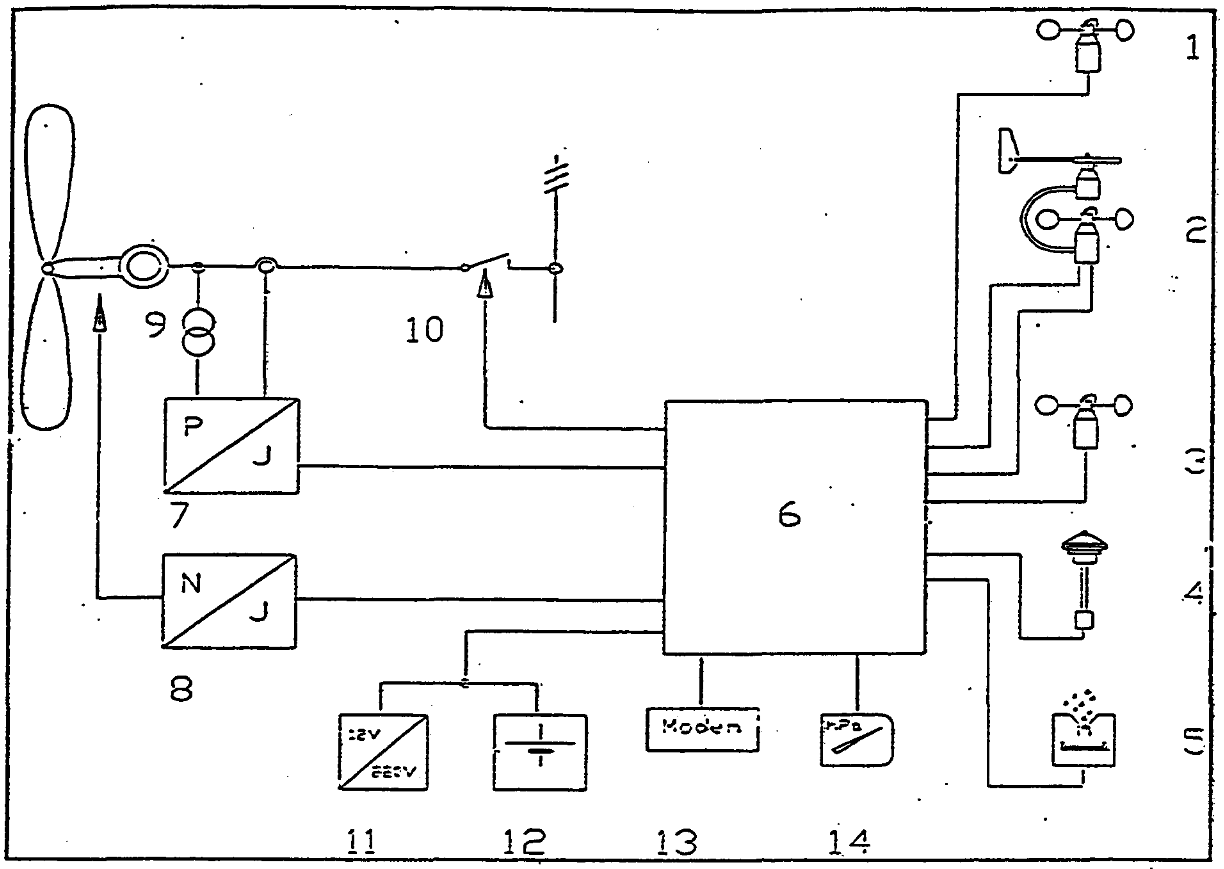
SODAR-Meteorology

Load Spectra

Acoustics

Power Quality

Data Acquisition System



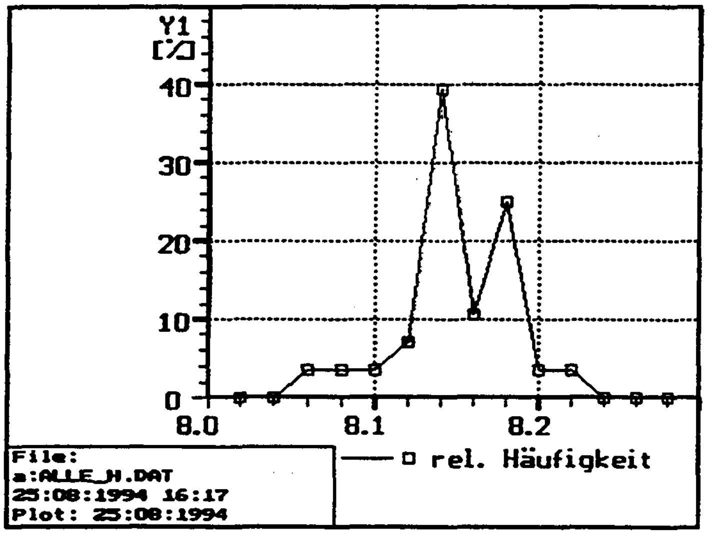
1. Wind speed at hub height
2. Wind direction and reference wind speed (1.5 m below hub height)
3 Wind speed at 10 m height
4. Temperature
5. Precipitation
6. Datalogger
7. Powerconverter
8. Rotorspeedconverter
9. Voltagetransformer
10. Status
11. Power Supply
12. Power Supply
13. Modem
14. Barometric Pressure

3. Statistical Analysis

3.1 Reproducability

Date	a	b	m/s (150 1/s)	%
08.03.93	0.04880	0.350	8.16	-
09.03.93	0.04870	0.340	8.13	- 0.4
06.04.93	0.04862	0.373	8.15	- 0.1
30.04.93	0.04835	0.428	8.16	0
18.01.94	0.04828	0.425	8.15	-
05.03.94	0.04814	0.430	8.13	- 0.2
24.03.94	0.04773	0.490	8.13	- 0.2
04.05.94	0.04852	0.364	8.13	- 0.2
08.07.94	0.04864	0.406	8.19	- 0.5

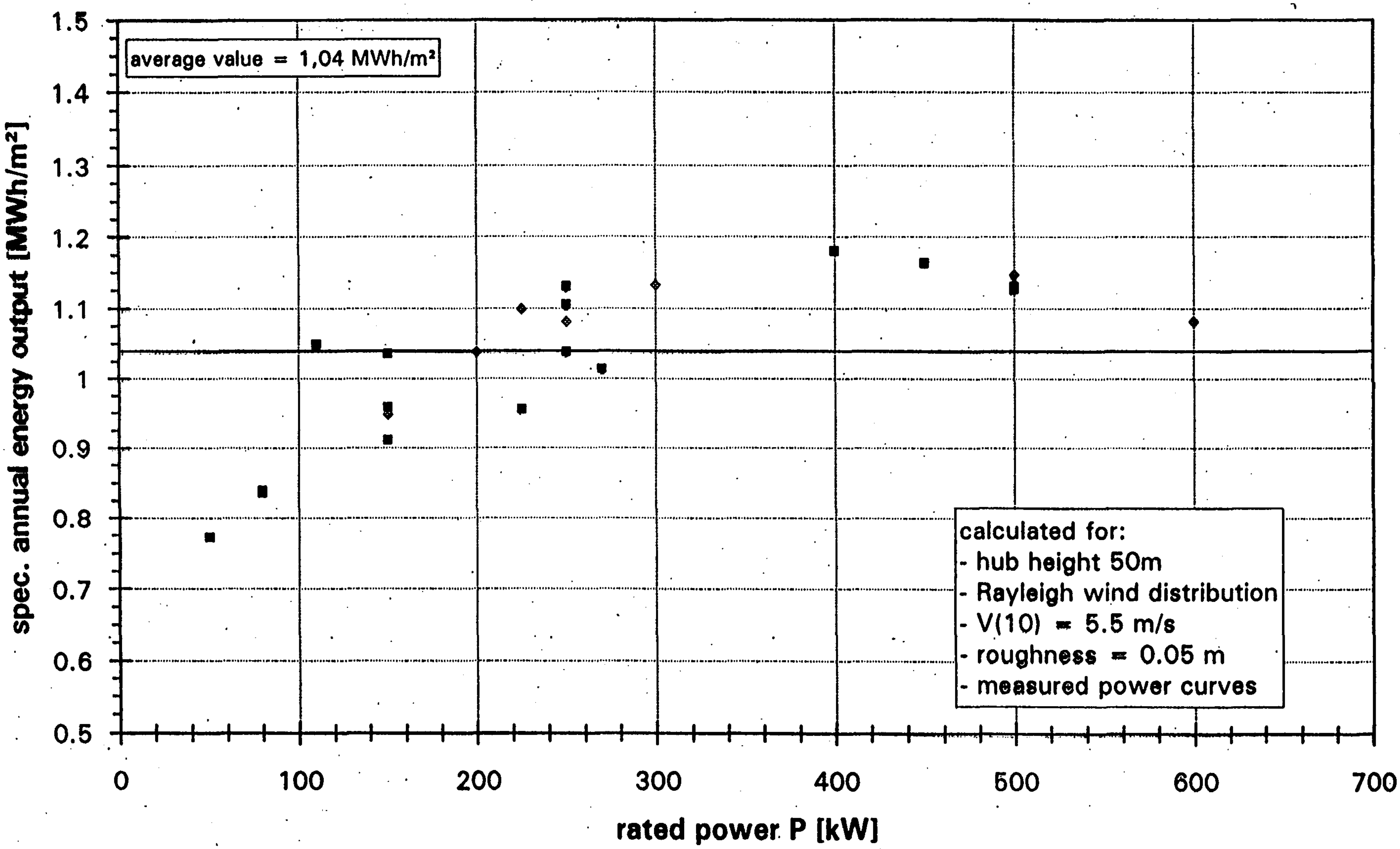
Tab. 12 Reproducability of 5 calibrations for two anemometers. The last calibration (08.07.94) was done with a different pitot tube.



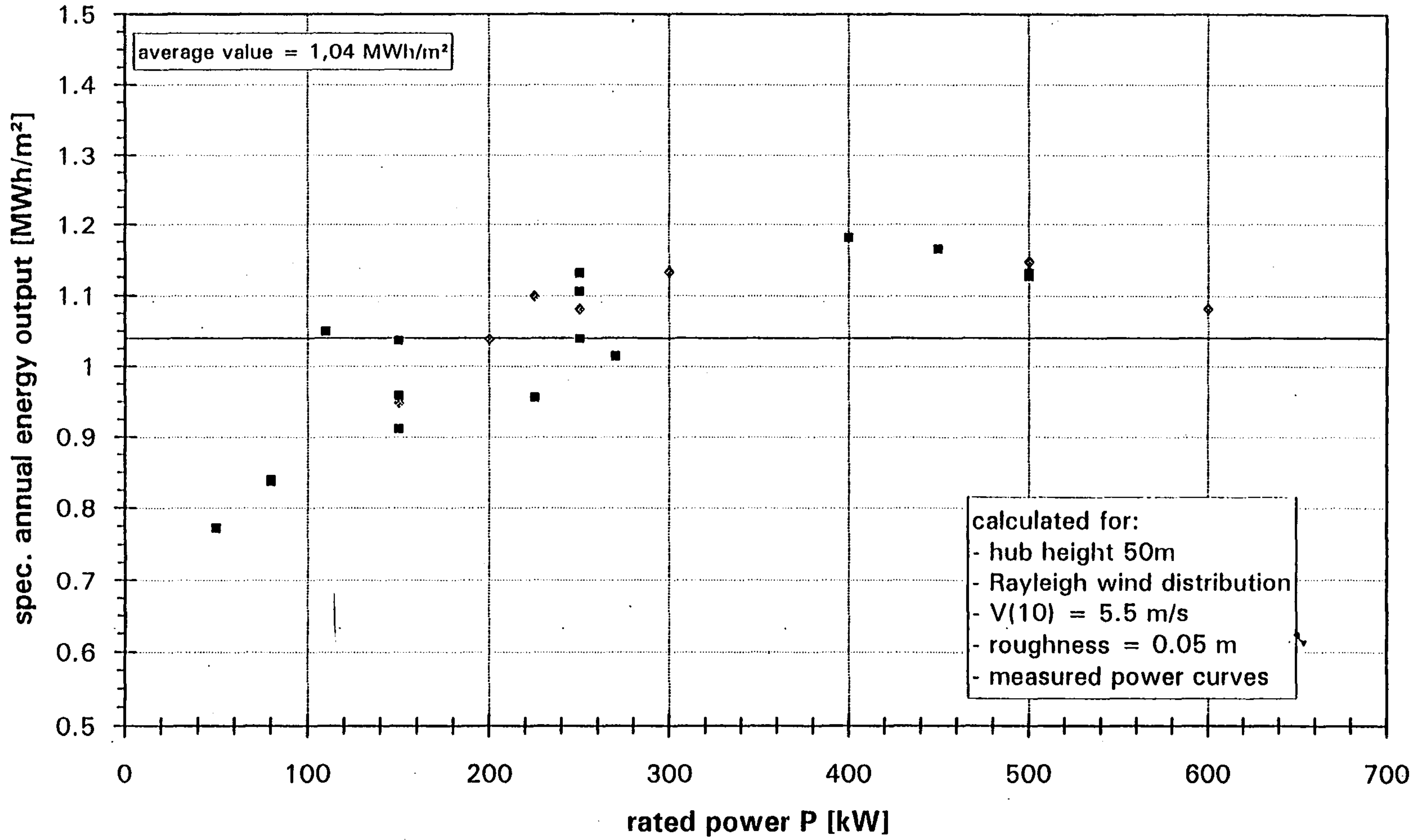
Klasse	Häufigkeit
8.02	0.00 %
8.04	0.00 %
8.06	3.57 %
8.08	3.57 %
8.10	3.57 %
8.12	7.14 %
8.14	39.29 %
8.16	10.71 %
8.18	25.00 %
8.20	3.57 %
8.22	3.57 %
8.24	0.00 %
8.26	0.00 %
8.28	0.00 %
8.30	0.00 %

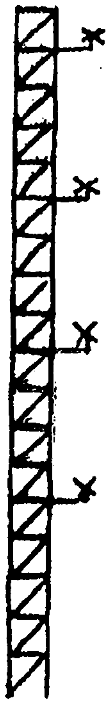
Datei:	a:\alle.dat
Kanal:	1
Datensätze:	28
Mittelwert:	8.15
Sigma:	0.03
Maximum:	8.21
Minimum:	8.06

Fig Frequency distribution of 28 DEWI anemometer calibration results at 160 Hz. The average is 8.15 m/s with an standard deviation of 0.0 3 m/s.

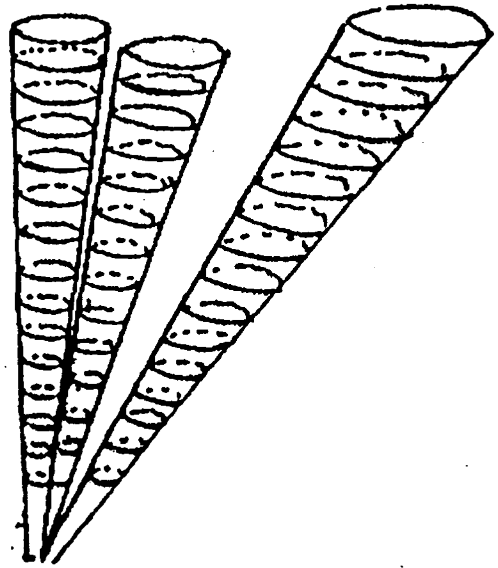


average value = 1,04 MWh/m²
calculated for:
- hub height 50m
- Rayleigh wind distribution
- V(10) = 5.5 m/s
- roughness = 0.05 m
- measured power curves
spec. annual energy output [MWh/m²]
rated power P [kW]
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0
100
200
300
400
500
600
700

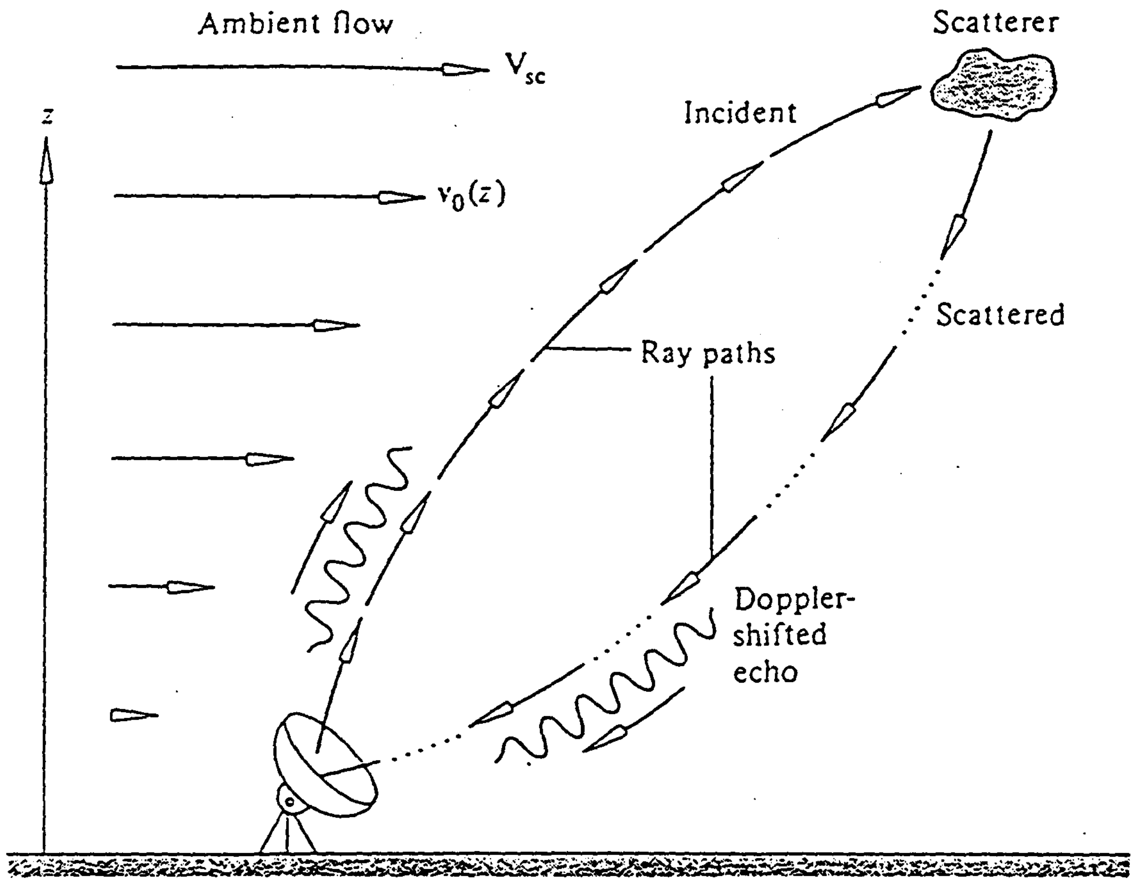

average value = 1,04 MWh/m²
spec. annual energy output [MWh/m²]
rated power P [kW]
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0
100
200
300
400
500
600
700
calculated for:
- hub height 50m
- Rayleigh wind distribution
- V(10) = 5.5 m/s
- roughness = 0.05 m
- measured power curves

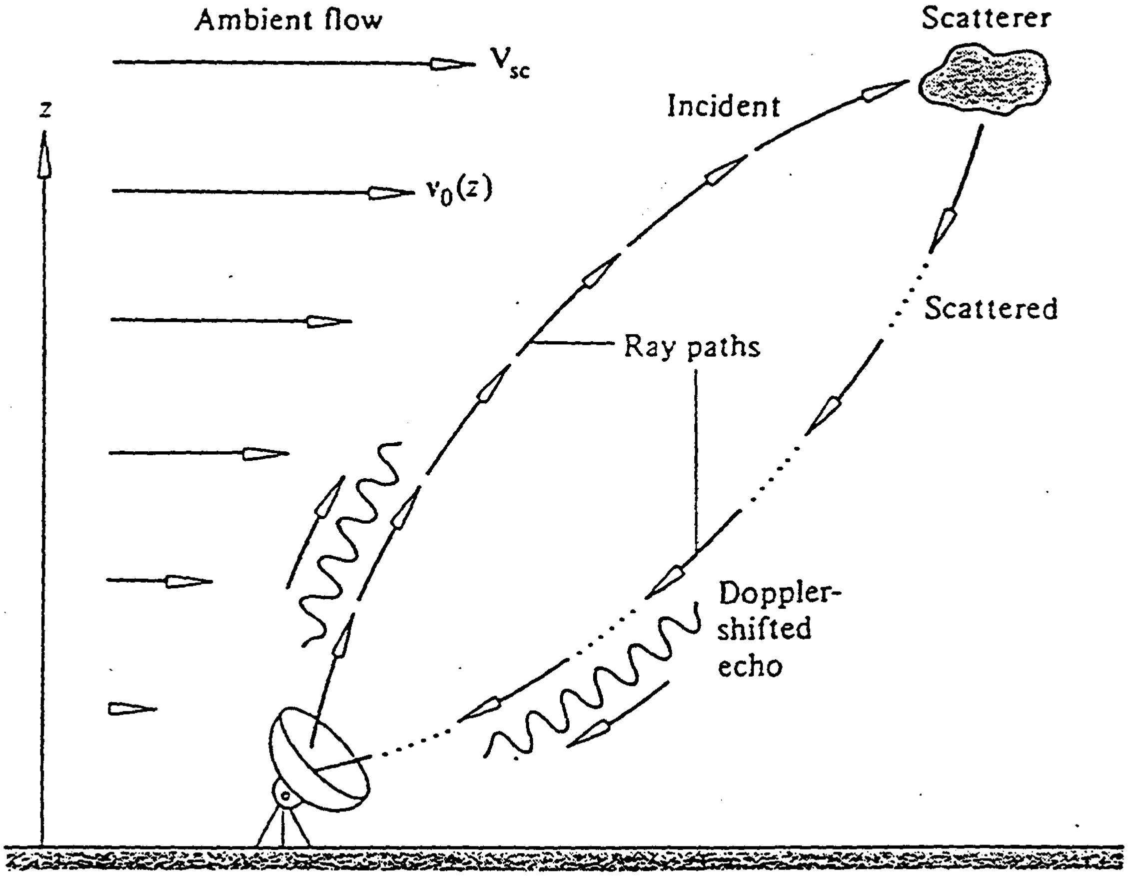


Requirement	Mast	Sodar
measurement place	fixed if erected	mobile
flow field	influences free flow	remote measurement no flow distortions
height range	10-30 m above very expensive	10-200 m
height resolution	5-20 m (increasing costs with incr. resolution)	1-10 m
time resolution	1-20 Hz	0.1-1 Hz

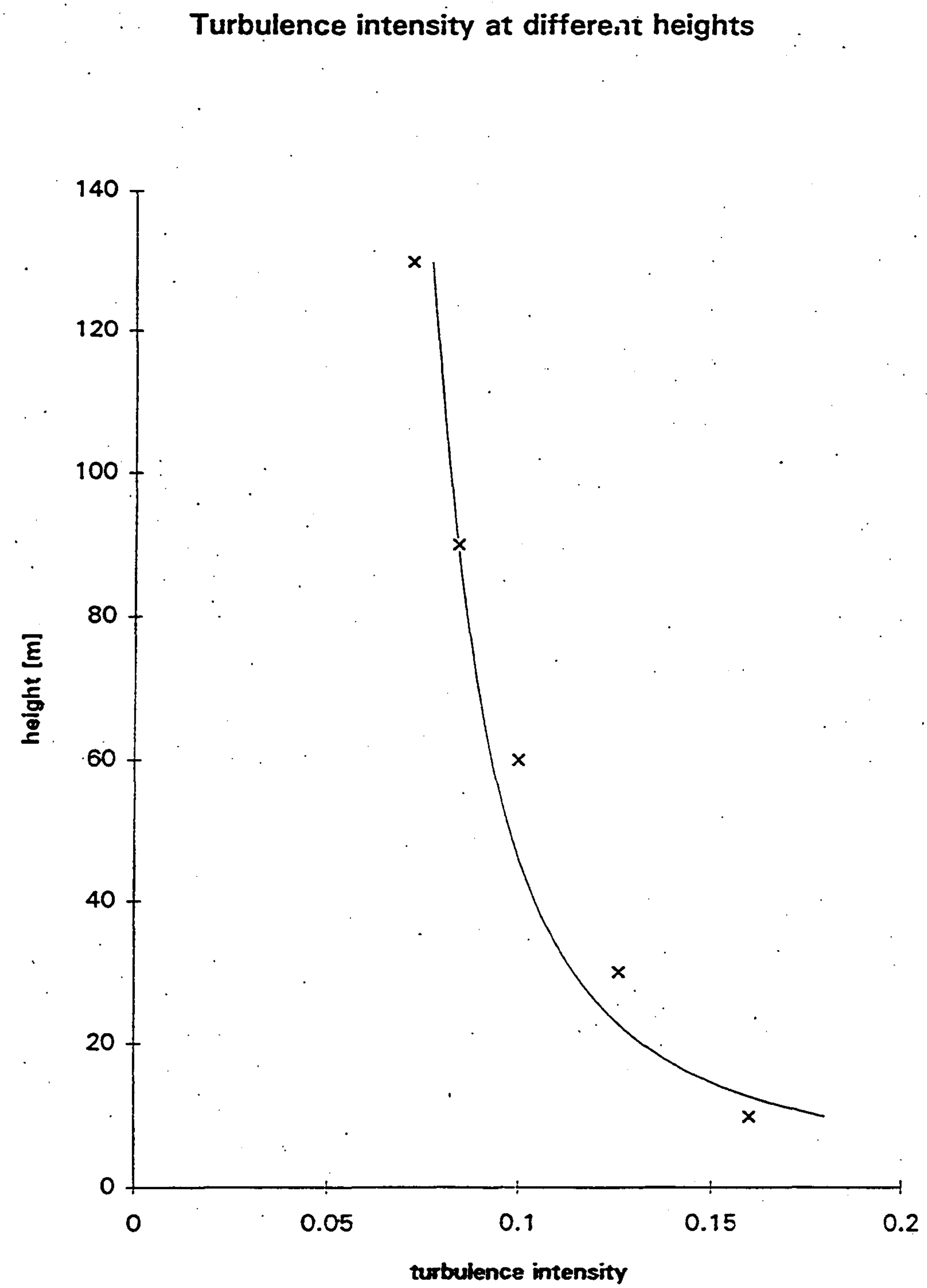


Comparison Meteorological Mast - SODAR


Ambient flow
V_{sc}
Scatterer
Incident
z
$v_0(z)$
Scattered
Ray paths
Doppler-
shifted
echo


Ambient flow
V_{sc}
Scatterer
z
Incident
$v_0(z)$
Scattered
Ray paths
Doppler-
shifted
echo

SODAR

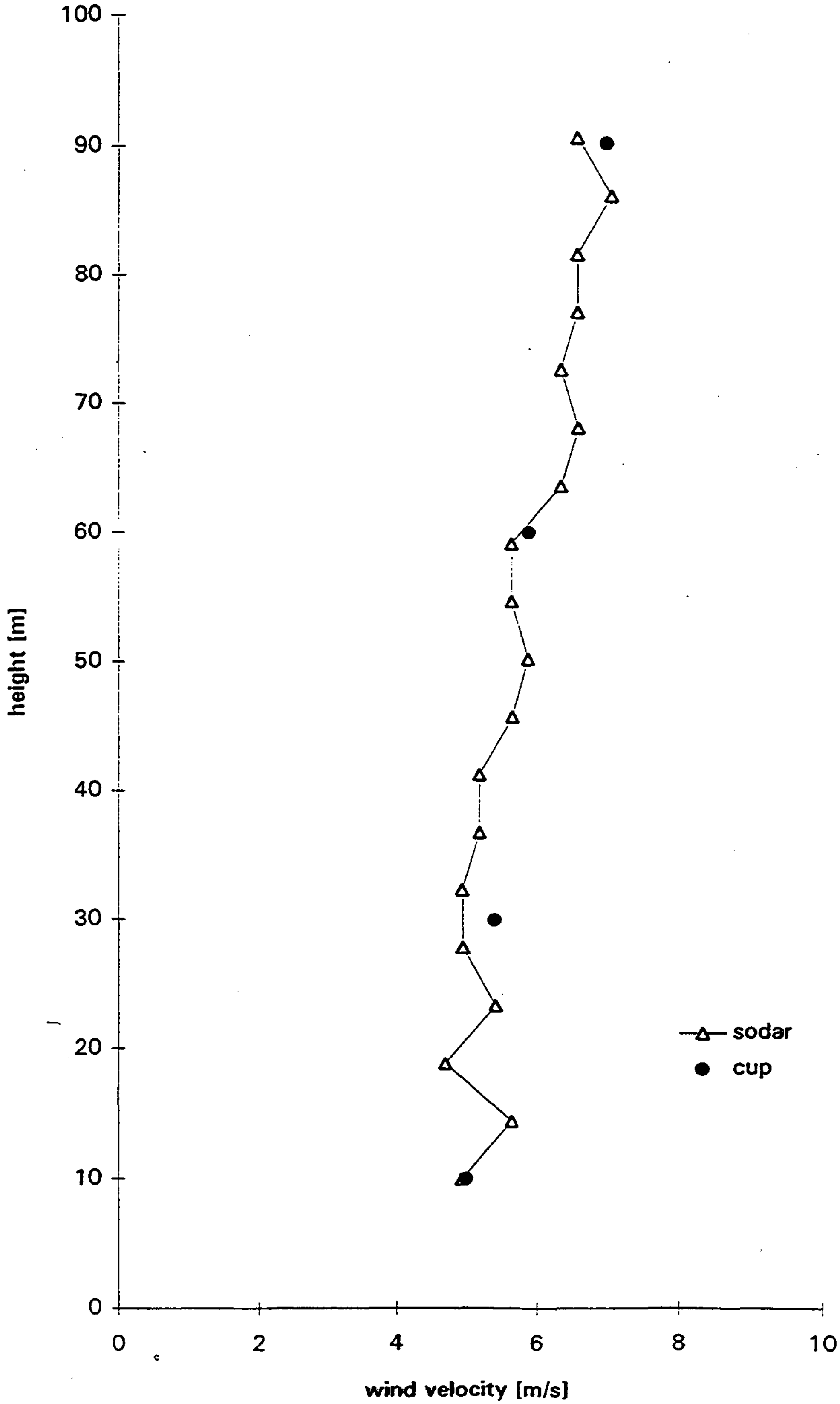


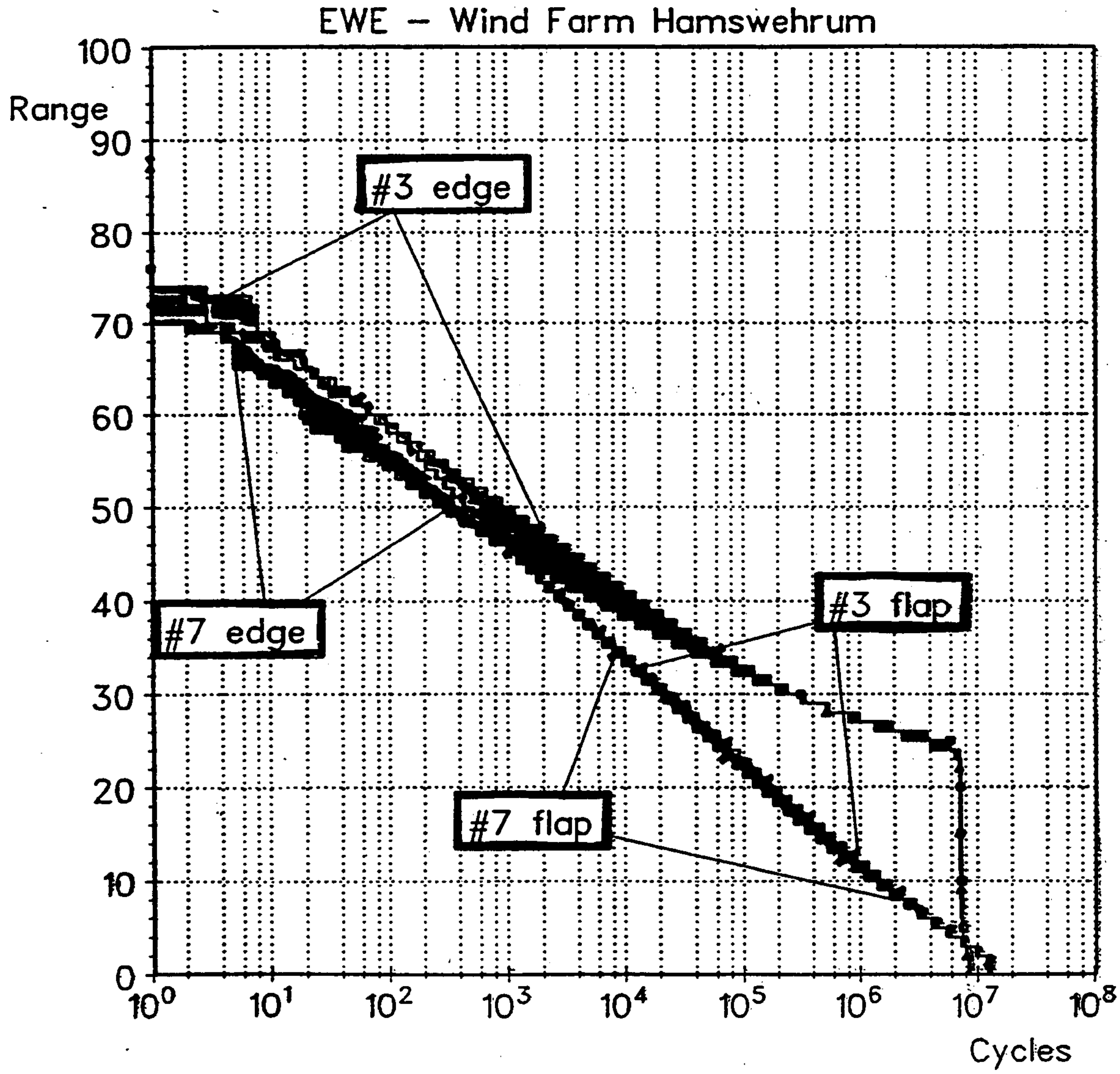
× mean turbulenc intensity in 1993 meausured at Jade Windenergiepark in Wilhelmshaven, meantime 5 minutes, sample rate 1 Hz

—— reverse logarithmic profile based on averaged turbulence intensities, resulting rougness lentgh 1,47m

Regression: $\frac{1}{T} = \frac{1}{T^*} \cdot \ln \frac{h}{z_0}$

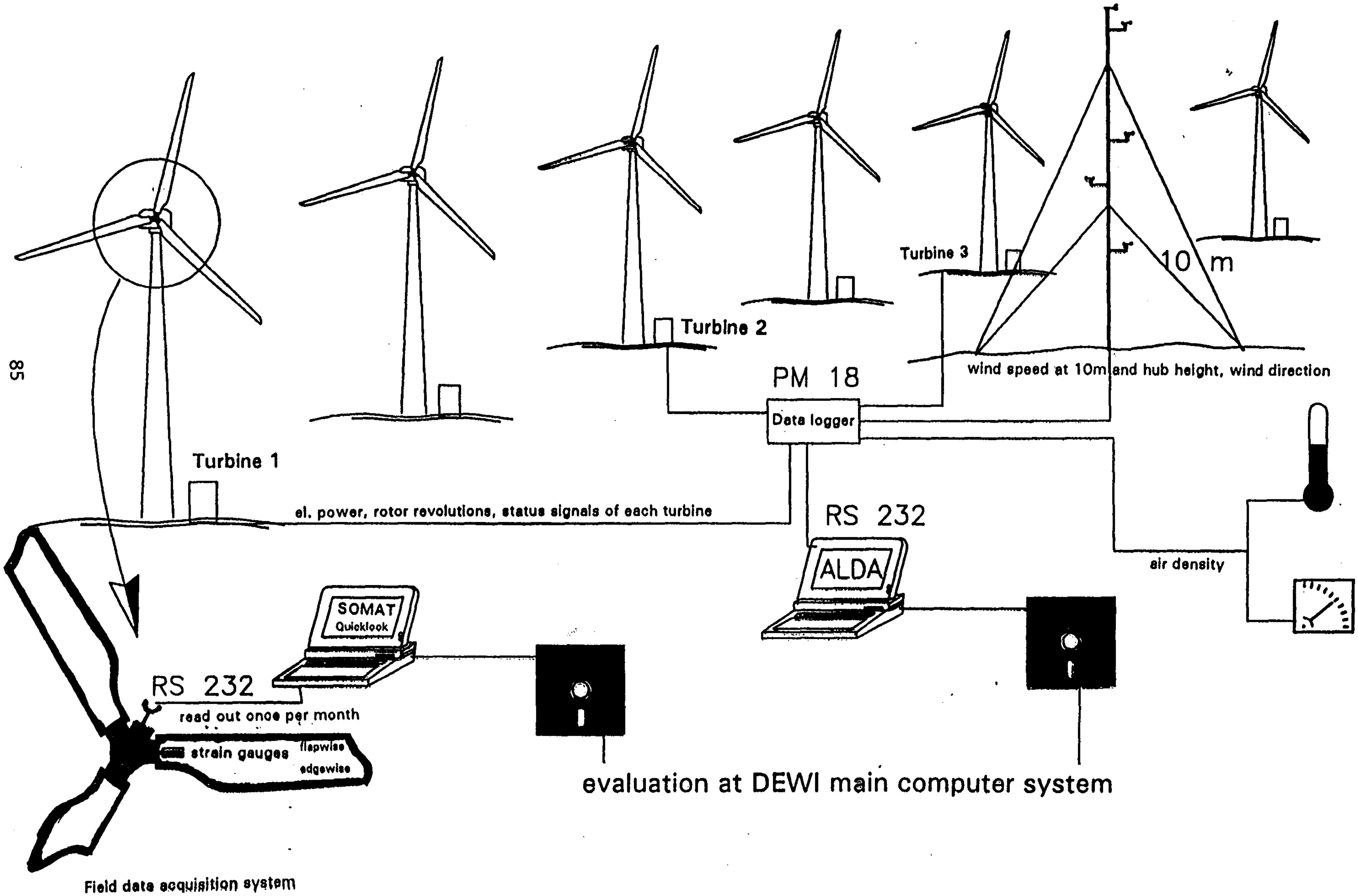
Comparision of sodar and cup anemometer measurements



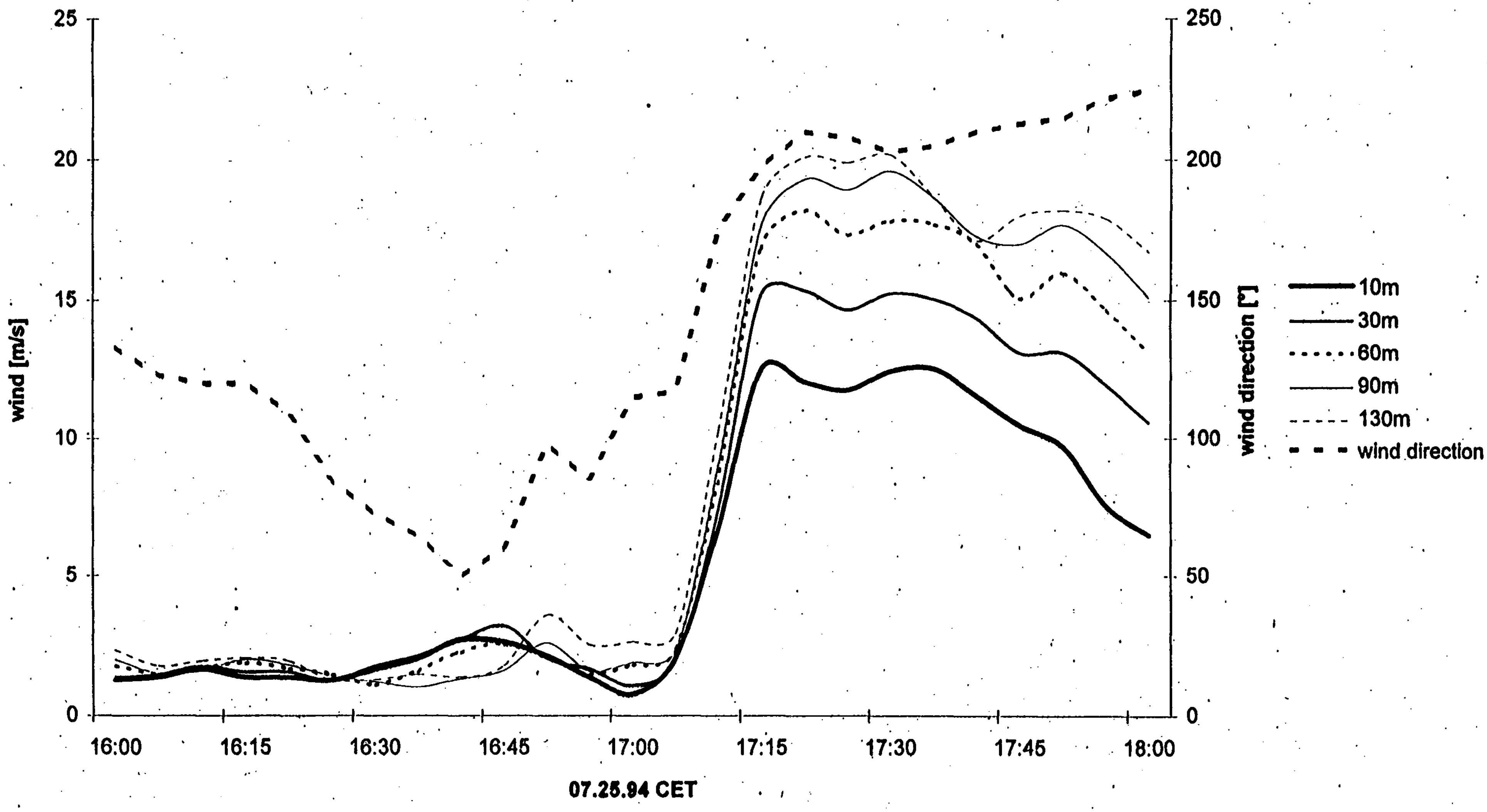


EWE - Wind Farm Hamswehrum
Range
Cycles
#3 edge
#7 edge
#3 flap
#7 flap
100
90
80
70
60
50
40
30
20
10
0
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8

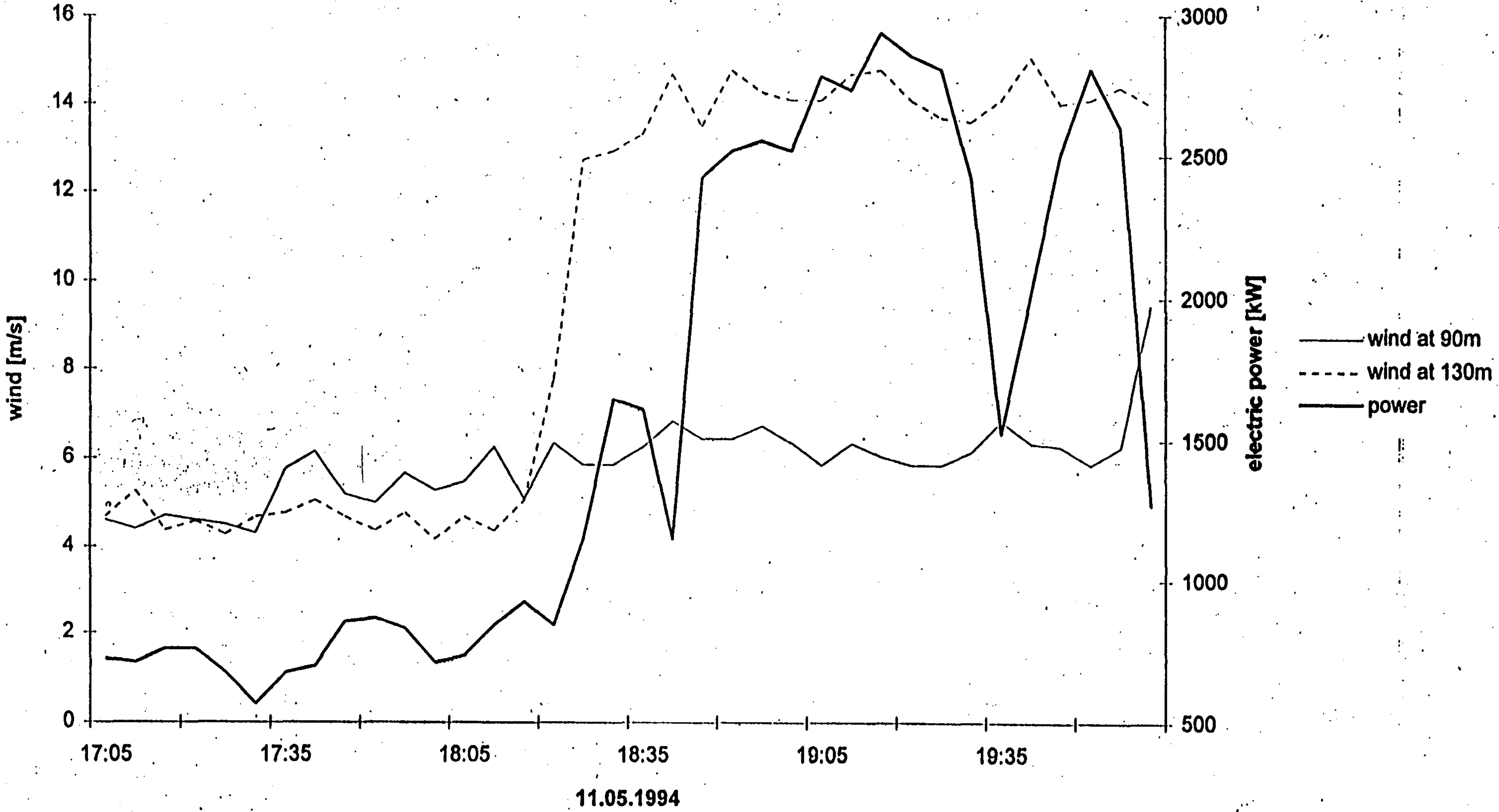
Monitoring Fatigue Loads in Wind Parks



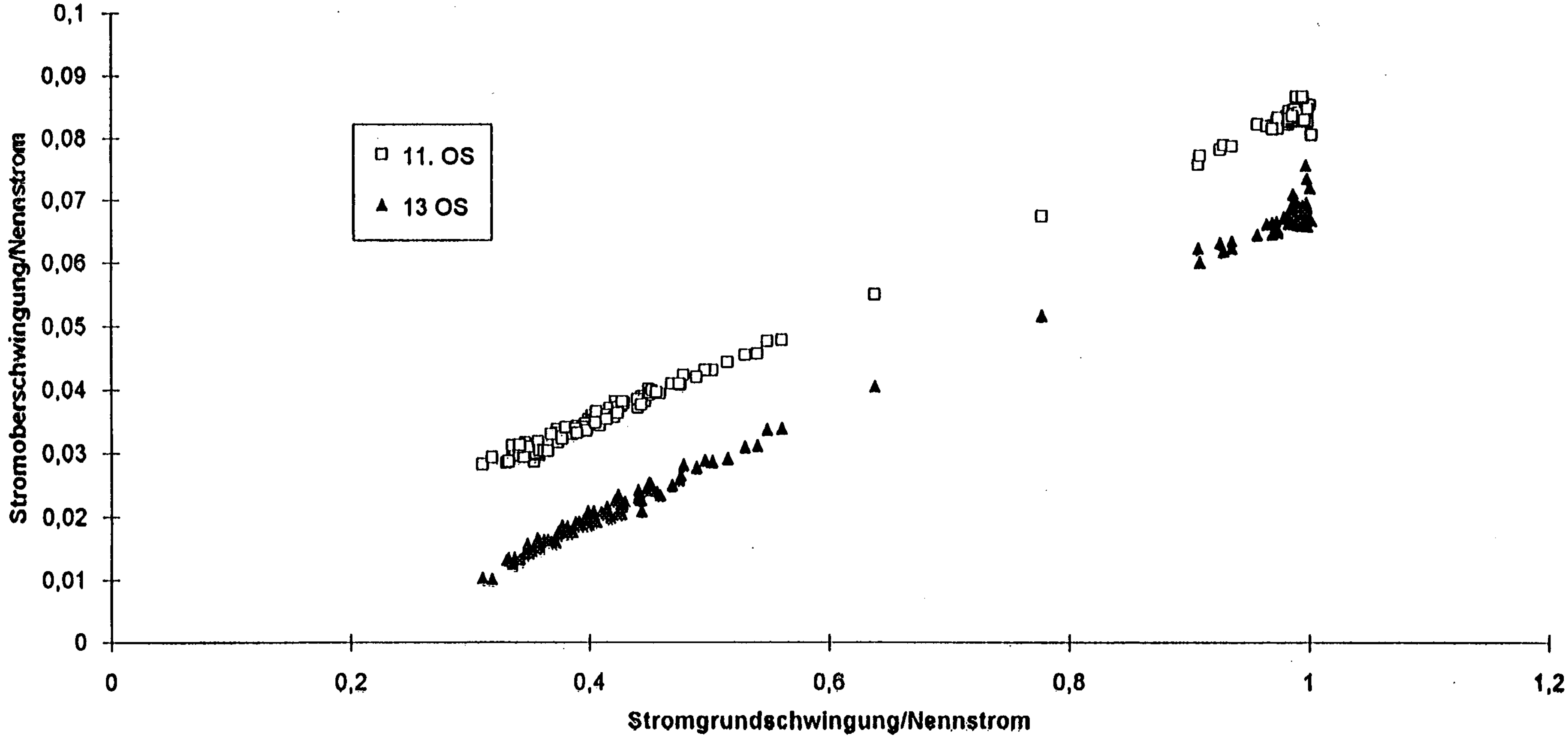
extreme wind gradient in time



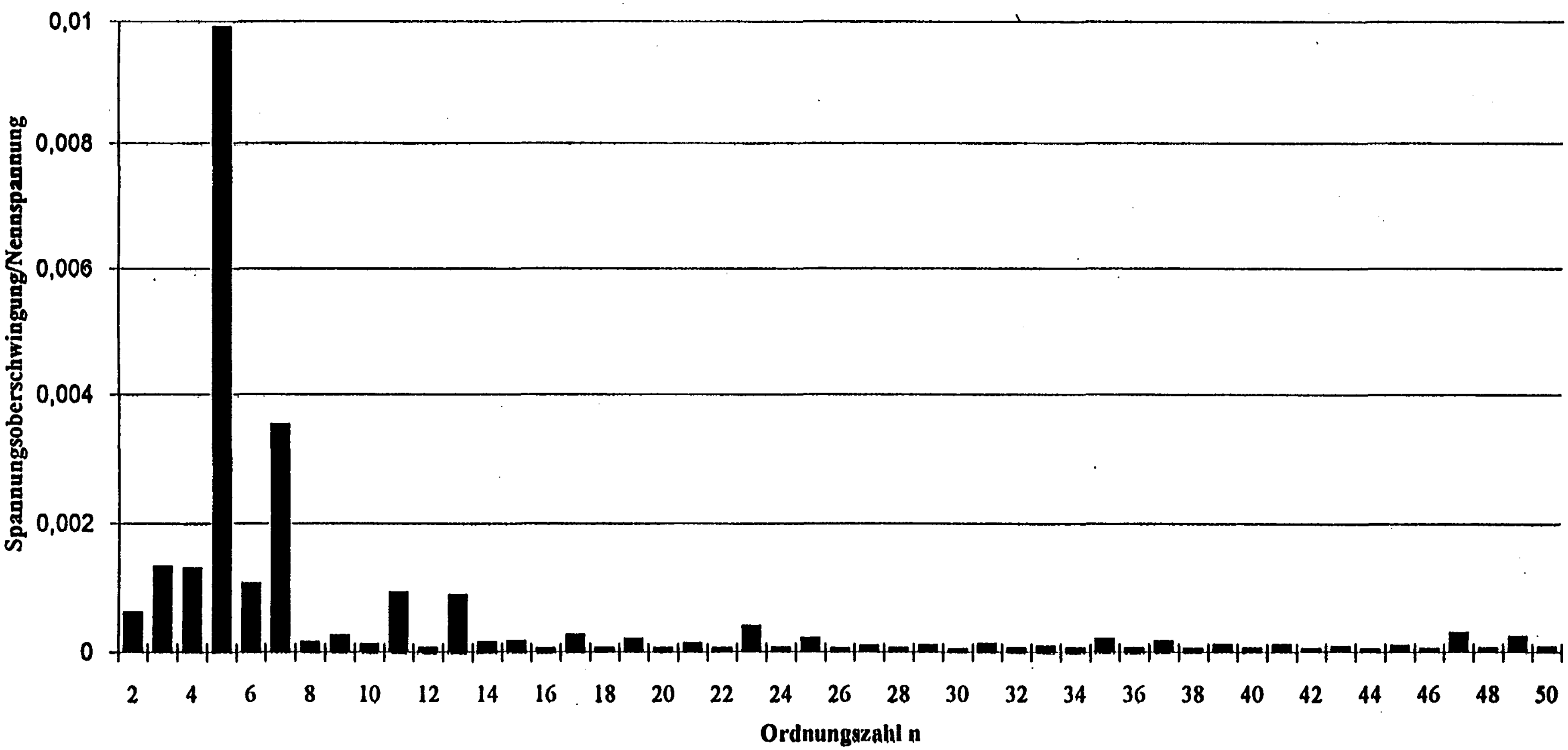
time series at JWE



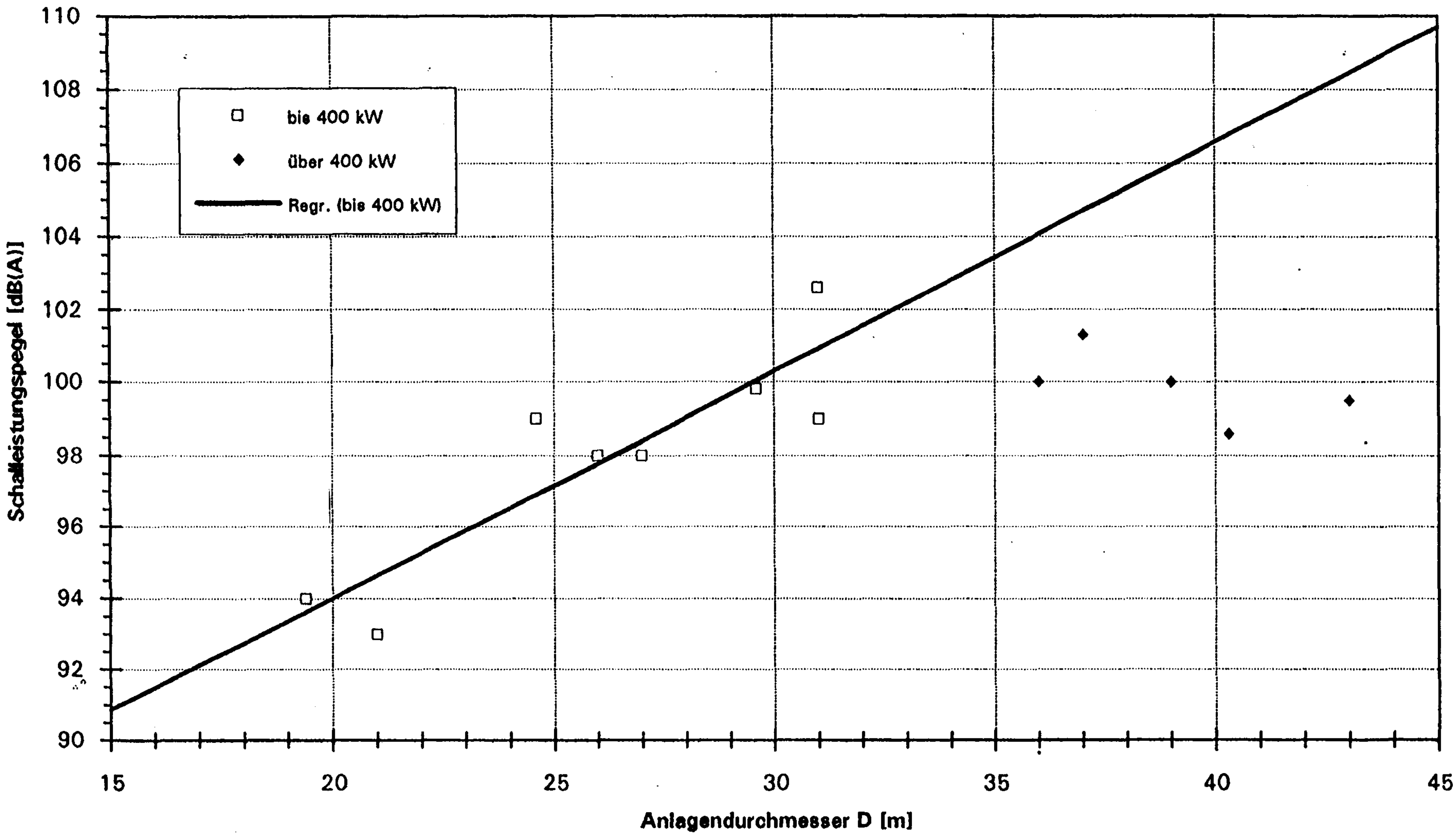
Windkraftanlage F3



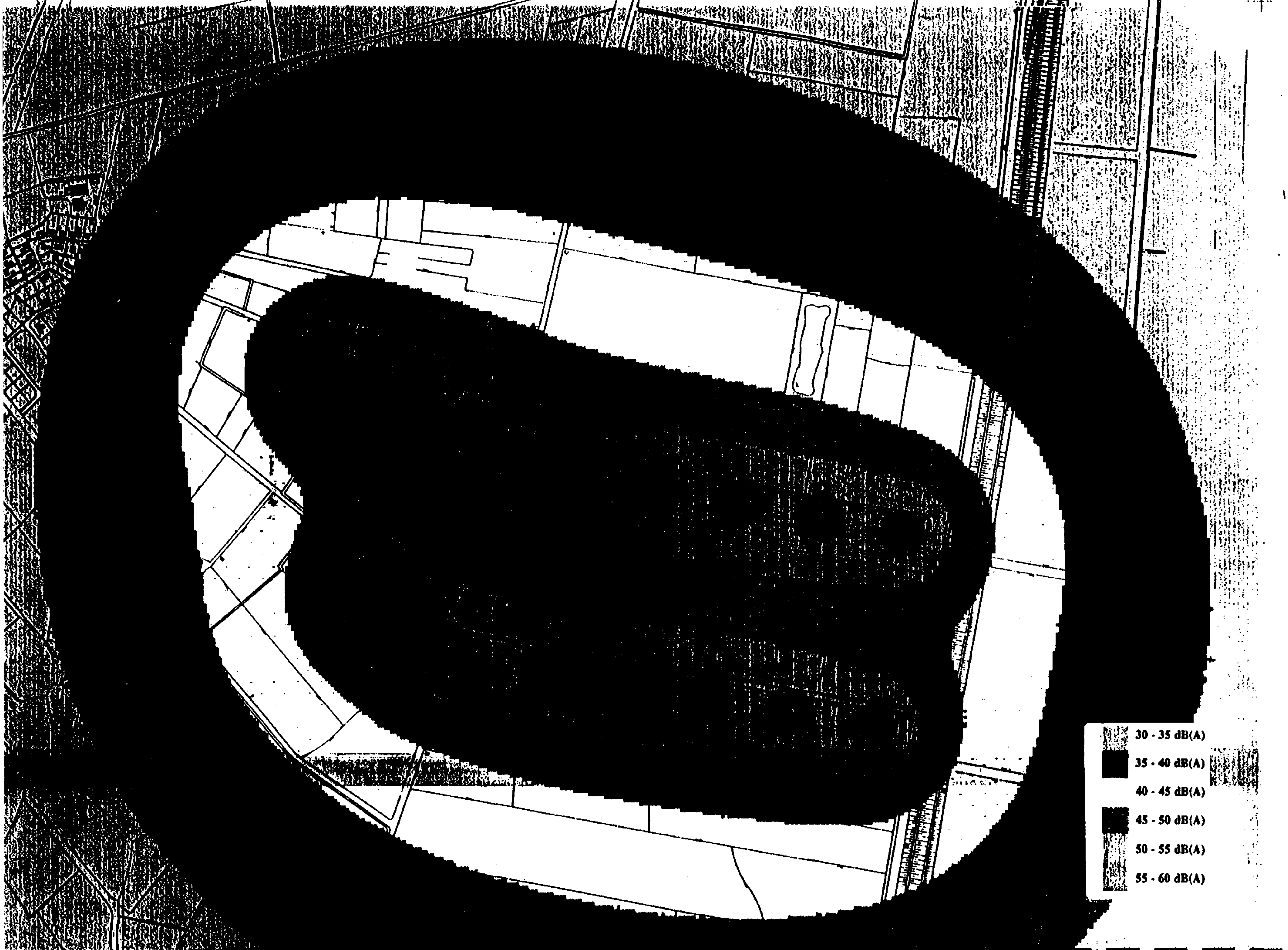
Maximal aufgetretene Oberschwingungsspannungen

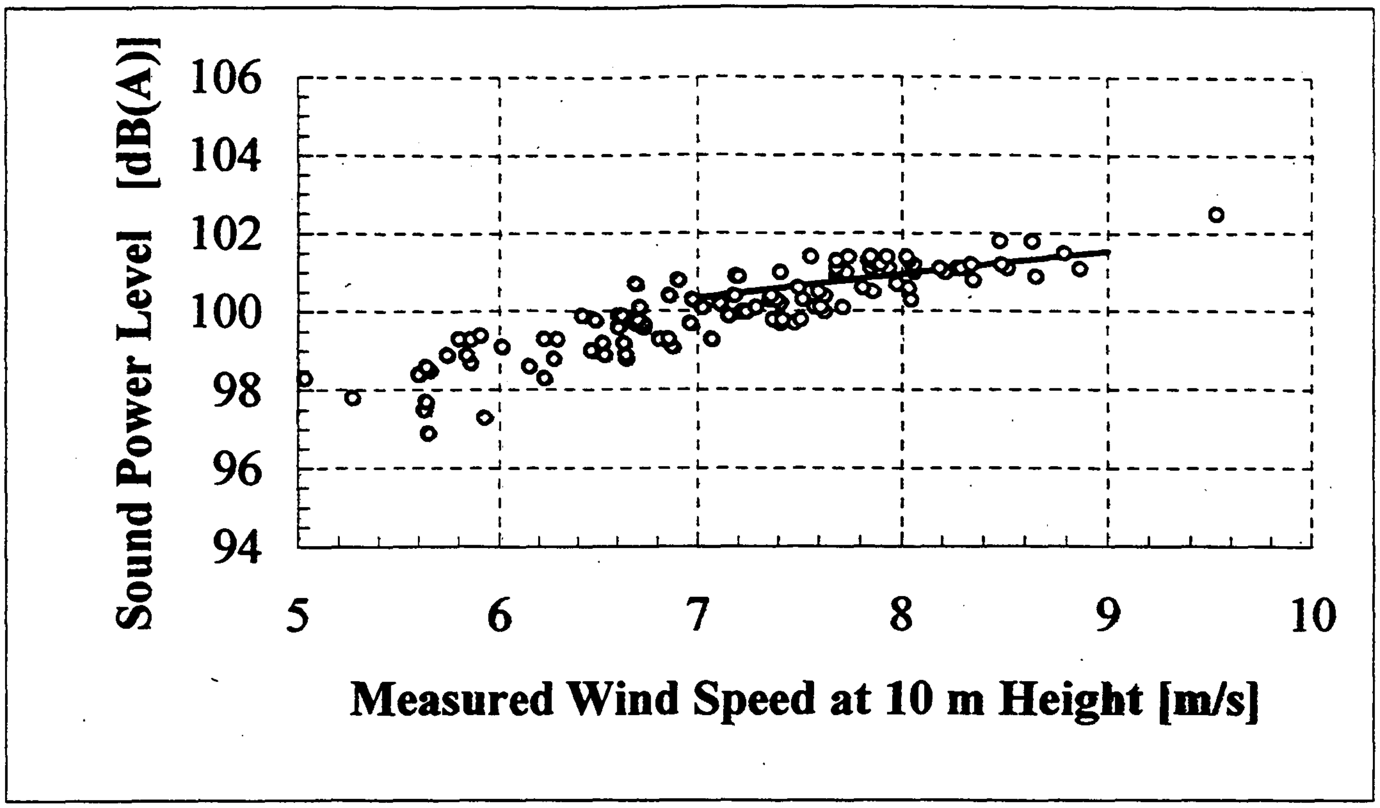


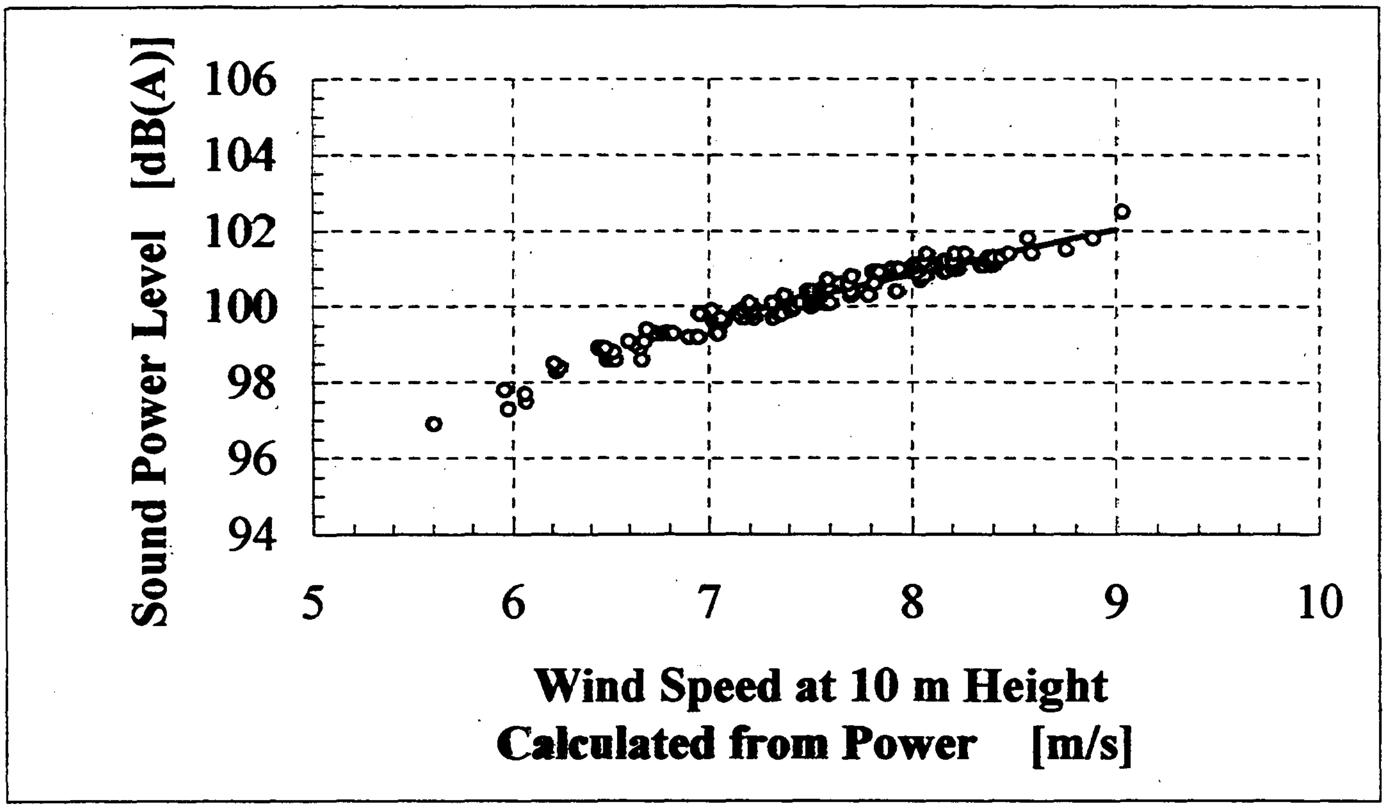
90

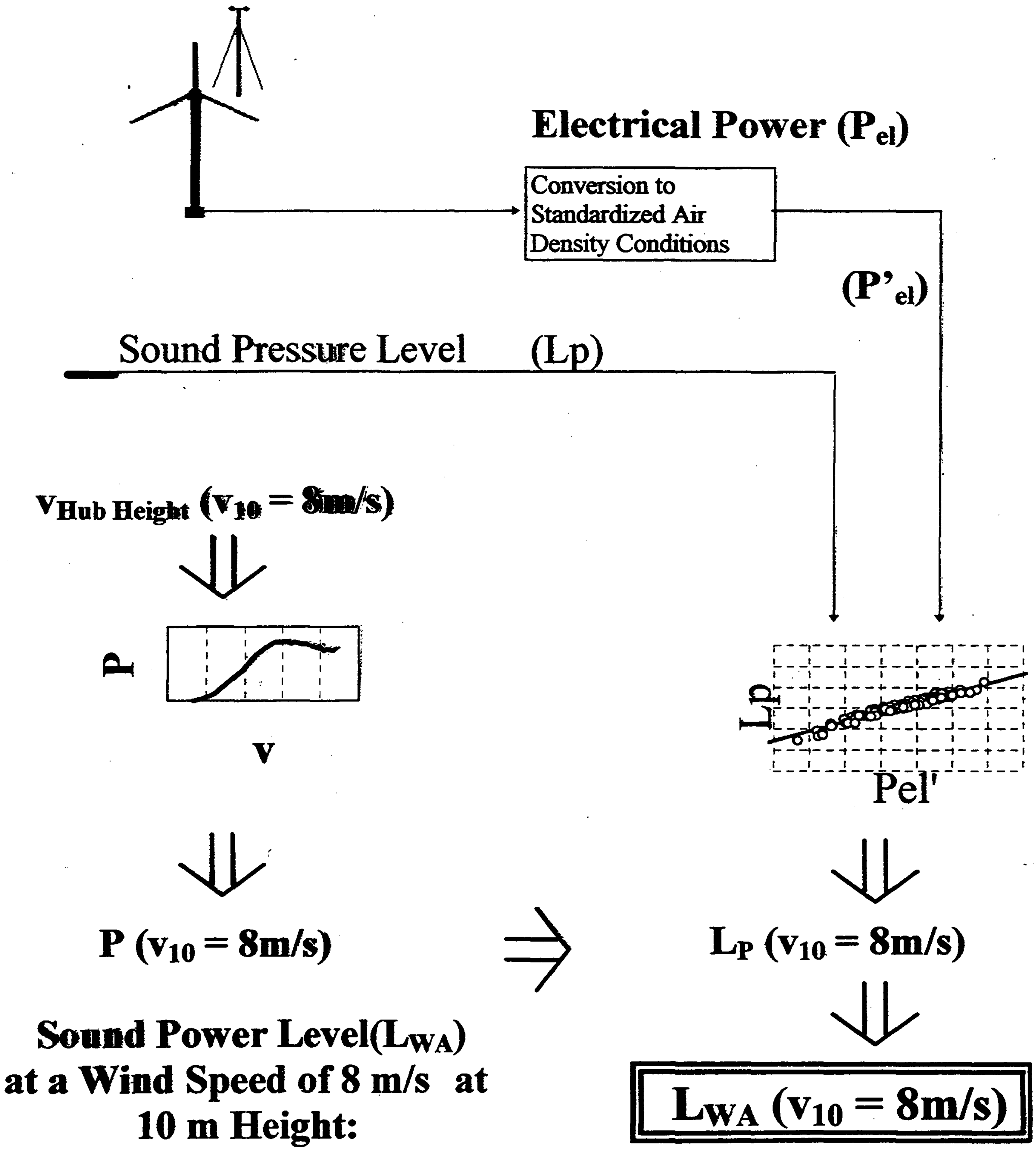


bis 400 kW
über 400 kW
Regr. (bis 400 kW)
Schalleistungspegel [dB(A)]
110
108
106
104
102
100
98
96
94
92
90
15
20
25
30
35
40
45
Anlagendurchmesser D [m]

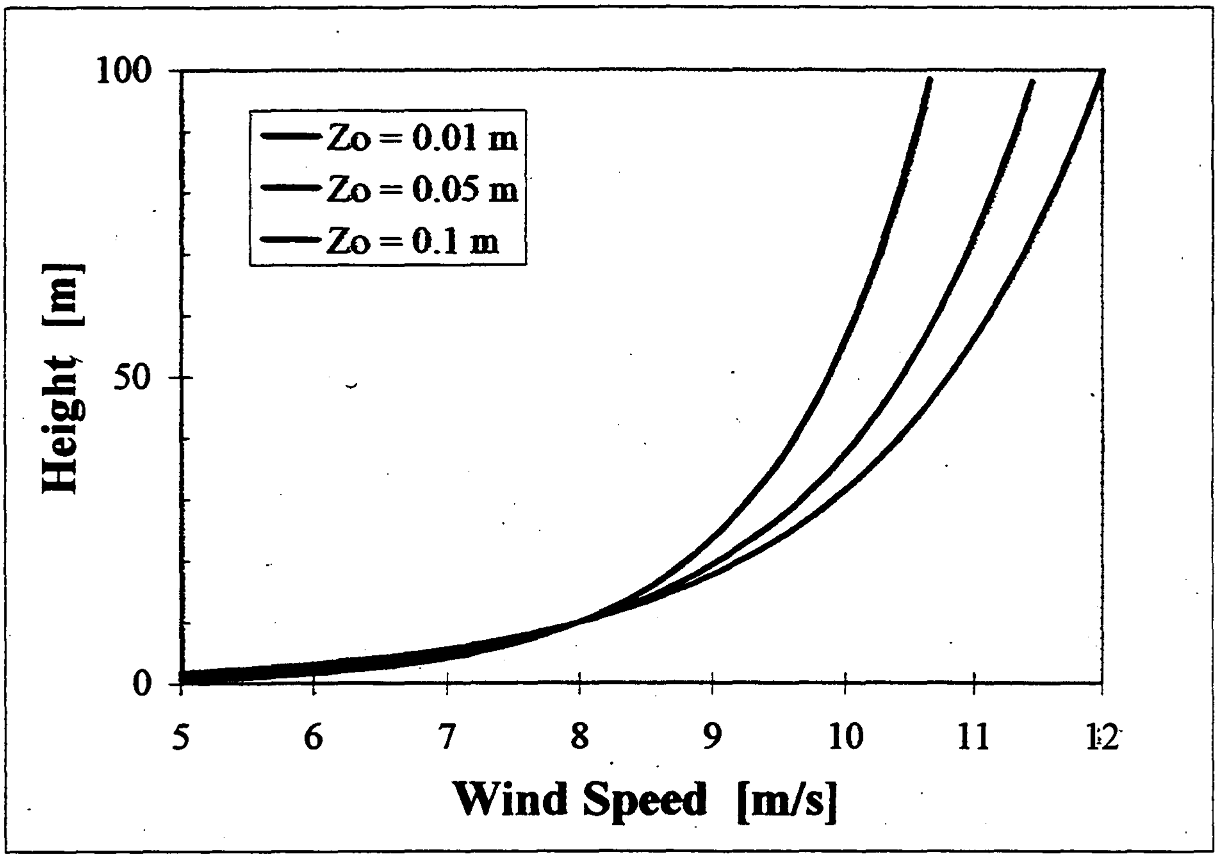

30 - 35 dB(A)
35 - 40 dB(A)
40 - 45 dB(A)
45 - 50 dB(A)
50 - 55 dB(A)
55 - 60 dB(A)


Sound Power Level [dB(A)]
106
104
102
100
98
96
94
5
6
7
8
9
10
Measured Wind Speed at 10 m Height [m/s]

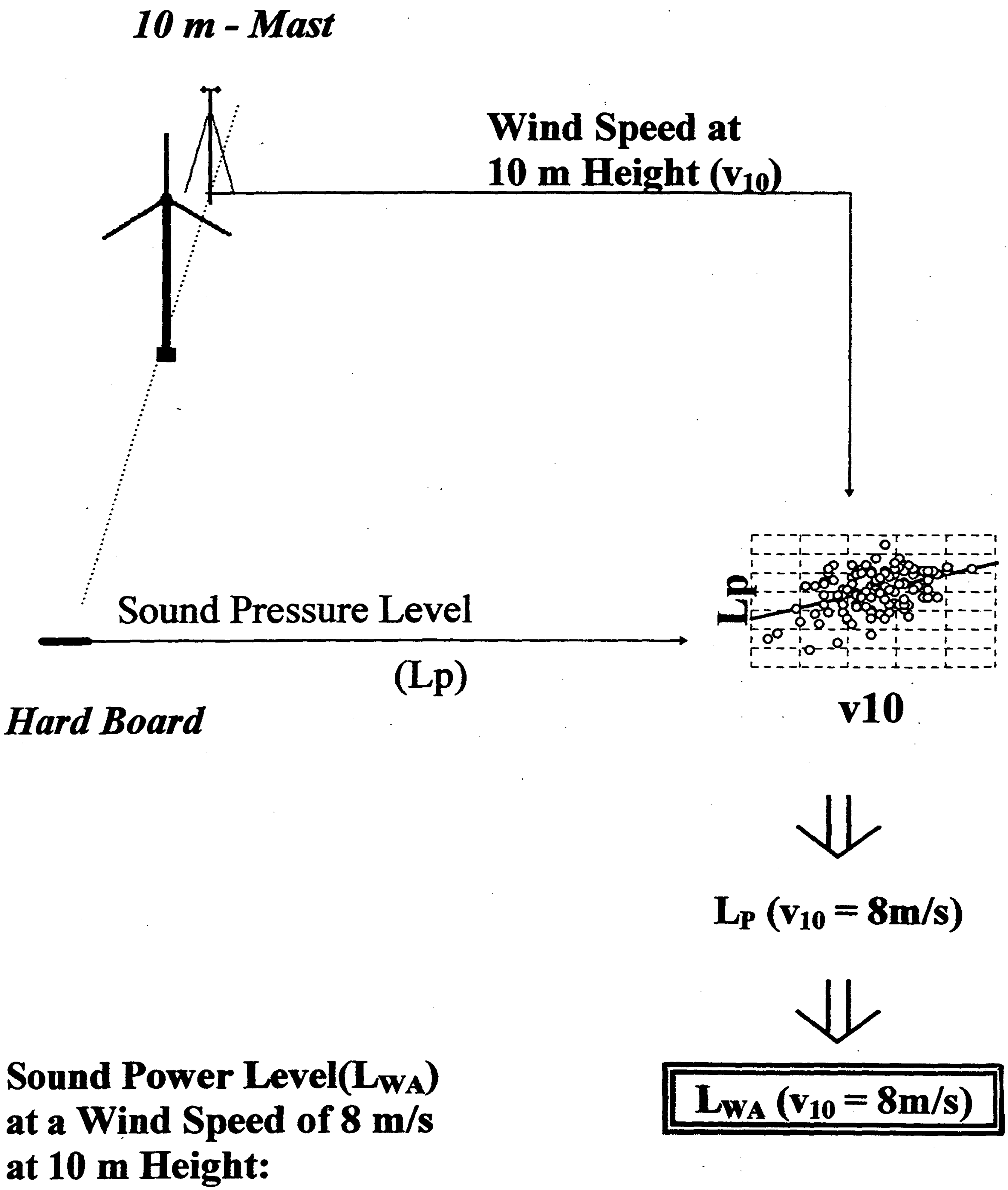

Sound Power Level [dB(A)]
106
104
102
100
98
96
94
5
6
7
8
9
10
Wind Speed at 10 m Height
Calculated from Power [m/s]

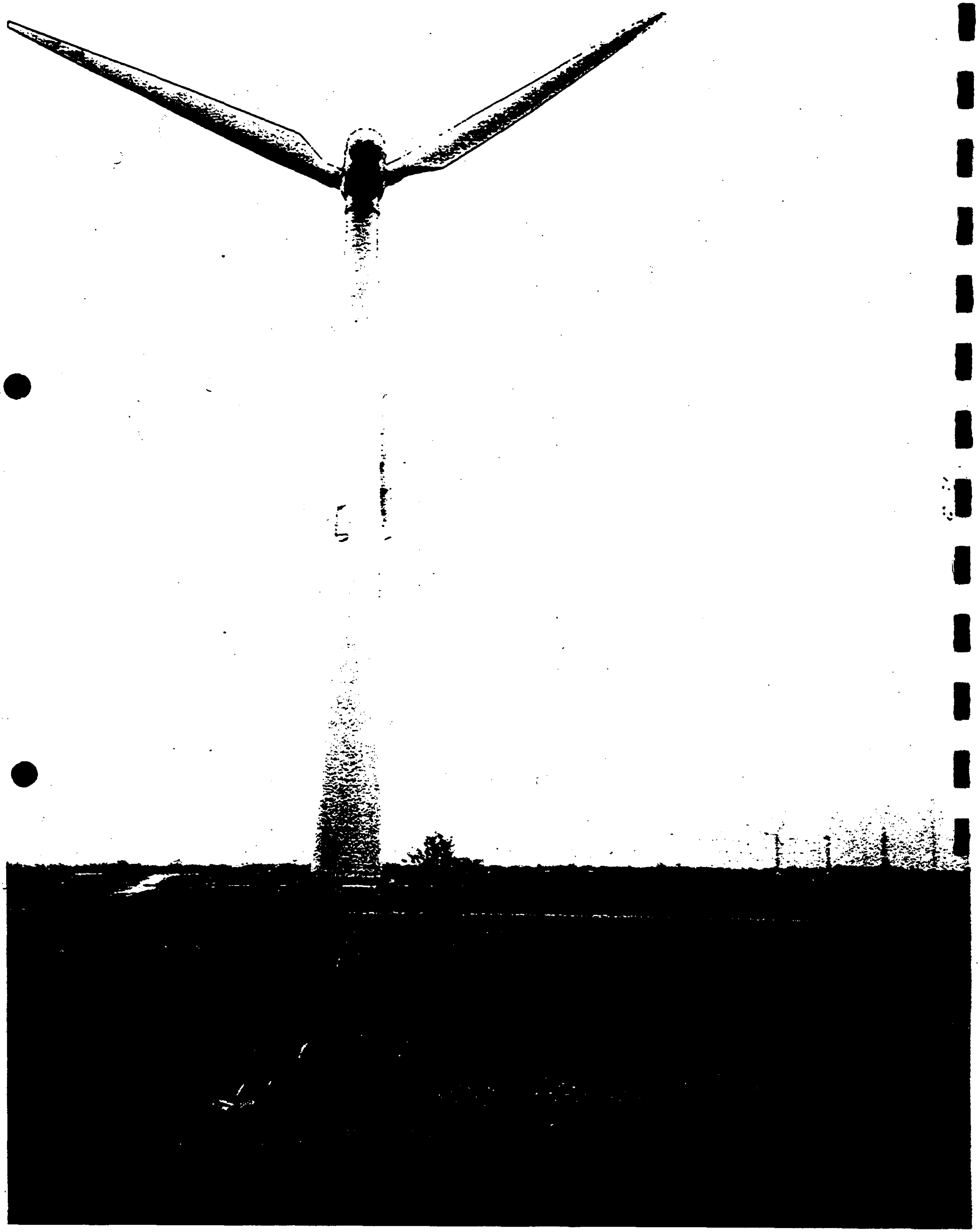

Electrical Power (P_{el})
Conversion to Standardized Air Density Conditions
(P'_{el})
Sound Pressure Level (Lp)
$v_{Hub\ Height}$ (v_{10} = 8m/s)
P
v
Lp
Pel'
P (v_{10} = 8m/s)
L_P (v_{10} = 8m/s)
Sound Power Level(L_{WA}) at a Wind Speed of 8 m/s at 10 m Height:
L_{WA} (v_{10} = 8m/s)

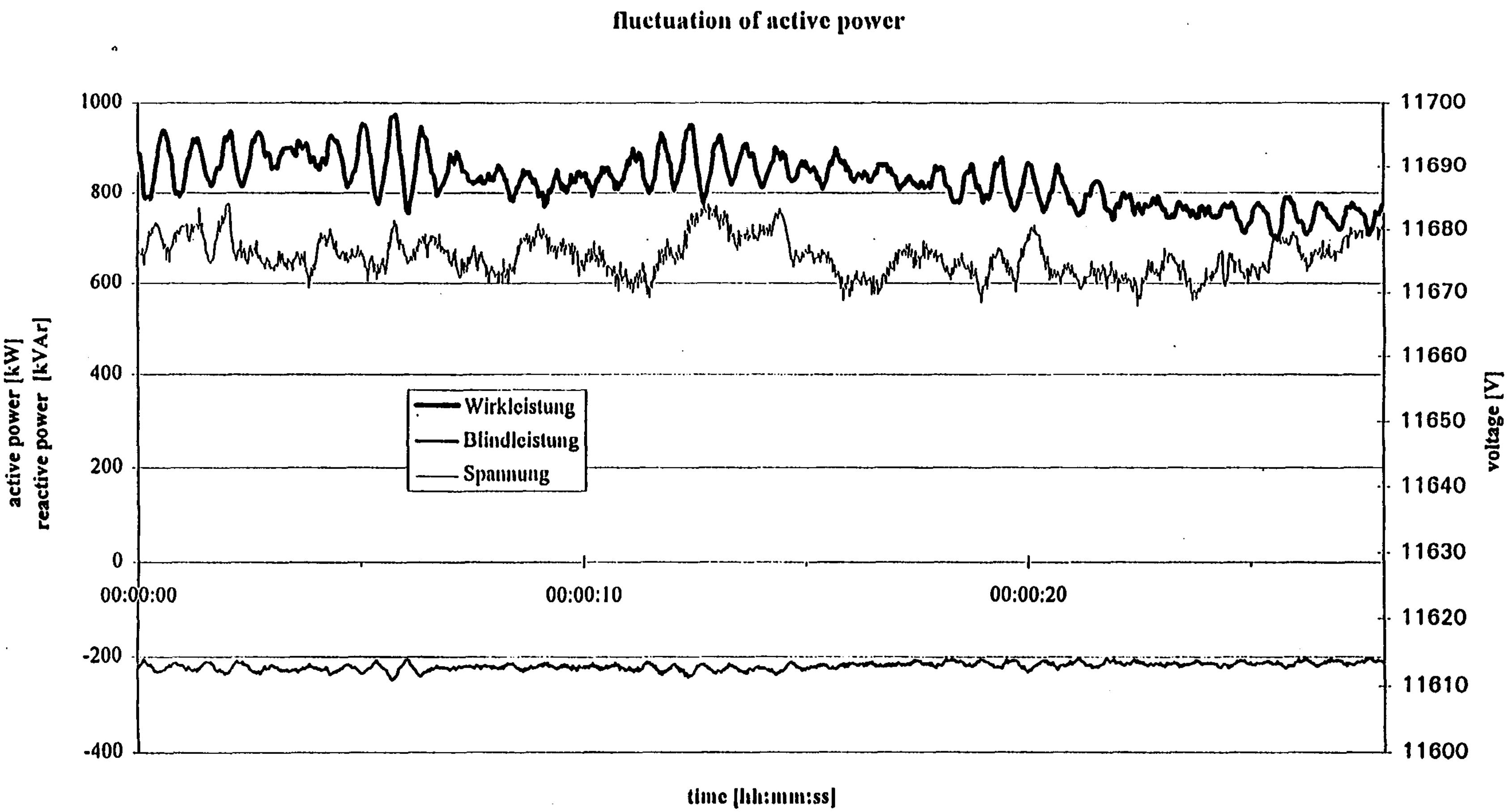
Site Influence

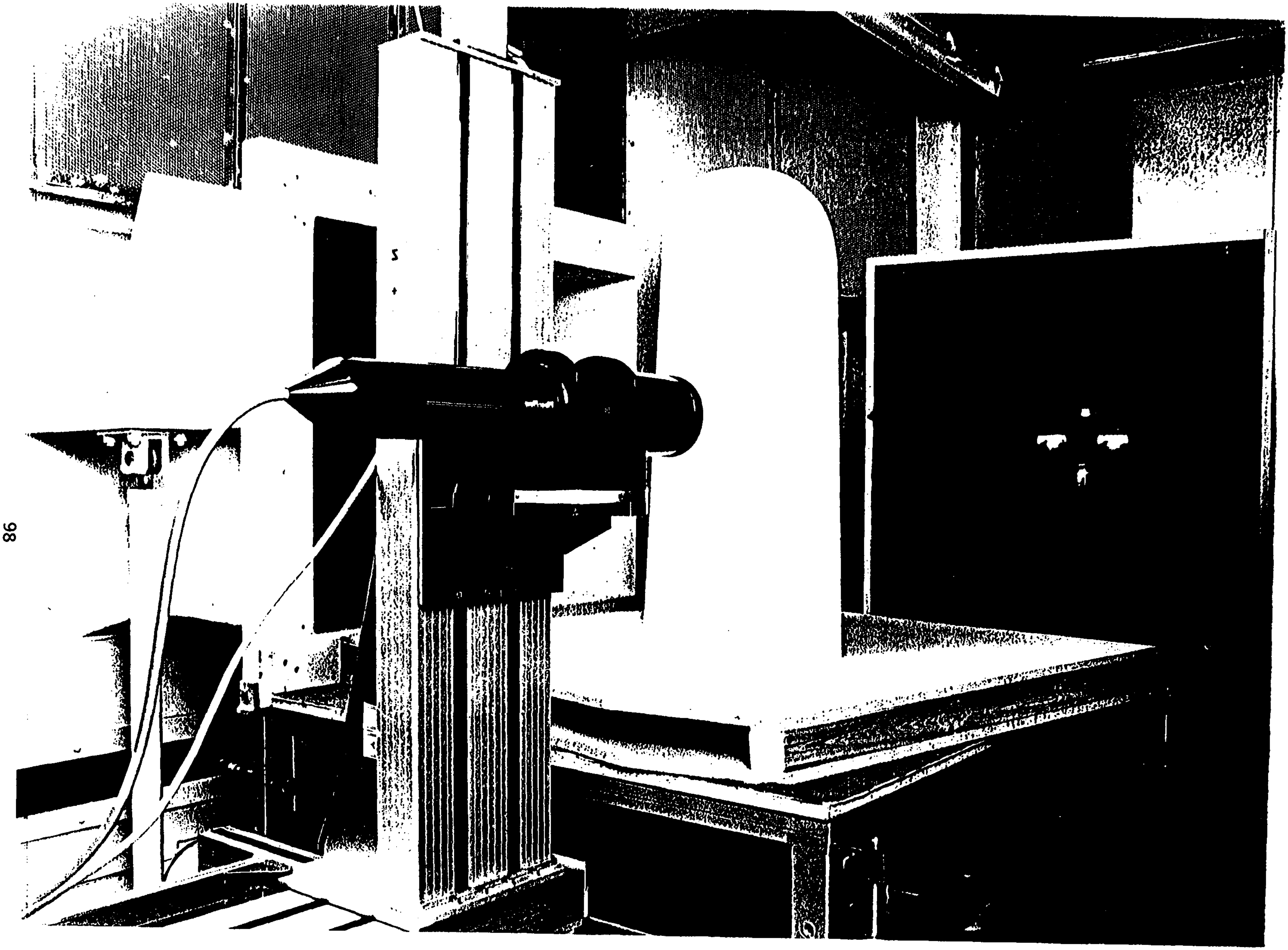


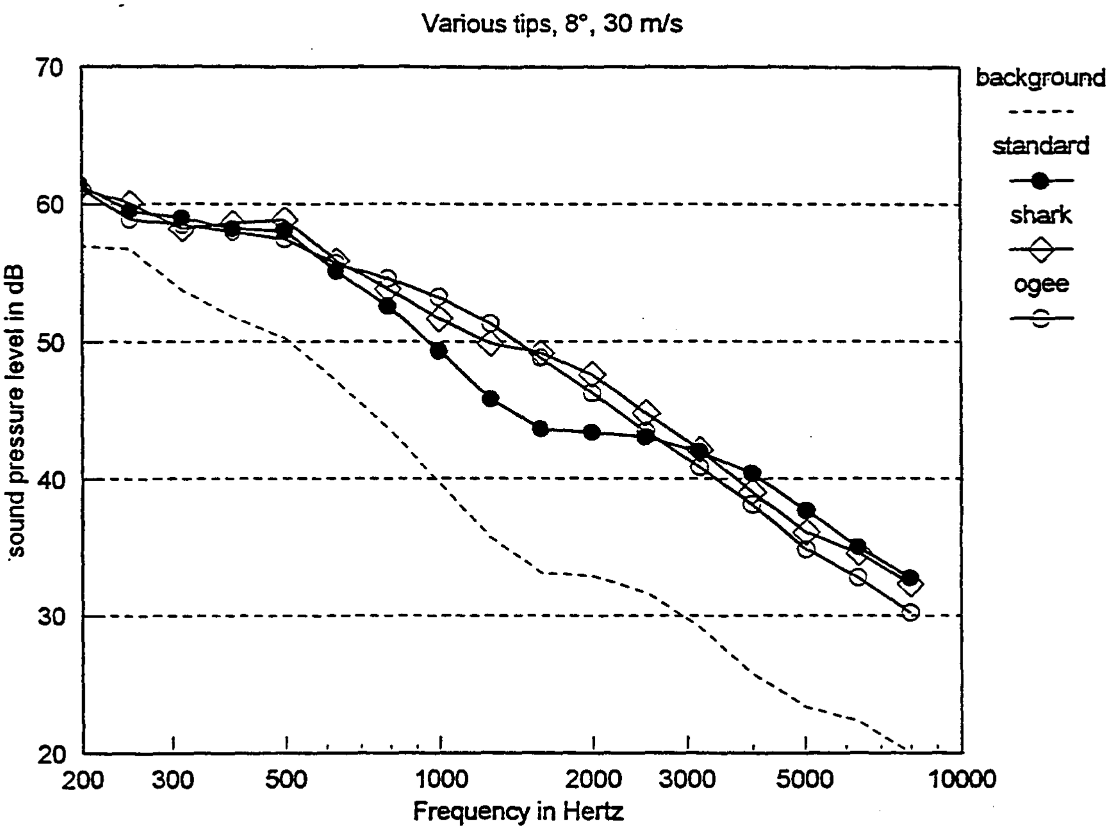
Roughness	Zo [m]	v10 [m/s]	v50 [m/s]	P [%]	Lw [dB(A)]
< standard	0.01	8	9.9	53.6	99.3
standard	0.05	8	10.4	60.3	100.0
> standard	0.1	8	10.8	64.7	100.5

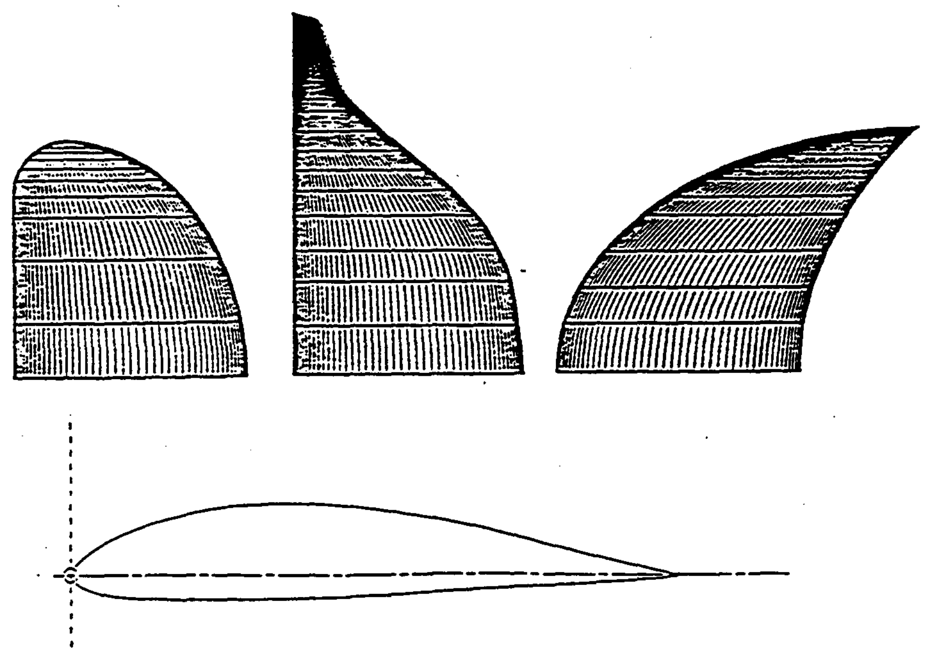

10 m - Mast
Wind Speed at
10 m Height (v10)
Sound Pressure Level
(Lp)
Hard Board
Lp
v10
Lp (v10 = 8m/s)
LWA (v10 = 8m/s)
Sound Power Level(LWA)
at a Wind Speed of 8 m/s
at 10 m Height:



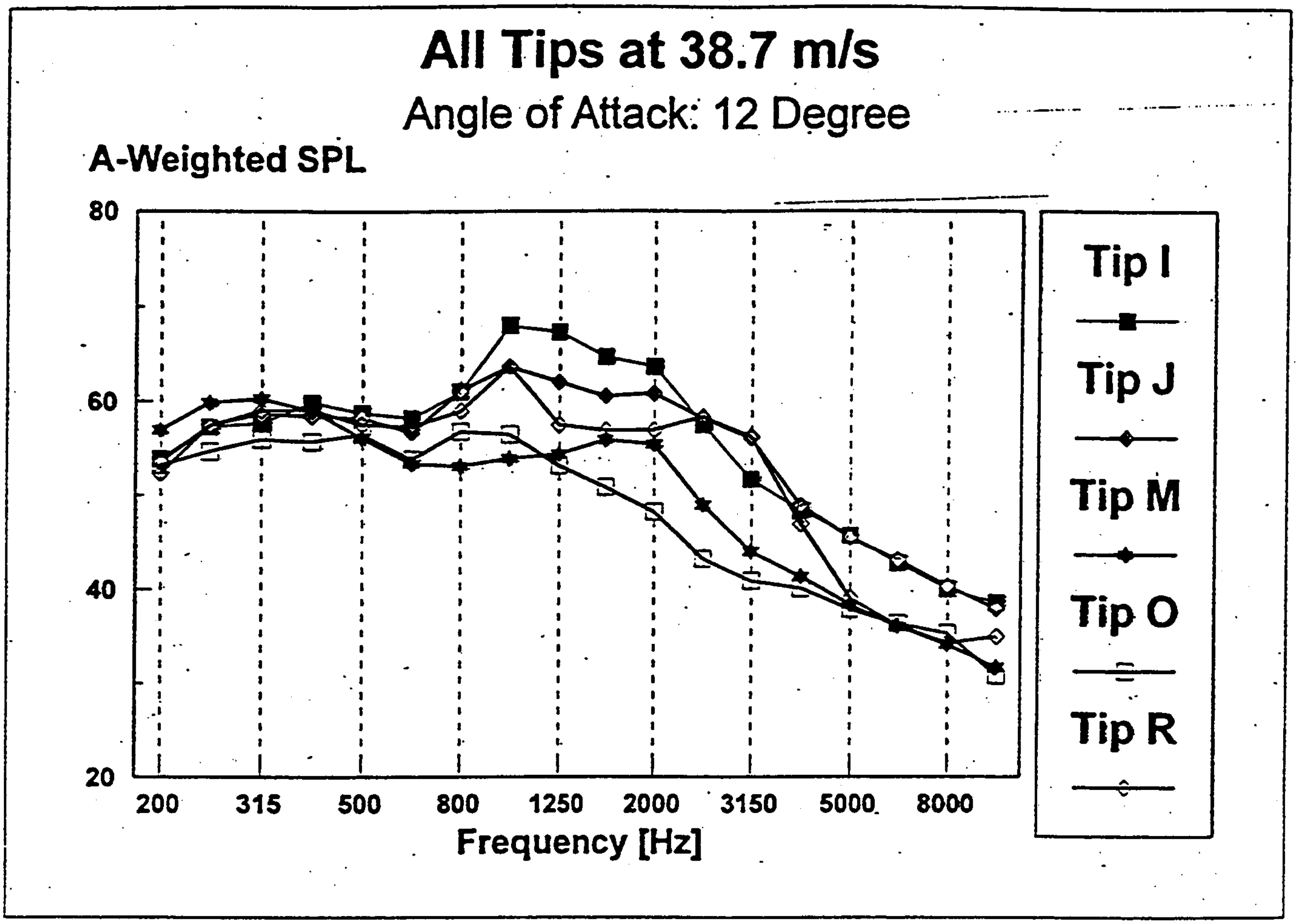

fluctuation of active power
1000
800
600
400
200
0
-200
-400
11700
11690
11680
11670
11660
11650
11640
11630
11620
11610
11600
active power [kW]
reactive power [kVAr]
voltage [V]
Wirkleistung
Blindleistung
Spannung
00:00:00
00:00:10
00:00:20
time [hh:mm:ss]



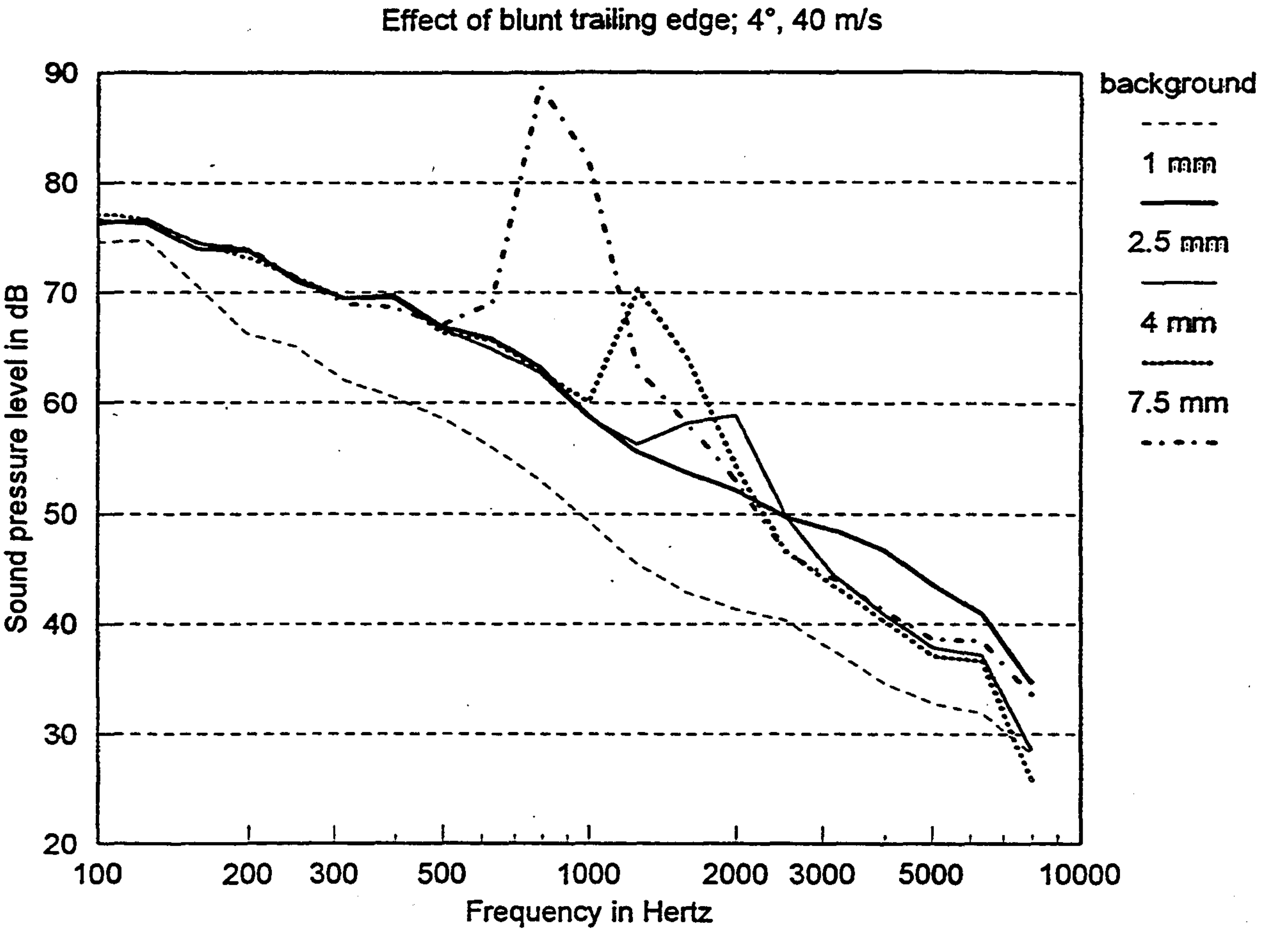




Plot of planforms REFE, OGEE and SHARK and airfoil FX 79-W-151A


All Tips at 38.7 m/s
Angle of Attack: 12 Degree
A-Weighted SPL
80
60
40
20
200
315
500
800
1250
2000
3150
5000
8000
Frequency [Hz]
Tip I
Tip J
Tip M
Tip O
Tip R


Direction of rotation
Std
E
I
J
M
O
R


Effect of blunt trailing edge; 4°, 40 m/s
Sound pressure level in dB
90
80
70
60
50
40
30
20
100
200
300
500
1000
2000
3000
5000
10000
Frequency in Hertz
background
1 mm
2.5 mm
4 mm
7.5 mm

IEC TC88 Noise and Performance Testing

Allan Johnston
NEL

14th International Meeting of Test Stations
12-13 September 1994
Boulder, Colorado, USA

Activities at the

National Wind Turbine Centre,

NEL, UK

Raymond S Hunter & Allan G Johnston

NEL

- 250 Staff
- Turnover 93/94 £13.5 M
- 1989 Government announced that NEL should be privatised
- 5 year transition to a customer driven organisation operating on a commercial basis
- Objective to attain commercial viability prior to privatisation
- NEL will be privatised by seeking a trade sale in the summer of 1995
- To be completed before the end of 1995
- To achieve laboratory wide ISO 9001 accreditation in 1994

NEL

NEL is an international technology services organisation providing a range of engineering technology skills in the following fields throughout the UK, Europe and Worldwide:

- energy, the environment and process engineering 29%
- oil, gas, water and multi-phase flow measurement 36%
- structures and materials testing 17%
- computer based measurement and control systems 16%

NEL

The services offered include:

- Problem - solving
- Consultancy
- Contract R&D
- Design
- Simulation & Modelling
- Measurement & Testing
- Training & Technology Transfer

National Wind Turbine Centre (NWTC)

NWTC

- 14 Full-time members of staff
- Over 10 years experience in wind energy
- 1985-93, Government contracts to carry out under-pinning research for the development of wind turbine standards

NWTC

1993

- Reduction in Government business due to organisation and policy changes within government department

- NWTC core business from commercial contracts with utilities, windfarm operators, and developers in the following areas

NWTC

- Performance verification
- In-service load monitoring
- Noise emission measurement
- EMI consultancy
- Tendering for Power Supply Contracts

NWTC

The NWTC services are utilised by the following client base:

- Land Owners and Developers
- Manufacturers
- Government & European Commission
- Financiers
- Utilities and Windfarm Operators

NWTC

The NWTC facilities are extensive and comprise of:

- Wind Turbine Test Site (Myres Hill)
- Mobile Wind Monitoring Systems
- Mobile Performance and Load Monitoring Kit
- Wind Modelling Software
- Extensive Design and Modelling Software
- Blade Testing Laboratory
- Materials Laboratory
- Anemometer Calibration facility

Hönö Test Site Activity

Magnus Ellsén
Chalmers University

WIND ENERGY RESEARCH AT CHALMERS

Departements:

Dept. of Electrical Machines and Power Electronics

Control Engineering Laboratory

Personel:

Electrical system	5
Hönö Test Station	1/2
Control Engineering	2

WIND ENERGY RESEARCH AT CHALMERS

1994 - 96

ELECTRICAL MACHINES

Directly Driven Permanent Magnet Generator

Modelling of Induction Machines - Wind Farm

Design of Synchronous Machine

Temperature Modelling of Induction Machines

CONVERTERS

Transistor (IGBT) with simple control

ELECTRICAL SYSTEM

Optimal Control, low losses, increased speed

POWER QUALITY

CONTROL ENGINEERING

Methods - Variable Speed,

Tests at Hönö

HÖNÖ TEST STATION

Stall control, variable speed, measurements

Directly driven Permanent Magnet Generator

WIND ENERGY RESEARCH AT CHALMERS

COMPARITION BETWEEN TWO ELECTRICAL SYSTEMS FOR VARIABLE SPEED.

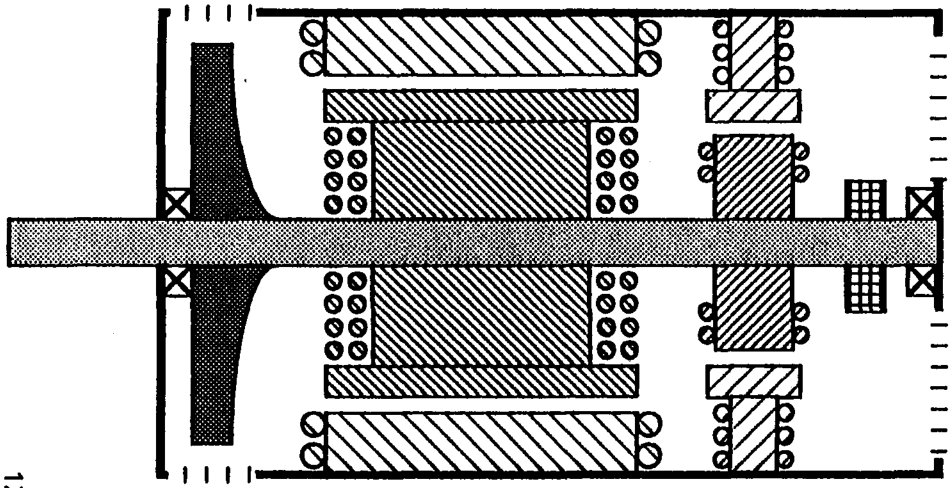
- Synchronous Generator with Diode Rectifier

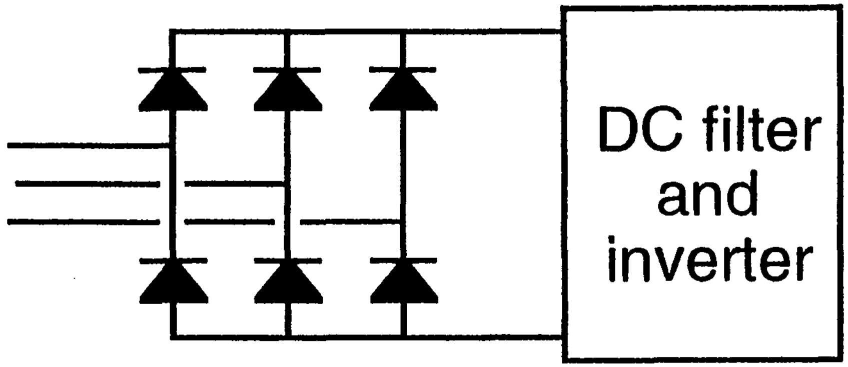
-Induction Generator with Transistor Rectifier

by

Ph.D. Ola Carlson
M.Sc. Anders Grauers
M.Sc. Jan Svensson

Synchronous generator and diode rectifier





+ Can be used with a diode rectifier

– More parts and larger than an induction generator

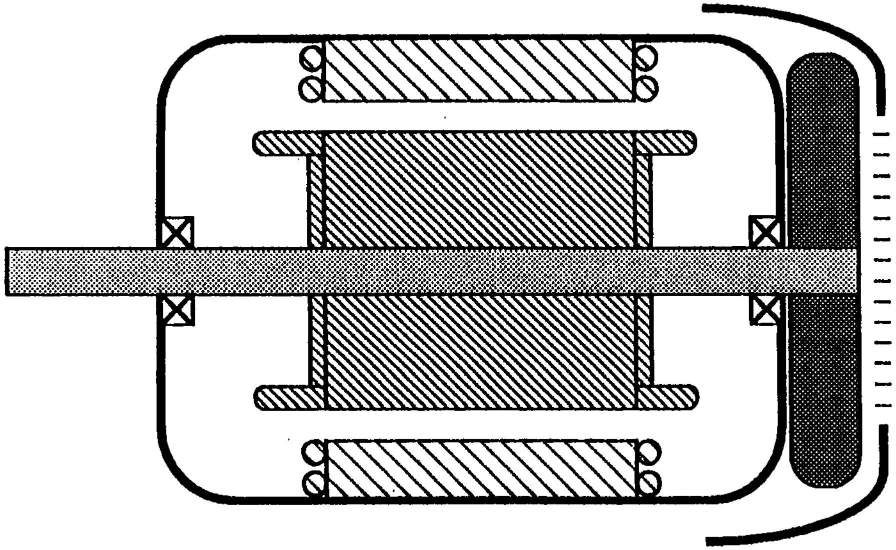
– More expensive than an induction generator

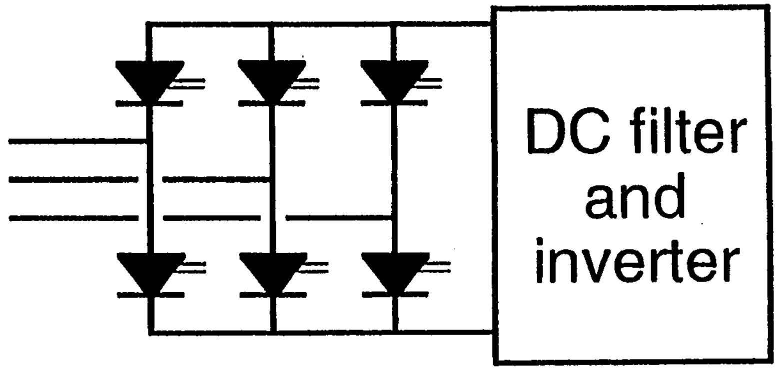
+ The least complicated rectifier

+ Low losses

– Non sinusoidal generator current

Induction generator and transistor rectifier





+ Very simple design
– Needs an expensive rectifier

+ Can control the DC voltage
+ Nearly sinusoidal generator current
– High losses
– Much more expensive than a diode rectifier

Economical comparison

for 400 kW systems:

Losses that reduces the energy production by 1% is assumed to cost 1% of the wind turbine price
(1% losses ≈ 4500 $)

All costs and prices are related to the price of a 400 kW induction generator
(≈ 17 000 $)

Relative costs for a 400 kW system

	Synchronous generator and diode rectifier	Induction generator and transistor rect.
Generator price	1.2	1.0
Cost of generator losses	1.9	1.3
Rectifier price	0.1	2.0
Cost of rectifier losses	0.5	1.3
total cost	3.7	5.6

Comments

Both systems can be used for wind turbines.

Non sinusoidal current in the generator is no big disadvantage. It only increases the losses a little

If the turbine needs motorstart a system with diode rectifier must have extra start equipment

Synchronous generators are usually open (IP23) but enclosed generators (IP54) are also made. Enclosed generators are preferred in wind turbines. The price in this comparison is for a enclosed synchronous generator.

Synchronous generators can be made with about the same efficiency as the induction generator.

Conclusions

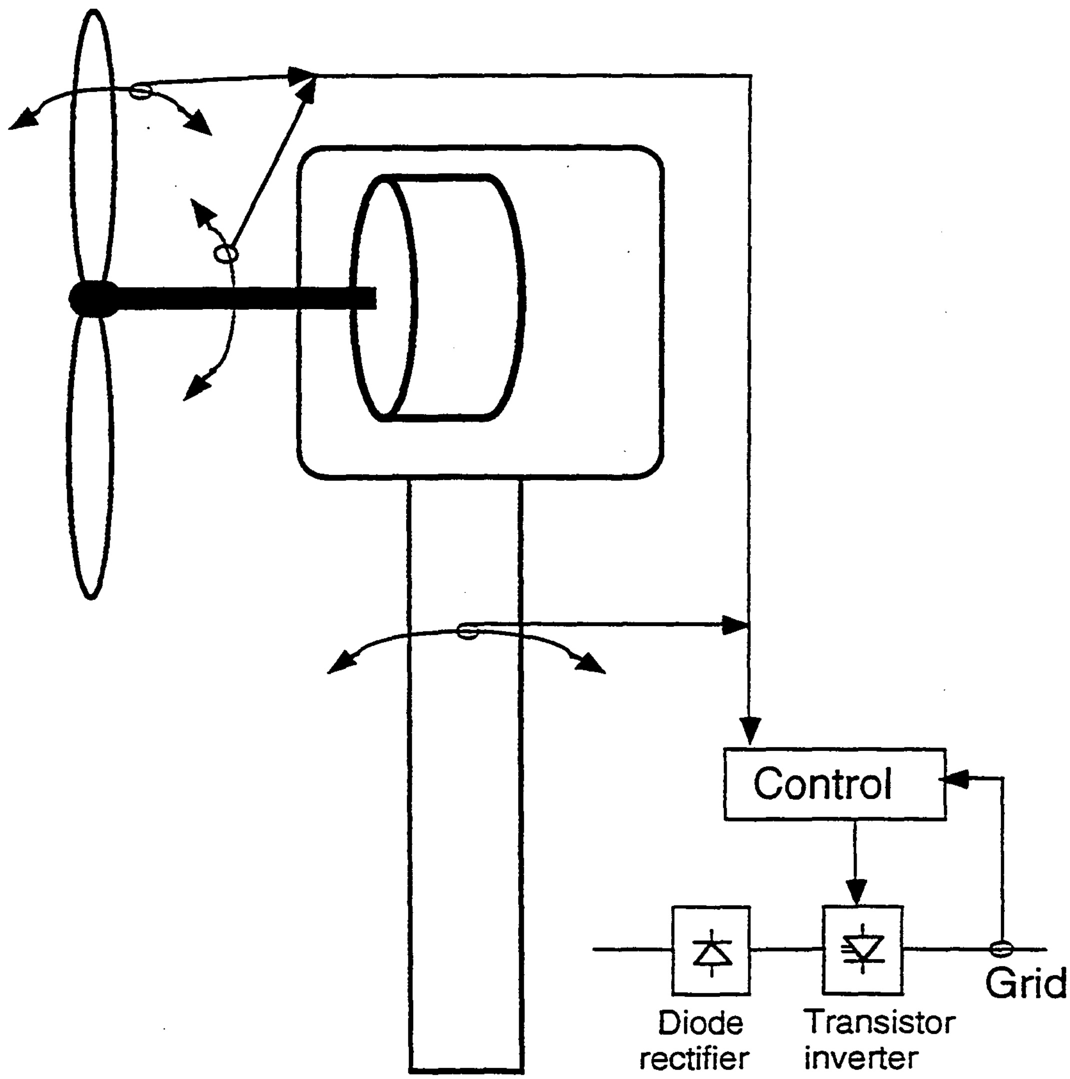
The cost of generator losses are often more important for the total cost than the generator price!

Even if the transistor rectifier becomes much cheaper its losses will still make the diode rectifier a more economical choice.

The synchronous generator only have one advantage compared with the induction generator, but it is an important advantage: It allows the use of the cheap diode rectifier!

WIND ENERGY RESEARCH AT CHALMERS

The wind turbine of the future ?



INTEGRATION OF Structure dynamic, Aerodynamic
Electrical and Control systems

Certification Activity at Risø

Peter Hjuler Jensen
Risø National Laboratory

THE DANISH TYPE APPROVAL AND CERTIFICATION SYSTEM

Peter Hjuler Jensen
Head of The Test Station for Wind Turbines
Risø National Laboratory, Denmark.

Jørgen Lemming
Head of the Wind Turbine Section
The Danish Energy Agency.

1. INTRODUCTION

The majority of wind turbines build in Denmark have been regulated through a public systems approval scheme as a part of the administration of the Danish subsidy scheme for renewable energy installations. This approval scheme has been in force since 1979.

In connection with the decision to stop the subsidy scheme for wind turbines in Denmark, a new system for type approval and certification of the quality assurance systems for production and installation was established in 1991. The new and more comprehensive system is presented in the present paper.

The background for the establishment of a new approval scheme in Denmark is a common desire from manufacturers and users that a coherent set of rules and quality control systems for wind turbines should be created covering the complete process from design to installation.

2. THE DANISH TYPE APPROVAL AND CERTIFICATION SYSTEM

2.1 General

The legal basis for the approval scheme is a law (no. 2 of January 2nd 1981) about the utilization of renewable energy sources etc., which was last modified by law no. 302 of May 16th 1990.

The approval scheme includes the complete process from design and production to installation. Approval is mandatory for grid connected and non grid connected wind turbines with a rotor diameter larger than 6 m.

The approval scheme consists of a type approval and a certification of the quality control system for the production and the installation.

In addition, principal components can receive a limited approval. Principal components are components whose value constitutes a substantial part of the production price of the wind turbine installation. Examples are blades, machine frame, transmission system, gearbox, generator, tower, foundation and control.

The approval scheme must ensure compliance with current safety requirements but must also ensure, that quality aspects such as performance and noise emission are properly documented.

It is the goal that the system shall satisfy as far as possible those requirements set by both producers, wind turbine owners, insurance companies and authorities.

The approval is based on a verification of the wind turbine supplier's documentation of his product, possibly supplemented by control calculations, and tests.

The approval scheme applies for wind turbines installed in Denmark excluding the Faroe Islands and Greenland.

Both land-based and off-shore wind turbines are covered by the approval scheme. Generally an effort is made to ensure that the type approval can be used for all wind turbines erected either in Denmark or abroad.

The approval scheme has been adapted to requirements and procedures needed in the future with a view to the technical harmonization and application within the European Community after 1992.

An approval does not absolve a wind turbine supplier from the responsibility for his product.

2.3 Organization of the approval scheme

The scheme is administered by the Danish Energy Agency which has set up an advisory committee consisting of representatives from the following organizations:

The Association of Danish Wind Turbine Manufacturers
The Consumer Association of Danish Wind Power Works
The Society of Insurers
Danish Electricity Works Association
The Danish Energy Agency
Test Station for Wind turbines

The Danish Energy Agency chairs the committee and the Test Station for Wind Turbines provides the secretariat.

The supreme administration of the combined scheme is handled by the Danish Energy Agency in collaboration with other state authorities concerned, including especially the Agency of Industry and Trade for the accreditation of authorized bodies.

The Danish Energy Agency authorizes the institutions, certification companies etc. which act under the scheme and which must perform the concrete, practical approval work, including type approvals and certifications.

Institutions, companies etc. will be authorized in accordance with both nationally and internationally recognized criteria and standards in order to ensure impartiality in the treatment of the matter.

Further, the Danish Energy Agency will ensure that a co-ordination of the authorities' requirements occurs, and it will follow international work in the field of rules and certification together with the authorities appointed under the scheme.

3. TYPE APPROVAL OF WIND TURBINES

3.1 General

The objective of the type approval is to ensure a satisfactory quality of the documentation of the wind turbine design and specification (drawings, parts lists etc.) which are to form the basis for the production, installation, operation and maintenance of a wind turbine type or a main component of the same. The type approval is issued against the background of a verification of the wind turbine manufacturer's documentation of the wind turbine design or main component design concerned, supplemented with tests in relation to The Technical Basis for type approval and certification of wind turbines in Denmark (Ref. 1 hereinafter termed the Technical Basis) which is the present technical basis for Danish approval system.

The type approval of the wind turbines must, on the one hand, ensure compliance with current safety requirements concerning

- Safety systems
- Mechanical and structural safety
- Personal safety
- Electrical safety

and, on the other hand, ensure that the documentation of the Wind turbine type fulfills the requirements in the Technical Basis with respect to technical quality, including

- Life of machine and electrical components
- Efficiency
- Reliability
- Noise emission

For approval a complete and unambiguous documentation material must be present. The quality of the documentation shall be such, that if the production, installation, and operation of a wind turbine is carried as documented, it is ensured that the requirements in Technical Basis are fulfilled.

3.2 Wind Turbine Type Approval and its Maintenance

Under the type approval the following are approved:

- Design, including the external conditions assumptions

- A specific design with drawings, specifications and part lists, and also description of functioning

- Requirements for the specifications for production, transport, installation and maintenance of the wind turbine

Holders of a type approval must maintain the approval every year by documenting to the type approval authority :

- A summary of wind turbines erected
- Reports of substantial defects and accidents in operation which are known to the holder of the approval
- A product specification, emphasizing changes in construction or production
- A request for continuation.

The type approval authority shall approve all changes in the product specification.

3.3 Major Damage (accidents/incidents)

Major damage (accidents/incidents) of which producers or suppliers become aware shall be reported immediately to the approval body and to the Test Station for Wind Turbines. The type approval body decides on eventual consequences for the existing type approval.

3.4 Wind Turbine Classes

Three approval classes are defined, termed classes A, B and C.

Approval class A is the final comprehensive approval. It requires both a type approval A without any outstanding issues and a certified quality assurance system according to ISO 9000 for production and installation.

Approval class B requires a type approval B (type approval A, but possibly with a list of outstanding issues). No safety related points can be on the list of outstanding issues. A quality assurance system made on the basis of ISO 9002 for production and installation shall be described.

Approval class C is a pure safety approval normally for prototype wind turbines for a limited period (maximum 3 years).

3.5 Contents of Type Approval Documentation Material

The following documentation material must be enclosed with the application for type approval:

- design assumptions, including
    - environmental assumptions (e.g. wind conditions, park effects, soil conditions, temperatures, lightning, earthquake effects, icing, and for off-shore turbines also wave, current and ice load)
    - operating specifications (yaw error distribution, number and loads in relation to starts and stops, effectiveness of the brake systems, time and number of yawings, strategy for output regulation and control algorithms, loads on the electrical grid)
    - specification of the wind turbine foundations
    - the wind turbine control strategy and safety-systems
    - references to safety codes and standards used
    - preconditions for the production of the wind turbine
    - preconditions for the transport and installation
    - technical lifetime and efficiency.

- Drawings and specifications and parts lists for the wind turbine.
- Description of the function of systems for safety, control and regulation (electrical and mechanical).
- Loads, load cases, dynamic behavior etc. derived from a detailed description of the wind turbine's operational modes, both for the turbine operation, transport and erection, including a description of the wind turbine's dynamics.
- Demonstration of the wind turbine's strength and robustness in wear and tear parts. The documentation must be produced by the manufacturer on the basis of eg. safety codes and standards, with the aid of calculations and measurements etc. If using non-standard materials, material properties must be documented.
- Documentation of the strength of the load carrying parts of the wind turbine.
- Specification and documentation of ultimate and fatigue loads in the joint between the tower and foundation.
- Documentation of the electrical system with respect to personnel safety, according to the Danish regulation for electrical safety, and to loads on the grid.
- Specification of the quality control requirements for production and installation .
- Instructions for production processes, including tolerances, materials, temperatures, etc.
- Instructions for transport and installation. The instructions must be included in an installation manual.
- Procedures for the commissioning of the wind turbine.
- Operation and maintenance instructions. The instructions must be contained in a service manual.

A time schedule for the provision of the necessary documentation must be agreed upon between the applicant and the approval body. If the time schedule is are not adhered to by the applicants, the approval body is entitled to report the rejection of the application.

The technical rules in the Technical Basis for approval is based on existing national and international codes and standards which are relevant in the field of wind turbines.

Where possible, Fields not covered by the above codes and standards are supplemented with instructions in the present basis for approval and in the set of recommendations, given in Ref. 3: "Recommendations to fulfill the Technical Basis for type approval and certification of wind turbines in Denmark".

The rules in the Technical Basis for approval can be waived if it can be documented in a satisfactory manner that the safety and quality level are not reduced.

The documentation can be supplemented with reports documenting supplementary measurements of loads etc, and with documentation of component tests and tests of details which are undertaken by the manufacturer or his sub-contractors.

Where a component approval exists, it is normally sufficient to present the approval document and to demonstrate, that the use of the component is in accordance with the component approval.

For both classes A, B and C a wind turbine prototype is inspected by the type approval body in connection with the processing of the application for a type approval.

The approval body shall inspect the wind turbine in operation. During this inspection and under his own responsibility, the manufacturer must demonstrate through function tests the correct functioning of the wind turbine including all control and safety system functions. At the same time personnel safety measures is examined.

The type approval body can further undertake random spot check of wind turbines that have been erected. Under these checks, the identity with the approved wind turbine type is checked.

3.6 Required Measurements

Where a wind turbine documentation includes results of measurements which are carried out by a non-authorized body, the type approval body can request an independent verification of these. The verification must as a minimum contain an examination of the calibration, measuring equipment, measuring procedures and results, a visit to the test facility and, if the test runs over several days, a further unannounced inspection during the tests.

For verification of the wind turbine documentation the type approving body can arrange further tests where the documentation is uncertain, where values in the documentation deviate from the expected ones, or where generally accepted calculation procedures are not used. A differentiation is made between a basic measurement program, a systems measurement program and component tests. The tests must be carried out by an institution or a firm which is recognized by the Energy Agency.

The type approval body will further initiate inspection on a random selection among the erected Wind turbines.

3.6.1 Basic Measurement Program Requirements

Where the type approval body considers that the documentation of safety systems, noise emission and power curve (power performance) forwarded is insufficient, the type approval body will require that a basic measurement program is undertaken. Normally the type approval body requires the measurements to be carried out by an accredited body.

3.6.2 Systems Measurements Program Requirements

Where the type approval body considers the documentation of a wind turbine insufficient as a result of unusual features in the wind turbine designs which are not documented in verified measurements, for example a new rotor design, a new wind turbine concept, or a new wind turbine size, the type approval body will arrange a more comprehensive check, a systems measurement program. The contents of the systems measurement program shall be adapted to the wind turbine type concerned and its special problems.

3.6.3 Component measurements

Where the documentation of a part in the wind turbine is insufficient, the type approval body can request a component measurement program.

The rigidity, strength and fatigue properties of the blades must be documented by calculation and by both ultimate and fatigue testing of the blade.

For blades, the following are the minimum requirements on the measurements:

- For wind turbines which are approved according to class A and B the documentation must as a minimum include the result of a basic measurement program and a blade program where the properties of the blade are demonstrated.

- For wind turbines which are approved according to class C the documentation must as a minimum include the result of a proof test of the blades where the properties of the blade are demonstrated.

3.7 Type Approval Reporting

The type approval work is concluded with the issue of a certificate of approval and a report giving an account of the approved wind turbine type, of the verification work carried out, of the assessments made, and of possible disputes during the approval process.

The report must contain a description of the approval work and of the result of the assessments given. In addition the report must include:

- a list of approved drawings
- a list of approved part lists and specifications
- a list of reports
- a list of requirement specifications
- a list of wind turbine manuals
- a list of outstanding matters and a timetable for the clarification of the outstanding reservations
- an inventory of documentation received

The report is drawn up in triplicate, one copy to the applicant, one to the Test Station for Wind Turbines, and one to the type approval body.

3.8 External Conditions

3.8.1 General

This section describes the climatic and other external conditions assumptions used for the design of wind turbines for erection in Denmark, excluding the Faroe Islands and Greenland.

For erections abroad, a special investigation must be made on the adequacy of the climatic assumptions below. In some cases, corresponding information on climatic and external conditions for the potential installation sites must be obtained and used in the design of the wind turbine.

Climate conditions

The following climatic conditions have to be taken into account in a design in accordance with Danish Standard 472 "Standard for loads and safety for Wind turbines", Ref. 2:

- Wind conditions (normal and extreme)
- Lightning
- Icing
- Hail
- Temperature (normal and extreme)

Other conditions

The following conditions have to be taken into account in a design in accordance with the Danish Standard 472 (ref.2)

- Terrain (roughness, overspeed and increased turbulence due to non homogeneous terrain)
- Erection in wind farms (increased turbulence)

In the selection of the wind condition assumptions account must be taken of the possible form of terrain where it is intended to erect the wind turbine type concerned. As a minimum the assumptions about the following terrain conditions must be stated in the documentation of the construction and dimensioning of the type of wind turbine.

- Roughness of terrain
- Overspeed effects with non-homogeneous terrain
- Increased turbulence in non-homogeneous terrain
- Shelters (increased turbulence)
- Air humidity
- Salt and dust content in the air
- Chemical effects
- Salt water spray
- Ultra-violet radiation

Besides these external conditions the following emission phenomena shall be specified in accordance with the requirements.

Noise conditions

In connection with the erection of wind turbines in Denmark requirements limiting noise emission are laid down by the Office of the Environment (Ref. 4). For the determination of the noise emission of a wind turbine the measurement and the method of calculation given in Ref. 4 shall be used.

Reflection conditions for blades

The assumed reflection conditions for blades must be stated in the wind turbine's documentation, according to the following classification:

Class	Description	Brilliance figure
I	Matt	< 30%
II	Half matt/half gloss	30-70%
III	High brilliance	> 70%

The reflection properties are measured according to DS/ISO 2613.

3.9 Requirements for the Control and Protection System

In the following the requirements for the control and protection system are given.

Control system

The control system must keep the wind turbine within its normal operating range. The normal operating range must as a minimum be given with:

- a maximum 10 minutes average wind speed at hub height V_{max} (stop wind speed), under which the wind turbine may be in normal operation.
- a maximum output P_{max} averaged over 10 minutes, which must not be exceeded for a wind speed at hub height of $V_{10min,hub} < V_{max}$,
- a maximum frequency of rotation $n_{r,max}$ for the wind turbine.
- a maximum long term mean power P_{nom} (nominal power) understood as the highest power on the power curve in the Wind velocity interval V_{min}-V_{max}

The control system shall monitor operating parameters which are of importance for functioning and safety. As a minimum in the design stage one must consider whether the following parameters should be monitored:

- wind speed
- external temperature
- critical temperature in components(generator, gearbox, etc.)
- twisting of cables
- voltage and frequency
- network (or single phase) outage
- power output
- rotational speed
- yaw deviation - difference between the wind direction and the wind turbine orientation

The control system must initiate the necessary actions to keep the wind turbine within its normal operating range, e.g.:

- yawing
- blade regulation
- activation of brake system
- connection to the electrical grid
- power limitation

The control system's monitoring and actions must be adapted to the design of the wind turbine.

Safety system

The following requirements are set for the safety system:

- The safety system must be fail safe for a failure of the power supply

- The safety system must be tolerant of a single fault in a sensor, in the electronic and electrical as well as in the hydraulic system or in active mechanical mechanisms, i.e. an undetected fault in the system must not prevent the system from detecting a state of failure and carrying out its function.

- The safety system takes precedence over the control system. Only manual activation of emergency stop must have priority.

- Structural parts in mechanisms in the safety system are classified in a high safety class.

- The safety system's reliability must be sufficient for one to be able to ignore a situation where the safety system fails with exceedence of the extreme operating range as a result. This extreme operating range is defined by a maximum operating and a maximum transient speed of rotation. Reliability can be ensured with

    - over-all fail safe quality of the complete safety system, or

    - duplication of those parts of the safety system where there is no fail safe quality, or

    - frequent checking of the safety system's level of functioning, where the interval of checking is determined through a risk assessment an evaluation of the risk.

The requirements for the wind turbine's safety system can be fulfilled by complying with Danish Standard DS-472 Norm for Load and Safety of Wind turbine Constructions (Ref.2).

3.10 Structural and Mechanical Safety

3.10.1 Safety

Wind turbines must be designed to

- withstand the presumed stresses with a given safety
- function satisfactorily in normal use
- have sufficient resistance and robustness

during the expected life with correct use and maintenance.

Demonstration of the fact that the load carrying construction elements and machine parts have the prescribed safety can be done by calculation, testing or a combination of these.

The rotating parts in a wind turbine must be classified in a normal or high safety class.

The general safety requirements are contained in DS 472, Loads and Safety for wind turbines, Ref. 2.

3.10.2 Limit Conditions

A wind turbine's safety must be demonstrated in relation to the following limit states:

- fatigue limit state
- maximum load limit state (ultimate limit state)
- accident load limit state

The wind turbine limit states shall be investigated for load combinations which are derived from possible design situations, combined with the relevant external conditions to load cases in accordance with Danish Standard DS-472.

Furthermore, safety must be demonstrated in relation to the following usage limit conditions:

- corrosion
- crack formation
- wear.

The wind turbines limit states stall be investigated for both the normal and extraordinary load situations (or operational modes), combined with both normal and extraordinary climate conditions in accordance with DS-472. Extraordinary modes are only combined with extraordinary climatic conditions, if the mode is entered because of the extraordinary climate conditions.

3.10.3 Materials

The properties of materials used in wind turbines must be documented in accordance with existing design codes and standards or be documented at a corresponding level.

Materials must be marked in such a way that their properties can be identified in an unambiguous manner.

3.11 Personal Safety

3.11.1 General

In a wind turbine's design and dimensioning and also in the carrying out of instructions and procedures for transport and assembly, operation and maintenance it must be ensured that a wind turbine does not constitute an unacceptable risk for persons who are working on the wind turbine or are staying in its vicinity.

Furthermore, it shall be possibly to comply with the notice no. 43 of the Ministry of Labor of January 22nd 1981 "Notice about the setting up and use of technical aids" at all times.

3.11.2 Transport, erection and Installation

Instructions and procedures must be drawn up for the transport of the wind turbine, for the assembly and erection and also for the running in. The requirements for personal safety must be borne in mind when drawing up the instruction. Instructions and procedures must be described in an installation manual which must be approved.

The wind turbine and tackles for the erection must be dimensioned for the loads which can result during transport, assembly, erection and running in, compare above.

The maximum wind speed at which the wind turbine may be erected must be clear from the instructions.

It must be ensured that procedures and instructions are known and followed by the party responsible for transport and erection and also by fitters and others who are working on the wind turbine.

3.12 Electrical Installations

3.12.1 General

Safety requirements are set for the wind turbine's electrical installations with regard to personal protection, the wind turbine's own function, electro-magnetic disturbances and power network effects.

Further the rules in the Danish regulations for electrical installation must be adhered to, to the extent that they apply:

- Safety for persons and property
- Production without disturbances in operation
- Long life for the material and expedient maintenance.

Requirements concerning power network effect deal with both the wind turbine's effect on the power network and the effect of network variations on the wind turbine.

4. PRODUCTION CERTIFICATE

4.1 General

The approval scheme's requirements for a production certificate aim at ensuring the quality of each single wind turbine or main component, including compliance with the approval for the product.

The production certificate is based on the verification of the manufacturer's procedures for quality control during production complying with the type approved specifications.

It is assumed that the technical requirement specifications for production are specified in connection with the type approval, and that the necessary drawings and specifications are present.

4.2 Certification of the QA-System for Products

When applying for a certification of the quality assurance system for production or installation, the manufacturer must forward to the certification body the following documentation.

- All relevant information about the planned wind turbines which will be produced or installed, including copies of any type approvals issued.

- A description of the quality control system

- A statement from the producer/supplier to fulfil his obligations in connection with the quality control system used, including then maintenance of the system and its continuous proper and effective functioning.

- A quality manual complying with the requirements in DS/EN 29002, and describing all relevant conditions in the firm.

- A description of the quality assurance measures which ensure the desired quality of product normally described in activity plans/programs for the products concerned.

The following elements in the QA-system is certified by the approved body in accordance with DS/EN29002:

- The management's responsibility
- Document control
- Requirements for purchase
- Product identification and traceability
- Process control
- Inspection and checking
- Inspection, measuring and inn equipment
- Inspection and inn status
- Control of deviant products
- Handling, storage, packing and delivery
- Registration re quality
- Education and training
- Issuing of certificate
- General
- Procedure
- Maintenance of the certificate
- Verification
- Deviations
- Top level control

5. INSTALLATION CERTIFICATE

5.1 General

An installation certificate aims at ensuring the quality and safety of the wind turbine in connection with transport, assembly and running in.

A precondition for the issue of an installation certificate is that the requirements for the quality control system for installation are in accordance with the technical requirement specification laid down in connection with the type approval.

The installation certificate and the production certificate mentioned in chapter 6 can be combined if the applicant works in both fields and the procedures fulfil the combined requirements.

An installation certificate for wind turbines erected in Denmark includes a verification, that transport, assembly, erection, and running in of a given wind turbine installation have been carried out in accordance with the conditions in the type approval and compliance with current rules.

The following elements in the QA-system is certified by the approved body in accordance with DS/29002:

Quality control system
The management's responsibility
Document control
Requirements for purchase
Product identification and tractability
Quality in installation
Inspection and checking
Inspection, measuring and inn equipment
Inspection and inn status
Control of deviant product installation methods
Handling, storage, packing and delivery
Registration re quality
Education and training

Issuing of certificate
General
Procedure

Maintenance of the certificate
Verification
Deviations

Top level control

CONCLUSION

In the paper the Danish wind turbine approval system is presented. The system has now been working in 2.5 years and after the first corrections the system is now beginning to work as an operational approval system.

The system have been designed in accordance with the new approach for approving systems in the EU, and is now liberalized so that also institutions outside Denmark may obtain an accept to approve wind turbines for erection in Denmark.

In general the new approval system has increased the quality of the documentation significantly and it is expected that a long term reliability of the turbines will be improved.

REFERENCES

1 Technical basis for type approval and certification of wind turbines in Denmark

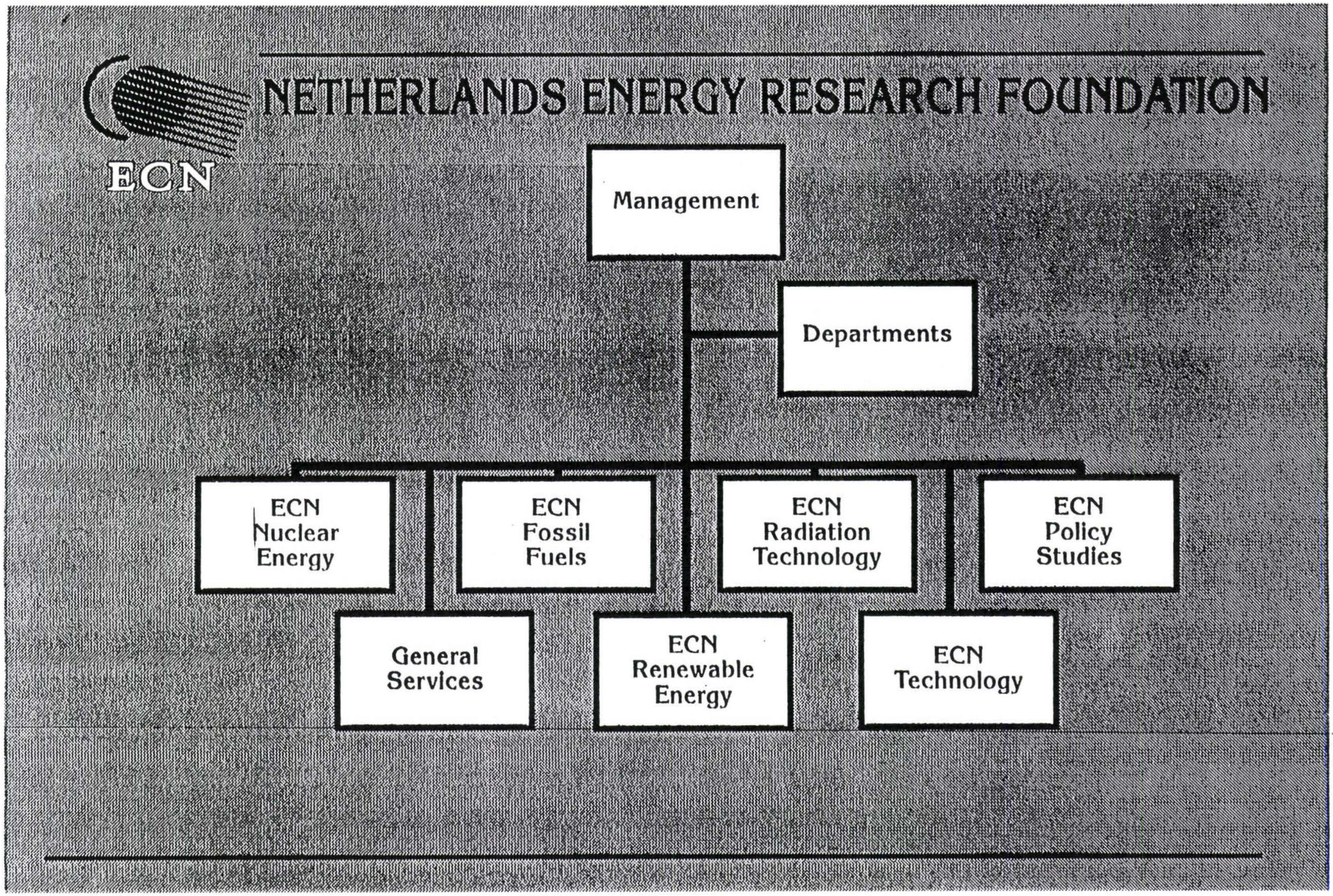
2 Danish Standard for loads and safety of wind turbines in Denmark, DS-472.

3 Recommendations to fulfill the technical Basis for Type Approval and Certification of Wind Turbines in Denmark.

4 "Notice about noise from wind turbines" - Bekendtgørelse om støj fra vindmøller, Miljøministeriets bekendtgørelse nr. 304 af 14 maj 1991.

ECN Certification Activity

Wim Stam
ECN


NETHERLANDS ENERGY RESEARCH FOUNDATION
ECN
Management
Departments
ECN Nuclear Energy
ECN Fossil Fuels
ECN Radiation Technology
ECN Policy Studies
General Services
ECN Renewable Energy
ECN Technology

ECN

BUDGET 1993

(in millions of guilders)

RECEIPTS	[illegible]
Government	61.0
Contracts	92.0
EXPENDITURE	[illegible]
OPERATING RESULTS	[illegible]

ECN

ENGINE components

- clean fossil
- safe nuclear
- affordable renewable

ECN ≡ RENEWABLE ENERGY

* WIND ENERGY
* SOLAR ENERGY
* BIOMASS (Waste included)

ECN

PHOTOVOLTAIC SOLAR ENERGY

ADVANTAGE

* LARGE POTENTIAL
* DISPERSED APPLICATIONS
  - Roofs
  - Parking area's
  - Highway verges & lay-by
  [Example: ^{235}U - enrichment)
* PASSIVE SYSTEM
  (No mechanical wear & corrosion)

DISADVANTAGE

* EXPENSIVE (Presently 5÷10*)
* STORAGE

ECN

(2/3)

PHOTOVOLTAIC SOLAR ENERGY

* NL-POTENTIAL ALONG: [kWh/yr]

- Highways's	:	2%
- Sec. RDS	:	22%
- Train tr.	:	1%
	≈	25%

* NL-PROGRAMME
2010 : 250 MWp
Energy savings: 2 PJ (< 1‰)

ECN

(3/3)

PHOTOVOLTAIC SOLAR ENERGY

ECN-RE R&D

* Cell & Cell material characterisation:
  - performance (current/voltage);
  - spectral performance;
  - local spectral performance (light beam induced current mapping);
  - recombination efficiency; (photocurrent decay measurements);
  - reflectance measurement, etc.

* Modelling

* Cel & module process improvements
  - defect passivation & gettering
  - surface texturisation
  - contact improvements

* Grid integration

* PV-field measurements

ECN

BIOMASS

* ENERGY CONSUMPTION IN NL: 2300 PJ

* POTENTIAL CAPACITY (per year):
  - Waste : 50 PJ
  - Forestry : 20 PJ
  - Manure : 20 PJ

		90 PJ
- Energy crops		140 PJ
- Balance		30 PJ
	Total ≈	260 PJ

* TARGET (2010) : ≈ 4½%

* PRESENTLY (1994) : ≈ 1% (Waste & Forestry)

ECN

WIND ENERGY

* NL-PROGRAMME: 1000 MW : 2000

- Presently installed	: 130 MW
- Assume WT	: 500 kW
- Number of WT	: 1800
- Time span	: 6 yr.
- Installation rate	: 300/yr

* STAGNATION

- Costs
- Reliability
- Siting !!!!!

ECN

WORKING AREAS ECN RENEWABLE ENERGY

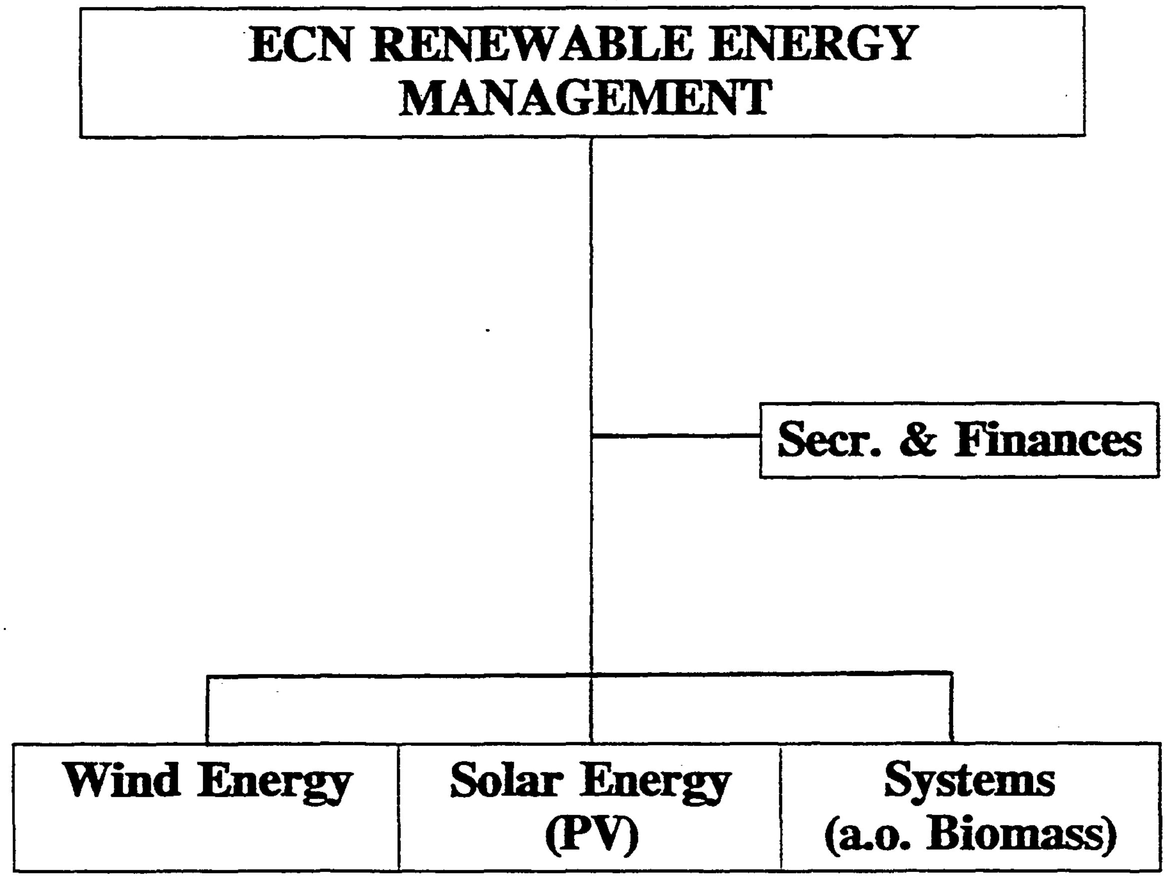
Solar Energy (PV)

* Characterization of cells & materials (8 characterization methods in state of the art. lab.)

* Modelling of high efficiency cells

* Cell & module process development (processing lab.)

ECN


ECN RENEWABLE ENERGY MANAGEMENT
Secr. & Finances
Wind Energy
Solar Energy (PV)
Systems (a.o. Biomass)

ECN

WORKING AREAS ECN RENEWABLE ENERGY

Wind Energy

* Wind field modelling

* Rotor aerodynamics (dyn. stall, dyn. inflow, field aerodyn. facility)

* Loads (integral model)

* Strength & Fatigue (fatigue testing lab. & procedures)

* Concept developments (FLEXHAT concept, WEGA study)

ECN

WORKING AREAS ECN RENEWABLE ENERGY

Systems

* Electrical conversion & control
  Wind: direct drive generator, AC/DC/AC convertors, Control strategies
  PV: module integrated invertor DC/AC, invertor development and testing

* Monitoring
  Wind turbines: power, wind speed, acoustic noise, loads
  PV systems: power, solar insulation, efficiency

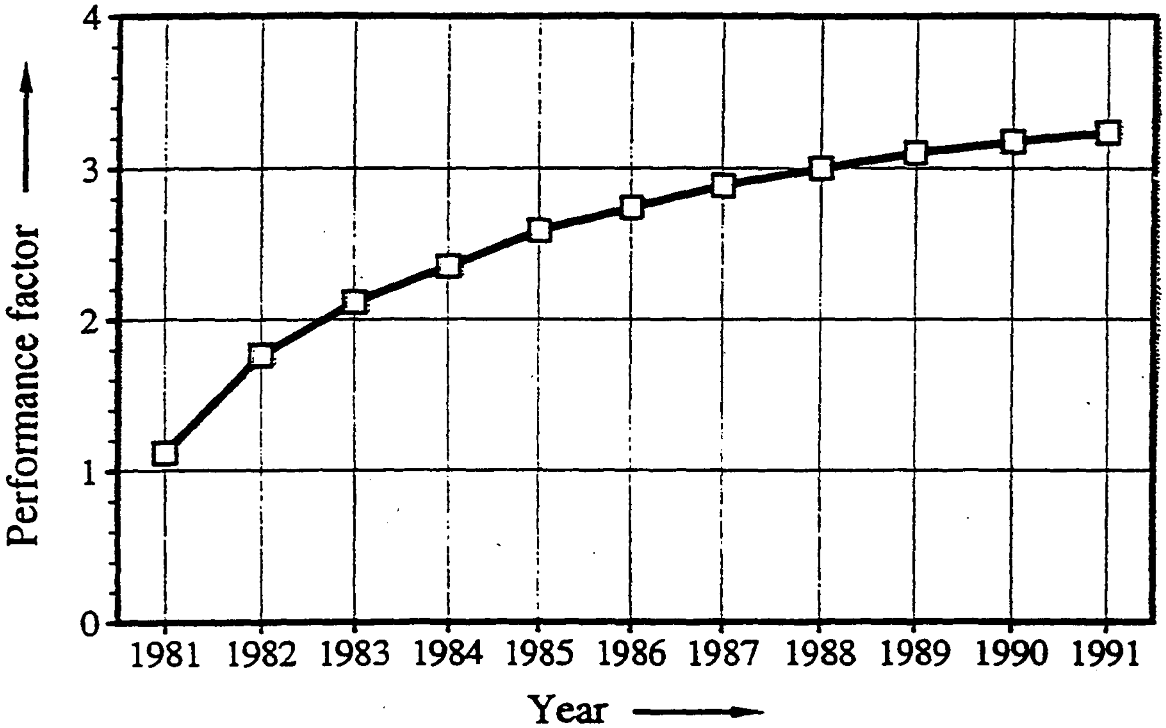
* PR(S)A
  Wind turbines

* Certification tests and standards
  Wind turbines, Solar systems (PV and thermal) (in preparation)

* Biomass gasification/gasturbine
  BURE pretreatment, BUFF: gasification, gas cleaning

ECN

THE DEVELOPMENT OF THE PERFORMANCE FACTOR OF WIND TURBINES AS A FUNCTION OF THE YEAR OF MANUFACTURE [1]



Risø Testing Activity

Troels Friis Pedersen
Risø National Laboratory

(Unavailable at time of printing)

Weibul Wind Distribution

Valeri Minin
IEN

KOLA SCIENCE CENTER RUSSIAN ACADEMY OF SCIENCES

I E N

INSTITUTE for PHYSICAL and TECHNOLOGICAL PROBLEMS of ENERGY in NORTHERN AREAS

Fersman str., 14, Apatity,
Murmansk region, 184200 RUSSIA

Phone: 37-312; 32-426
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APATITY
1992

History.

Energy research within the Kola Science Centre(KSC) of the USSR Academy of Sciences started in 1948. In 1973 the KSC energy research group recieved the status of the separate Energy Research Department. In 1987 the USSR Counsil of Ministers made the decision to strengthern investigation in the field of energy at the KSC in acordance with which three years later the Energy Research Department was reinstituted into the Institute for Physical and Technological Problems of Energy in Northern Areas (IEN) of the Academy of Sciences.

Research Directions.

General research objective of the IEN is working out the effective regional energy policy as well as the means of its promotion under modern social and economic conditions. To reach this objective the Institute carries its research in the following directions:

- search for and investigation of socially and ecologically effective paths of energy development under emerging market conditions with accounting for specifics of northern regions;
- studying problems of reliable and effective electricity supplies to the consumers under specific conditions of the North;
- development of electric impulse technologies of destructing minerals.

Today the main scientific, personnel and financial potential of IEN isconcentrated on the first of above-mentioned directions. In the frame of this direction we disingwish the following problems as the most important ones:

- working out effective energy concervation policy;
- analyses and examination of environmental impacts of energy programmes and projects;
- perspective utilization of renewable and unconventional energy sources.

The Institute's structure

THE BOARD

Research Council — General services

DEPARTMENT of energy consumption and conservation	DEPARTMENT of energy supply	DEPARTMENT of power engineering and electrophysics
Laboratories:	Laboratories:	Laboratories:
of industrial energy demand	of systems development	of electrophysics
of social problems of energy	of ecological problems of energy	of electric impulse technologies
	of unconventional and renewable energy	highvoltage testing

At present there are 64 staff members working at the Institute, 22 of which are researchers including 10 doctors and professors.

Our intentions and opportunities.

Our sincere wish is to offer fair energy research service to regional and municipal planning and managing bodies as well as to energy utilities and consumeres in order to assist in solving current and prospective issues in relation to working out and implementing effective energy policy while accounting for concrete local factors and limitations. We would be most happy if those who once asked for our help, become permanent friends and clients of the Institute. And for this we try to do our job efficiently, ?interestedly, with high quality and at minimal cost for those, who apply to us.

Only by this way we can successfully solve our own problems of financing, sufficient for basic research, educational programmes, research equipment provisions, etc.

To fulfil any ordered study we:

- concentrate all necessery effort within the Institute;
- attract the services of leading specialists and use advanced methodologies from other USSR research centres;
- do our best to use international experience and expertise.

What opportunities has IEN already had for this?

1. Within the frame of USSR Academy of Sciences the IEN has had responsibilities for undertaking and guiding two nationalscale basic methodological research projects. This show good position we have in academic spheres of the country.

2. The Institute became co-founder of the national Center for effective energy use, aming at working out and stimulation of energy conservation policy in the country. About two dozens of Soviet well-known research and projecting organizations as well as several institutions from the USA are members of the Center. Through the Center we can attract to our at-home research almost any USSR team as well as foreign experts.

3. We have established a profit expertizing & consulting center (ECC) as an independent of IEN. Its activities will be oriented entirely to carring out applied research and promoting results into the practice of regional energy management. Through ECC we have anohter channel of settling cooperative relations with other research teams while undertaking at-home research.

4. The IEN has rather wide ties with different institutes and scientists not only in the USSR, but in the countries of Eastern and Western Europe, in USA,Japan, New Zealand.

The IEN research projects

No one research institute can successfully accomplish simultanious researches in many directions. We understand that and try to concentrate our efforts on a few research task at the same time. Today the Institute is carring out the following works:

1. Working out a computerized-decision support system for regional programmes of energy development. The system will allow by means of computer dialogue to outline the targets and best ways of regional energy development, to make corrections according to chenges in external conditions, and to select the admimistrative, legal, and economic incentives to permit market promotion of the programmes worked out. We believe the planning and managing bodies of regions,and energy supply enterprises and consumeres will have sence of necessity in such a tools very soon.

2. Working out a simulatition system for environmental examination of regional energy programmes and projects. The computer map & schemes (CMS) of current and prospective ecological situation in a region with reference to a broad range of different indices (emissions, concentrations, their influence on human beings, vegetation and animals) allow the user to swiftly estimate changes in it. This estimation can be done for region as a whole, for its section, and for a specific site. Such a system is absolutly essential for regional environmental control authorities by now.

3. Working out the complex programme of radical efficiency improvement of district heating systems and legal & economic means for its promotion. We think that the implementation of this programme at national scale permits to save billion roubles annually in several years due to fuel saving.

4. Working out strategies of development and increasing relyability of highvoltage network of regional power systems.

Other research and consulting opportunities.

The IEN by itself or through its expertizing & consulting centre can make wide range of specific elaborations, if these issues are in line with above-mentioned basic projects. As examples we can reffer to works on different aspects of heatsupply systems development and on ecological expertize of power industry objects. Besides these items, the Institute now can offer:

- consultating service on the issues of restructuring regional management and regulation systems under the market conditions;
- working out recommendations on different aspects of rural energy development and improvement;
- estimation of potential and ways of using of renewable sources of energy;
- arrangement of the modern computer's software of seaching optimal ways for development, reconstruction and restoration of heating networks, for conducting hydraulic operating conditions with appropriate stuff training:

same for water-pipe supply systems;
same for gas-pipeline systems.

Our coordinates:

Address: " IEN " , 14 fersman street, Apatity, Murmansk region, 184200, USSR.
Phone: 3-73-12 Telex: 126129 KOLSC SU ;

Director: ~~**Dr. Alexander A. Papin**~~ **phones: 3-73-12;** 3-24-26

~~**Deputy director:**~~ **Dr. Vladislav R. Elokhin phones:** 3-73-12; 3-76-11

Scientific secretary: Dr. Valery A. Minin phones: 3-73-12; 3-76-11

IEN KSC, Institute for Physical and Technological Problems of Energy in Northern Areas.

Address: *Fersman st. 14, Apatity 184200, Murmansk region, Russia.*
Tel. *32426, 37-312.* **Telex** *126129 KOLSC SU.*

Director: *Alexander A.Papin, Ph.D. (Energ.).*

Deputy director: *Vladislav R. Elokhin, Ph.D.(Energ.).*

Scientific secretary: *Valeriy A. Minin, Ph.D.(Energ.).*

Research activities: Working out the effective regional energy policy as well as the means of its promotion under modern social and economic conditions; searching for and investigation of socially and ecologically effective paths for energetic development under emerging market conditions with accounting for specifics of northern regions; studying problems of reliable and effective electricity supplies to the consumers under specific conditions of the North; research in wind-power development and investigations in non-conventional energy development of the North regions of Russia, including pump-storage plants, tydalpower plants.

Presently the main directions of researches are: working out effective energy concervation policy; analyses and examination of environmental impacts of energy programmes and projects; perspective for utilisation of renewable and unconventional energy sources.

Staff: 23 scientists and besides 41 auxilliary personnel.

The Institute includes 7 laboratories: industrial energy demand, social-economic problems of energy, regional energy policy, ecological problems of energy, unconventional and renewable energy, overvoltage and insulation, highvoltage testing.

Areas of scientific cooperation: Assessment of regional energy development and environmental impact of energy systems; new technical solutions on increasing of reliability of electric power systems.

Wind Energy North of Russia

Grigori Dmitriev
IEN

Indicies of joint exploitation of Serebrianskie HPPs and WEC's pool with the capacity 200 MWt (mln.KWt.h)

Indicies	1985	1986
Actual electricity productions by HPPs (totally)	863	1195
same by HPP N1	443	626
same by HPP N2	420	569
WECs pool production	558	727
Possible replacement of HPP's production by WECs pool		
Replacement of HPP N1	236	273
Replacement of HPP N2	102	109

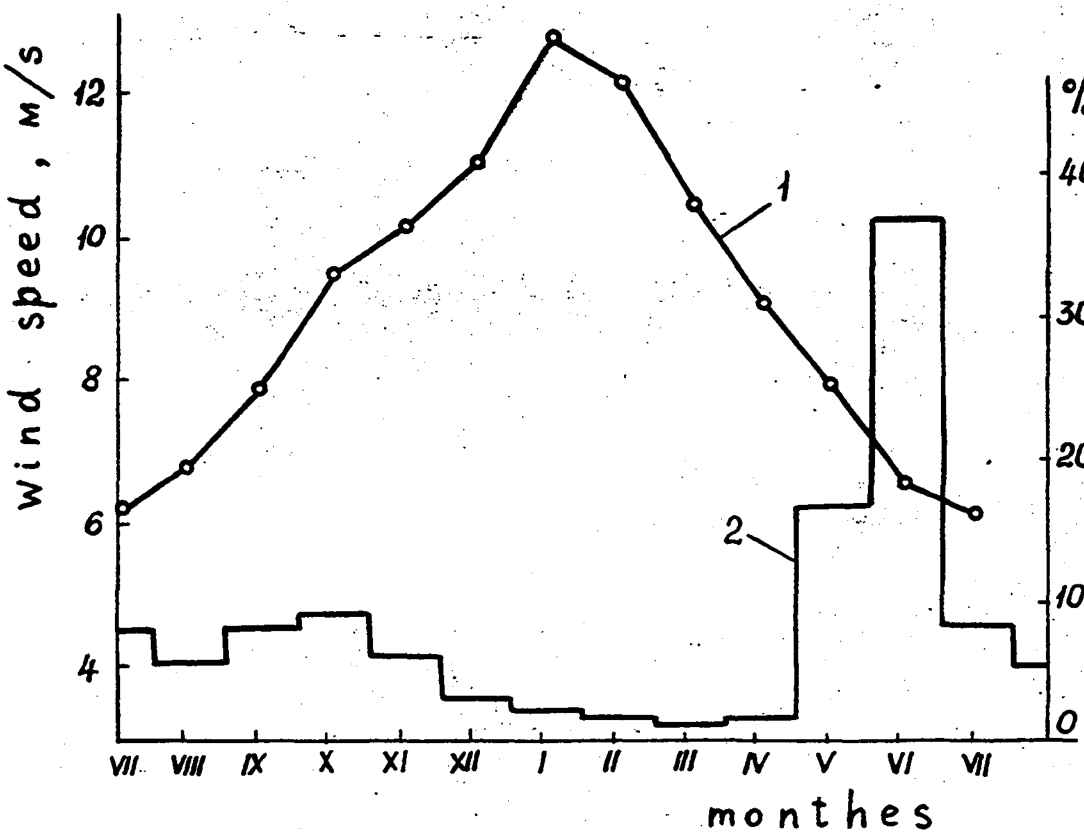


Fig.2. The seasonal trend of wind speed (1) and the distribution of rever's discharge (2) on Kola peninsula seacoast.

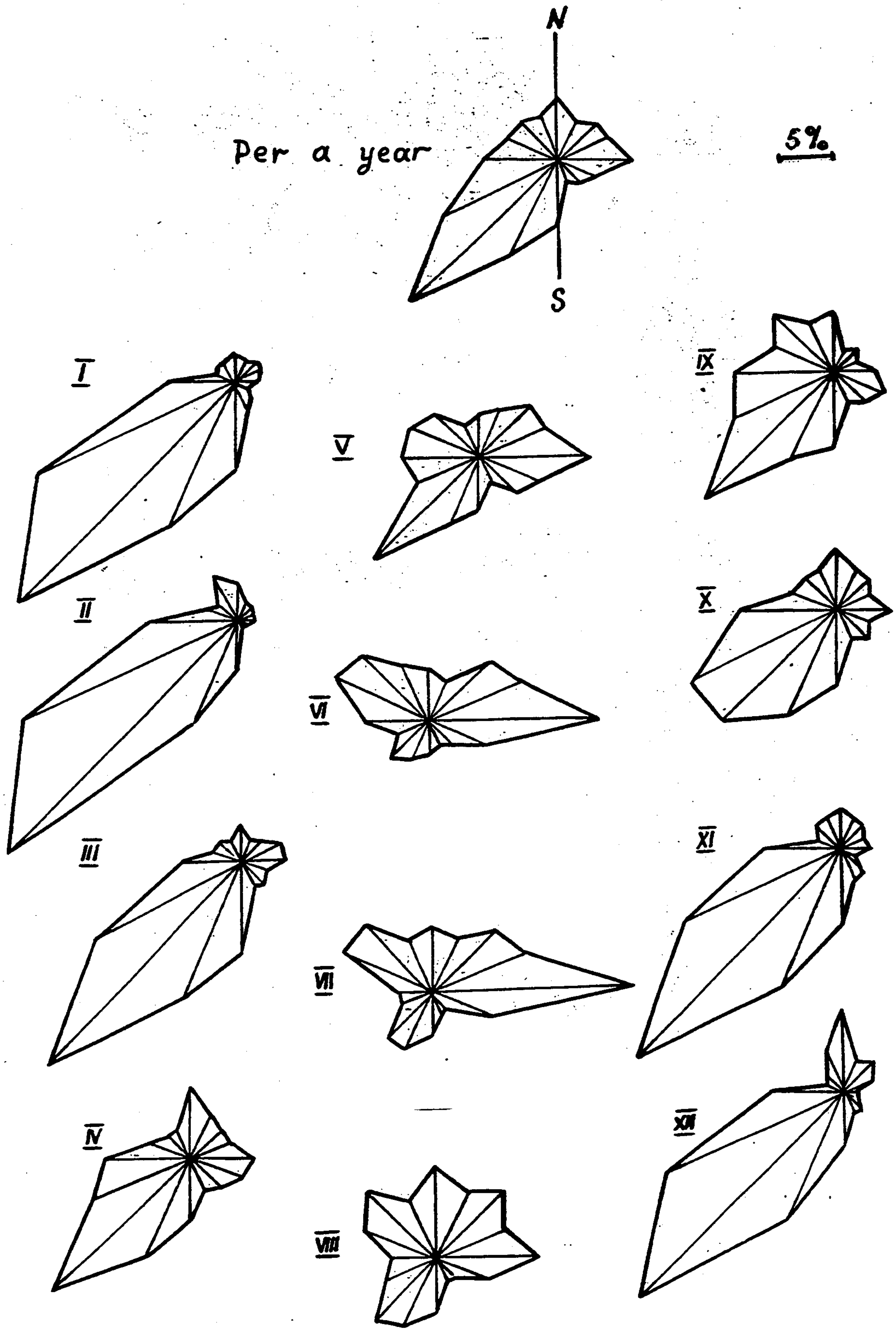
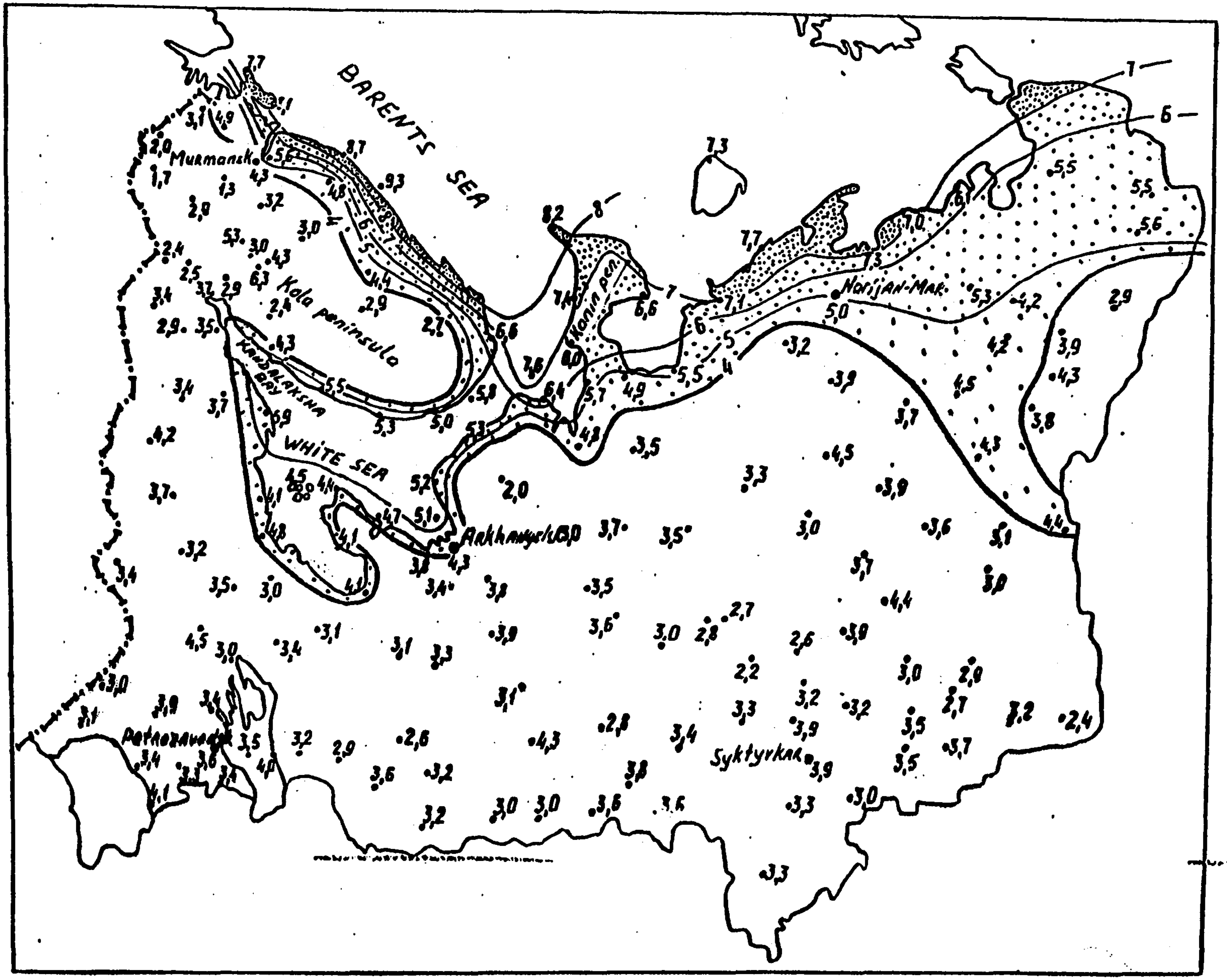


Fig.3. Annual and monthly windroses at the meteorological station Dalnie Zelentsy.


BARENTS SEA
Murmansk
Kola peninsula
Kandalaksha Bay
WHITE SEA
Kanin pen.
Narjan-Mar
Arkhangelsk
Petrozavodsk
Syktyvkar

Pic. 1

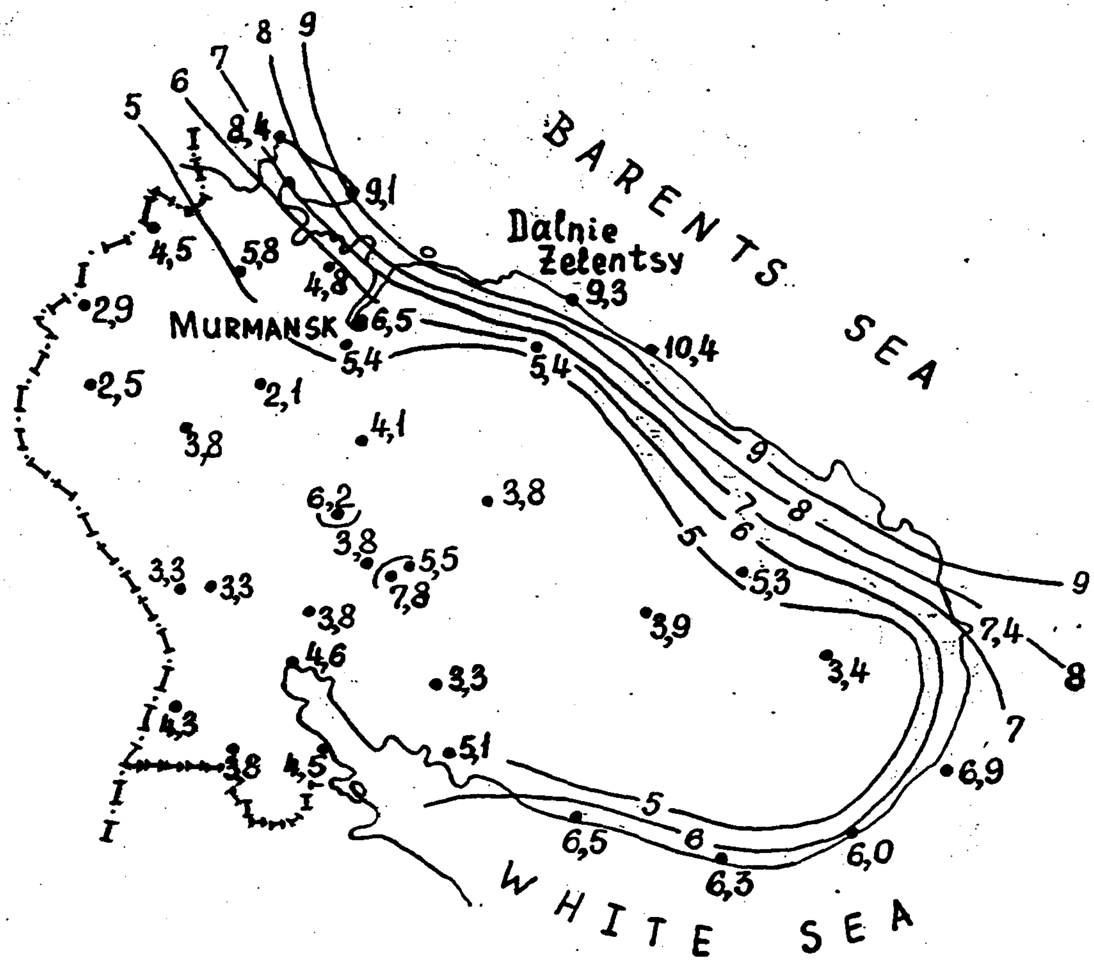


Fig.1. Average annual multiyears wind speed, upon open flat landscape conditions on the height of 30 meters above sea level.

KOLA WIND TEST STATION ON THE BARENTS SEASHORE

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and Technological Problems of Energy in Northern Areas,
Kola Science' Center Russian Academy of Sciences

The great attention is given to wind energy using in many countries of the world. In Russia also has been working out and now is under realization scientific-technological programm on producing and application of wind power converters (WECs). In serial are producing small WECs, under the trial are WECs with the capacities 100-250KW, the big WECs with the capaciti-es 1MW and more are under construction and projecting.

The wind energy application are most favourable in dis-tant regions, isolated from centralized energy supply systems and having local fuel' resources shortage. In their number are several northern regions of Russia, which possess high wind energy potential.

In the Institute for Physical and Technological Problems of Energy in Northern Areas Kola' Science Center has been done considerable volume of scientific investigations on revealing of reasons for practical wind energy using in distant regions of Russian European North. These investigations include:

- studying of the modern conditions of fuel- and energy supply of the distant and isolated regional consumers;
- the technical-economic indices assessment of conventio-nal energy supply' schemes in perspective;
- wind energy' characteristics studying and defining the regions, most siutable for practical wind energy using;
- the WECs testing in specific northern conditions.

Lets see the wind energy' characteristics culculations results in the regions of European North of Russia. In figure is shown the map of average multiyears wind' speed distributi-on along the regions territory. It was made on the base of 10-years row of observations treatment taking into account 169 meteorological stations. From the map it's clear that the hig-hest wind energy potential take place along the Barents and

White seashores. Here at the 10 meters hoight average multu-year wind' speed is 7-9m.p.s. The annual specific wind' capacity reachs 1000-1500 Wt/sq.m. In these regions take place the seasonal unevenness of wind' intensity. The highest wind' speed is observed during the cold seasons of the year. On Kola' peninsula northern seashore in winter monthes the average wind speed in 2,0-2,3 times higher than in summer and it is about 10-12 m.p.s. Kola peninsula seacoast has really unique resources of wind energy. Only in the northern seacoast in coastal strip with the width 15-20 km. and with tho length 400 km. the technical wind energy resources could be estimated in 150 mlrd.KWh annually, with the corresponding installed capacity of WECs about 50 mln.KW.

In 1974 on the northern Kola peninsula sea-coast near Dalnye Zelentsy settlment was established wind test station for WECs practical verifying. The test station' ground is founded in the hill, with the altitude 60 m. above sea level and is characterised with high rate of openness. In the center of test station is installed meteomast, equiped with devices of wind' speed and wind' direction registration. According to longterm observations the average annual wind speed at wind test station at the 10 meters height above ground level is 8,0 m.p.s. In winter monthes (from November till March) average monthly wind speeds reach 9-12 m.p.s. During the winter storms and hurricanes are often observed. The investigation been made show, that maximum wind'speed once during 10 years in 3 seconds gust could reach 48-50 m.p.s., and once in 20 years - 52-55 m.p.s.

The region of wind test station' is characterised of availability of prevailing wind' directions. In winter monthes winds of South-West quarter blows 60-80 % of time. Due to influence of worm Atlantic flow - Gulfstream, the Barents Sea along the northern seashore of Kola peninsula is nonfreezing. The prevailing of the winds, which blow from cold continent to the worm sea cause such an important peculiarity of this region as absence of rime and icing. During more than 15 years of wind test station' existence there wasn't any of such a pheno-

THE KOLA PENINSULA WIND-ENERGY POTENTIAL AND POSSIBLE DIRECTIONS OF IT'S USING.

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RUSSIA

Abstract

In this report is shown the distribution of wind energy potential on Kola peninsula territory. Are described the possibilities of large-scale utilization of wind-power regional resources. Here is made the preposition on construction the large wind-farm, included into Kola' electrical powergrid on the Barents seacoast, near the existing chain of Serebryanskaya hydro-power plants.

1. KOLA PENINSULA' WIND-ENERGY POTENTIAL AND THE PROSPECTIVES OF IT USING

There is greate wind-energy potential on Kola peninsula.Our investigations /1-3/ define its value around 350 mlrd. of KWh. only in lower part of atmosphere till the height of 100m.These wind-energy data correspond to installed capacity of wind energy converters (WECs) of 120 Mln.KWt. Favorable area for wind energy utilization is the sea coast area (Fig.1), here the annual average wind' speeds on the 30 meters height are 6-10 m.p.sec. The value of specific power of wind stream for such wind' speeds are 1000 - 1500 Wt per sq.m. The technical wind energy resources of the narrow seacoast line (15-20 km. width), where the average annual wind speed are more then 8 m.p.sec., has been defined as 125 mlrd of KWt.h.when WECs' installed capacity is more then 40 mln.of KWt. These data far larger then the total production of electricity and installed capacity of Kola' electrical power system. All these mean, that even using of 2-3% of available wind power could make a big importence for Murmansk region' industry, because it signify several milliards of KWt.h of electricity and hundreds MWt of electrical power.

The results of 20 years wind speed observations data treatment (1966-1985) of the Kola peninsula' seacoast meteostations had show that in above mentioned regions there are favourable conditions of wind regime for wind energy converters (WECs) application. The average annual wind speed' variations from year to year are small and are characterized by coefficient of variation in average as 5-6%. The WEC's energy production variations are more sufficient, because of cubic mathematical dependence of WEC' capacity from the wind speed and this variations are about 9% for the northern peninsula' seacoast. By the way, the variations coeficient for river's discharge in Kola peninsula is about 16-18% during the same observation's period in 20 years. It makes clear, that in multiyears section the WEC's energy production is a little more stable then hydropower.

On the Kola peninsula's seacoast there is clear seasonal wind's intensivity variation. Maximum wind speed are observed during winter time (Fig.2) and this phenomenon coinside with seasonal peak of heat and electrical consumption. Essentially, that this trend is in opposite with seasonal variation of river's discharge in given region. It's mean that wind and water energies fortunatly adds one another.The unstability of WEC's capacity and difficulties connected with accumulation of WEC's energy in large amount makes the idea on joint WECs and hydro power plants exploitation especially attractive. Hydro power plants could be used for exploitation upon conditions of sharp variable load curve and to provide the wind energy accumulation according to that ability. Hence, all, mentioned above, create favourable conditions for joint usage of wind and hydro power.

Now in Kola' electrical power system the main part of generating units is located at the South of Kola peninsula, in the same time the main part of electrical consumers are concentrated in central and northern regions of the peninsula, where are located biggest industrial centers. As a result, here we have big transit electrical flow and considerable loses of electricity in electric grid, as well.The construction of large scale WEC's pools could to improve todays situation and could opens new additional possibilities for electric energy export to neighboring Finland. The increasing of Kola electrical power system installed capacity by construction of new bloks of nuclear and thermal power plants makes the problem of passing the peaks of the load curve more and more sharp. The including of WECs into energy system could to save large amount of water in hydro power plants' reservoirs, and this could provide conditions to increasing the capacities of hydro power plants, which could increase, in turn, the manoeuvrability of the energy system.

For the creation of large-scale WECs pool the greate importance has rational choice of constructional grounds and optimal location of each wind-power set on the terrain. The multiyears data of wind-speeds observations shows, that on Kola peninsula there are regions with prevailing wind' directions. At the first rate in their number there are the northern seacoast regions. As an example for this statement at Fig.3 is shown the wind-rose has been observed at Dalnye Zelentsy meteostation. The rose has been made on the base of 10 years observation data(1975-1984). The data shows, that more then half a year's time (54%) there they has the winds of South-West quarter. From the energy-consumer's point of view it's very important to know not only the prevailing wind' directions, but the energy' value of each wind's directions (possible generating capacity of the wind). We made all necessary calculations and made the corresponding generating wind-roses. It become clear that the resulting generating wind-roses were almost the same, as the wind-roses. All these mean, that in above mentioned regions the prevailing winds directions are, in the same time, the most valuables from the energy-consumer's point of view.

From Fig.3 it's become clear, that during the year, according to the seasons, the wind-rose and prevailing wind's directions are significantly changed. During winter monthes (October - March) the winds of South-West quarter blows during 60-80% of time. The prevaling of the winds from this quarter is overwhelming (the same is with the generating ability). During the warm seasons the picture is different. Then usually it's difficult to define the prevailing wind diretcions, and with general decreasing of wind intensivity, decrease the full volume of possible generating energy.

The availability of prevailing wind directions permits to settle WECs in compact place, as well, as with less expenses on the terrain. The distance between the WECs could be shortened till 2 diameters of wind-rotor. he calculations shows, that if WECs will be placed into "chains" , which would be perpendiqular to prevailing wind direction, in this case during 94% of time, annually, WECs wouldn't be "shadowed" and wouldn't make obstacles for one-another. During the winter monthes this index could be higher - till 96-97%. The energy loses, connected with such orientation of WECs are minimal and could be about 6-8% per a year. It's possible to decrease the loses during some of winter monthes till 2-3%.

2. POSSIBILITIES OF WIND-ENERGY INDUSTRIAL USING

According to above mentioned information in the laboratory was made the estimation of WECs pool construction's possibility on northern seacoast of Kola peninsula, near the existing hydro-power plants chain: Serebrianskie (365 MWt) and Teriberskie (156 MWt) hydro power plants (HPP), which could provide the rational using of WECs energy into electrical power system. In order to fulfil necessary calculations it's possible to use the data of series-produced WECs, with average capacities 200- 500 KWt, as example, such as Dannish made - DANWIN 23; VESTAS V27; WINDANE 34; VESTAS V39; e.t.c. Under the northern seacoast's of Kola peninsula's conditions (Fig.1), they could to work during 3700-4200 hours per year with installed capacity.

It seems, it will be the best if all energy, which would be produced by WEC's pool comes directly into power network, without any accumulation. But could to work like this, electrical power system must to have suitable generating capacity' units to drive such a regime. The best abilities for doing that has HPP. The HPP's capacity could be changed very swiftly, according to add's characters of energy income from WECs: HPPs could decrease their own capacities during strong wind's periods and accumulate, due to WECs activity, the water in reservoirs, without energy transformation; and HPPs could increase their capacities during weak wind's and calm periods.

If rational joint exploitation of WECs and HPPs is obtained, the accumulation of water in neighbouring reservoirs could be the way, on the base of WEC's energy, to provide an additional guaranteed capacity in electrical power system, which could be used during the peak periods. Such a possibility we have especially in northern regions of Kola peninsula during Autumn-Winter periods, when wind energy has especcially high potential and stability.

We have made the rethrospective analysis of the possible joint exploitation of multiunits WEC with total capacity 200 MWt together with Serebrianskaia HPP N1, with installed capacity 200 MWt and Serebrianskaia HPP N2, with installed capacity 150 MWt. In the base of calculations were taken the actual dayly electrical load curves of HPP N1 and N2 during year's term and the corresponding data on wind speed at the wind-energy experimental proving-ground of Kola Sciences Center in Dalnie Zelentsy settlement.

Consicuently putting onto the dayly HPP's electrical load curves the dayly curves of possible electrical production from WEC's pool we had obtained the results, shown in the table.

Indicies of joint exploitation of Serebrianskie HPPs and WEC's pool with the capacity 200 MWt (mln.KWt.h)

Indicies	1985	1986
Actual electricity productions by HPPs (totally)	863	1195
same by HPP N1	443	626
same by HPP N2	420	569
WECs pool production	558	727
Possible replacement of HPP's production by WECs pool		
Replacement of HPP N1	236	273
Replacement of HPP N2	102	109

From the table it's clear, that 338 and 382 mln.KWt.h. which were produced by WECs and replaced the same amount of electricity from HPPs, is saved in form of hydroresources and it could be used by Kola electric power system with heigher degree of freedom.

The affect, obtained due to joint exploitation of WECs park and HPPs has three components. The first is the replacement of hydropower plant's capacity and electricity production during the periods with strong wind. As it follows from the table, in 1985 and 1986 multiunits WEC could replaces correspondingly 338 and 382 mln.KWt.h. of electric production, producing usually by Serebrianskie HPPs. This quantity is about one third of average multiyears production of those plants.

Second part of the effect consist in accumulation the water, which was saved, due to replacement of HPPs by WECs, in reservoirs of HPPs. This water creates an additional energy potential for the power system. The accumulation process permit to convert unstable and accidental upon the time capacity of WEC into additional electricity production of HPP, garanteed by water, has been accumulated. This water, in case of installing an additional hydropower unit, could be the source of additional maneuvrous capacity of hydropower plant.

The third effect's component appears in those part of WECs possible production, which wasn't use as a replacement capacity according to load curve of above mentioned HPPs. Those part of WEC's production could be used in basic part of electrical load curve of whole electrical power system. It's mean this part of WEC's production could to rplace the production of most nonefficient thermal power stations.The presence of 17 HPPs in the electrical power system of Kola peninsula (total capacity of HPPs is more then 1,5 mln.KWt), having in their disposal multiyear's reservoirs of seasonal and dayly termed reservoirs, makes the solution of this problem easier.

In the above mentioned example of joint exploitation of Serebrianskie HPPs, of total capacity 355MWt, and the WECs pool of total capacity 200MWt, the following problems could be solved. At first, in the frame of the same electrical load curve of HPP's it's possible to replace one third of HPP's electricity production. The water has been saved, due to this, could be used for operation of additional peak's hydropower unit with the installed capacity of 340-380 MWt (h=1000 hours). Besides this, the energy obtained from WECs, which wasn't include into the load curve could be used as additional base energy into the whole power system load curve. This energy equal to 300 mln.KWt.h. per year, and this additional base energy could save greate amount of fuel in thermal power plant.

The exploitation of such a complex (WECs and HPPs) is equal to exploitation of new constructed peak hydro power plant of 350 MWt capacity. The WECs pool in this case play the role of equipment, which provide HPP with water for successful operation.

CONCLUSIONS

1. There is high wind energy potential at the Kola peninsula. At the northern seacoast average annual wind speeds at 30 meters height reaches 8-10 m.p.s., and average annual specific wind capacity - 1000-1500 Wt/sq.m. Maximal wind intensivity takes place during winter time. There are obviouse prevailing wind directions - from continent to the unfrosen sea. Here aren't the icing fenomenon.

2. One of the most preferable place for constructing the WECs park is part of seacoast near Teriberka, Tumannyj and Dalnye Zelentsy settlements. In this region there are the possibilities to construct large WECs park of total capacity about 200 MWt or more for joint exploitation with Serebrianskie and Teriberskie HPPs.

3. The data has been presented here shows the greate possibilities of such joint exploitation. WECs exploitation' calculattions and preliminary economical estimation shows high efficiency of such a dicision. The results shows the necessarity of further investigations of this problem, taking into account the economical changings, taking place now in Russia.

References

1. Dobrovolski V., Minin V., Kola Test Station for Wind Turbines/ An International Experts Meeting on Wind Power in Icing Coinditions. Helsinki, FMI, 1992.- pp.188-192.

2. Minin V.A., Stepanov I.R., Wind Energy Cadastr of the USSR's European North// Izvestia Ac. of Sc. USSR. Energy & Transport. 1983.N1, pp.106-114.

3. Zubarev V.V., Minin V.A., Stepanov I.R. Wind Energy Using in the Regions of the North. Leningrad.: Nauka, 1989. 208 p.

Testing Activities at the USDA

Nolan Clark
USDA-Agricultural Research Service

AGRICULTURAL AND REMOTE APPLICATIONS OF WIND ENERGY

USDA-Agricultural Research Service
Conservation and Production Research Laboratory
Bushland, Texas

MISSION

Develop and evaluate wind energy systems, both mechanical and electrical, for use by farmers and ranchers for pumping water for livestock, domestic use, and irrigation. To determine the long-term performance and reliability of wind-electric systems for supplementing the electrical grid in remote locations. Develop a sustainable energy generation system for remote areas using a hybrid systems composed of wind, solar, and engine generated electricity powered by biofuels.

STAFF

R. Nolan Clark, Agricultural Engineer, Director
Ronald G. Davis, Agricultural Engineer, Instrumentation
Brain Vick, Agricultural Engineer, Aerodynamics
Michael Bayless, Instrumentation Specialist

MECHANICAL WATER PUMPING

Wind Turbines currently being tested are:
- Aermotor--2.3m rotor diameter, 18 blades
- Dempster--2.3m rotor diameter, 16 blades
- Dutch Delta-5m rotor diameter, 24 blades

Pumps currently being tested:
- 45 mm brass piston pump
- 45 mm pvc piston pump
- 75 mm brass piston pump
- 75 mm brass piston pump with 30 mm drop pipe

Instrumentation used
- Data logger is Campbell Scientific CR7
- Data are sampled at 1 second intervals and recorded as 1 minute averages

Measurements made are:
- Wind speed
- Wind direction
- Water flow
- Water pressure and depth
- Stroke speed

ELECTRICAL WATER PUMPING

Wind Turbines currently being tested are:
- Whisper--1 kW, 2.5m rotor diameter, 2 blades
- Bergey 1500--1.5 kW, 3m rotor diameter, 3 blades
- Jacobs --17 kW, 9m rotor diameter, 3 blades
- Bergey--10 kW, 7m rotor diameter, 3 blades

Pumps currently being tested:
- 25 liter per minute (lpm), submersible pump with 0.5 kW electric motor
- 35 lpm, submersible pump, 0.75 kW electric motor
- 300 lpm, submersible pump, 7.5 kW electric motor
- 1000 lpm, centrifugal pump, 7.5 kW electric motor

Instrumentation used
- Data loggers are Campbell Scientific CR21
- Data are sampled at 1 second intervals and recorded as 1 minute averages

Measurements made are:
- Wind speed
- Wind direction
- Water flow
- Water pressure and depth
- Electrical frequency
- Electrical current
- Electrical voltage

ELECTRICAL GENERATION

Wind Turbines currently being tested are:
- Enertech 44--40 kW, 13.4m rotor diameter, 3 blades
- AOC 15/50--50 kW, 15m rotor diameter, 3 blades
- 34m VAWT --500 kW, 34m rotor diameter, 2 blades

Instrumentation used
- Enertech data logger is a Campbell Scientific CR21. Data are sampled at 1 second intervals and recorded as 5 minute averages.
- AOC data logger is a PC using Labtech Notebook. Data are sampled at 10 Hz and recorded as 1 minute averages.
- 34m VAWT Test Bed data logger is PC using LabVeiw. Data are sampled at varying rate beginning at 100 samples per second and averaged for 30 seconds, depending on the experiment performed.

Measurements made are:
- Wind speed
- Wind direction
- Electrical frequency
- Electrical current
- Electrical voltage
- Electrical power

- Blade strains
- Tower strains

WIND/HYBRID

Wind turbines currently being used are (described above):

- Enertech 44
- AOC 15/50
- Bergey 10 kW

Biofueled generators

- 50 kW diesel engines fueled with Soydiesel

Instrumentation used

- A PC system with LabView is planned for this new experiment in cooperation with a PLC controller for controlling the dump load and control system.

34-m VAWT Testing

Dale Berg
Sandia National Laboratories

34-Meter VAWT Testing Experiences*

Dale Berg and Mark Rumsey
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ABSTRACT

In the course of over six years of testing of the 34-meter vertical-axis wind turbine, we have performed many different types of tests, developed some new data analysis techniques, and developed and implemented new instrumentation. This paper describes a technique for using strain-gauge time series data to follow the variation of natural frequencies with turbine rotational speed, reviews a rotating modal test, discusses the development of a non-contact blade-surface mapping instrument, and summarizes our experience with a novel gauge that monitors fatigue damage.

INTRODUCTION

The 34-m Test Bed is a research-oriented vertical-axis wind turbine (VAWT) located at the US Department of Agriculture Agricultural Research Service facility in Bushland, Texas. Sandia National Laboratories designed and built this machine to perform research in structural dynamics, aerodynamics, fatigue, and controls. Official dedication of the Test Bed occured on May 10, 1988. Testing to determine turbine aerodynamic, structural dynamic, and control performance in various wind conditions and at different rotation rates has been ongoing for over six years.

The Test Bed is shown in Figure 1. The two-bladed rotor is 34 meters in diameter with a height-to-diameter ratio of 1.25 and a swept area of 955 m^2. This continuously-variable-speed machine has an operating range of 28 to 38 rpm with a rated power of 500 kW at a rotation rate of 37.5 rpm in mean winds of 12.5 m/s (28 mph). Table I summarizes the Test Bed specifications.

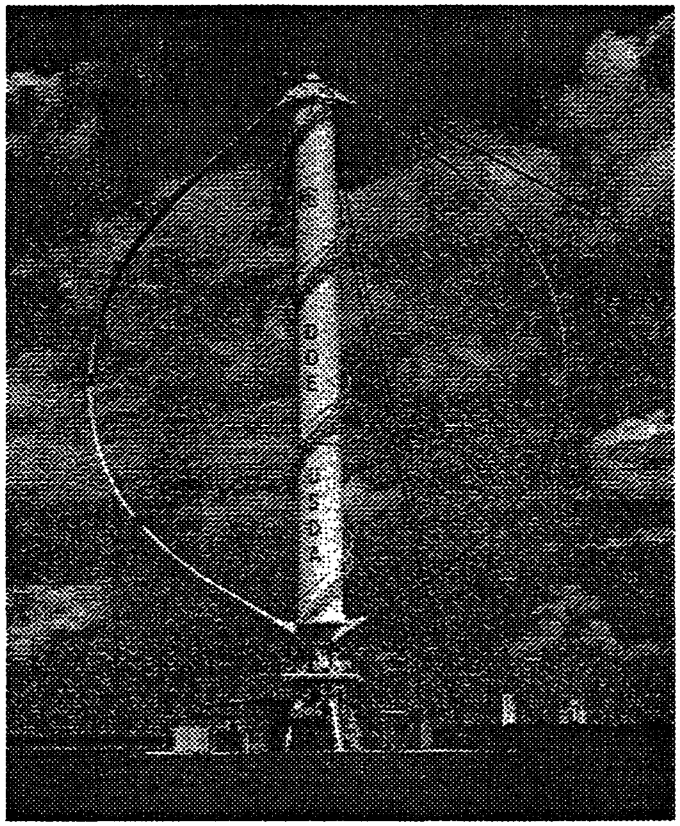


Figure 1. 34-Meter VAWT Test Bed

Compared to previously constructed VAWTs, the Test Bed blades are unique in that they are tailored both structurally and aerodynamically to

* This work was supported by the U.S. Department of Energy under contract DE-AC04-94AL-85000.

minimize stresses and maximize energy capture. The root sections are straight 1.22-m (48-in.) chord NACA 0021 profiles. The equatorial sections are curved 0.91-m (36-in.) chord SNL 0018/50 profiles, and the transition sections (between the roots and the equatorial sections) are curved 1.07-m (42-in.) chord SNL 0018/50 profiles. Figure 2 is a schematic of the blade shape geometry, including the lengths of each blade section. The SNL 0018/50 profiles are part of a family of natural laminar flow airfoils developed at Sandia specifically for use on constant-speed VAWTs (Klimas, 1984). The turbine and its environment are heavily instrumented to measure wind speed and

Table I. Test Bed Specifications

ROTOR		**GENERATOR**	
Diameter	34 m	Type	Variable Speed Synchronous AC
Height	50 m	Rating	625 kVA
Ground Clearance	7 m	Voltage	1200
Speed	28 to 38 rpm	Speed	280 to 1900 rpm
Number of Blades	2	Frequency	60 Hz
Blade Material	6065-T6 Extruded Aluminum		
Blade Length	54.5 m	**CONTROLS**	
		System-	Programmable Industrial Controller
Aerodynamic Control	Stall Regulation	Generator Speed and Torque-	Load Commutated Inverter
Airfoils	SNL 0018/50, NACA 0021		
Chord Dimensions, m	0.91, 1.07, 1.22	**PERFORMANCE**	
		Rated Power	500 kWe
		RPM at Rated	37.5
Swept Area	955 m^2	Wind Speed at Equator, m/s	
Solidity	0.13	Rated	12.5
Central Column		Cut-out	20
Material	Aluminum	Survival	67
Diameter	3 m		
Wall Thickness	12.5 mm		
Guy Cables			
Number	3 Sets of 2		
Tension	750-830 kN/Set	**DATA ACQUISITION AND ANALYSIS**	
Material	Steel Bridge Strand	Number of Channels	128
Diameter	64 mm	Maximum Data Throughput Rate	200 kHz
GEARBOX			
Type	Three-Stage Parallel		
Step-up Ratio	47.5:1		
Rating	709 kW		

direction, temperature, rotor torque, electrical power, rotational speed, and blade strains at many locations.

This paper describes some tests that we have performed on the Test Bed and some data analysis techniques that we have developed during those tests.

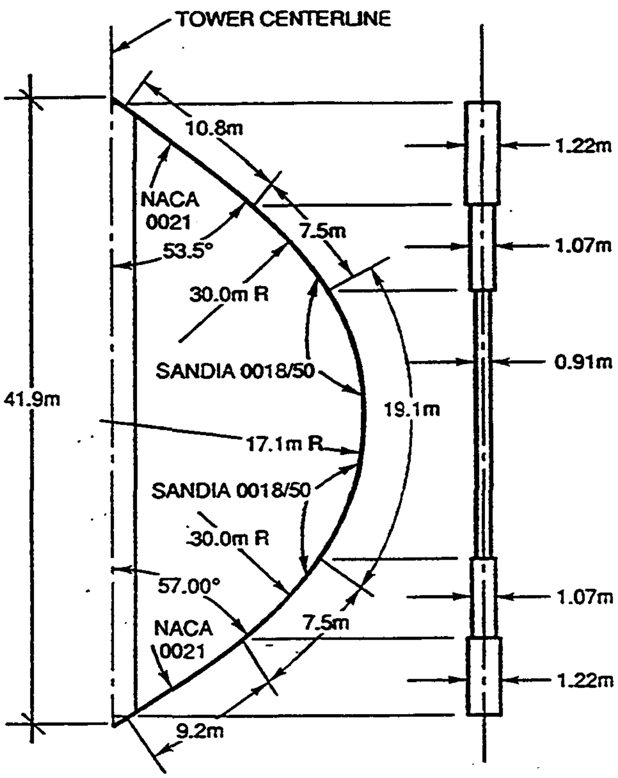


Figure 2. Test Bed Blade Geometry

MODAL FREQUENCY TRACKING

After the blades were mounted on the tower and before the turbine was placed into operation, a modal test was performed on the stationary rotor by Sandia's Modal and Structural Mechanics Division, as described by Carne, et al, 1989. Accelerometers were temporarily attached to the blades, tower, and cables, and frequency response functions were measured using both the usual step relaxation (snap release) and wind excitations. These measurements were used to determine the turbine mode shapes, their frequencies of vibrations, and their damping values. The mode shape and vibration data were then used to validate the turbine finite element model we had developed during the design of the turbine.

Table II compares the first 11 measured modal frequencies with those determined analytically. The mode number and shape are listed in the first two columns, while columns three and four list the measured modal frequencies for the stationary rotor resulting from wind excitation and the analytical values, respectively. There is excellent agreement between the measured and predicted frequencies for these modes. All predicted modes are within 2.6% of the measurements except for the first blade edgewise mode which is 5.2% low. Additional information about these comparisons may be found in Ashwill, 1990.

Mode Number	Mode Shape*	Modal Test	Analytical	Deviation
1,2	1FA/1FS	1.06	1.05	1.0%
3	1Pr	1.52	1.56	2.6%
4	1BE	1.81	1.72	5.2%
5	2FA	2.06	2.07	0.5%
6	2FS	2.16	2.14	1.0%
7	1TI	2.50	2.46	1.6%
8	1TO	2.61	2.58	1.2%

*Mode Shape Abbreviation Key:
1FA = First Flatwise Antisymmetric
1FS = First Flatwise Symmetric
1Pr = First Propeller
1BE = First Blade Edgewise
2FA = Second Flatwise Antisymmetric
2FS = Second Flatwise Symmetric
1TI = First Tower In-Plane
1TO = First Tower Out-of-Plane

Table II. Parked Modal Frequencies (Hz) - Test and Analysis

This good agreement between the model and the stationary rotor gave us increased confidence in the ability of the model to properly predict rotating turbine behavior. The predicted fanplot or Campbell diagram for the "as-built" finite element model with the brakes released is shown in Figure 3. Because the brake boundary condition is eliminated, some of the tower modal frequencies are, as expected, lower than the model frequencies shown in Table II. The blade modal frequencies are not affected by removing this boundary condition. Because resonances are possible wherever a modal frequency crosses a per-rev line, this rotor fanplot and a corresponding guy-cable fanplot were used extensively during the early turbine testing to identify and avoid resonances.

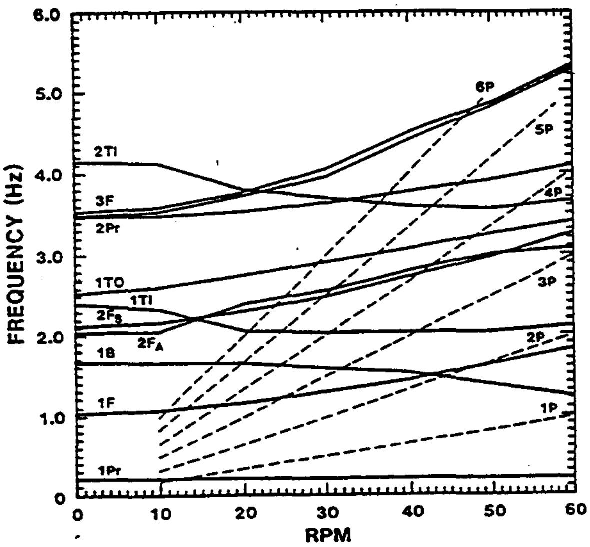


Figure 3. Rotor Fanplot - Brakes Disengaged

The turbine has operated at rotation rates from 6 to 40 rpm in winds up to 17 m/s (38 mph). By carefully monitoring strain-gauges, we could ensure that we were not operating at resonance conditions, but we weren't sure how accurately the model was predicting the turbine natural modes throughout the operating range. A rotating model test is the normal procedure that is used to validate a model under these conditions, but we developed a technique that utilizes strain-guage data to identify natural frequencies at any rotational speed.

A major thrust of our early testing was the acquisition of data from numerous strain-gauges at a 20 Hz sampling rate at each turbine rotational speed. A plot of a strain amplitude spectrum for a flatwise gauge at the upper root at 10 rpm is shown in Figure 4. The first five per-rev peaks and several other peaks that indicate modal frequencies are evident. By plotting these measured modal frequencies at several rotation speeds on the predicted fanplot, as shown in Figure 5, one can track the variation of several rotor modes with rotation speed The lower frequency modes (below 3 Hz), including the first and second flatwise (1F, 2F), the first blade edgewise (1BE), the first tower in-plane (1TI), and the second propeller (2Pr) modes all track along their predicted mode lines very well. The two measured first flatwise modal frequencies are either the antisymmetric and symmetric modes, which normally vibrate at the same frequency, or the two blades vibrating at slightly different frequencies. The first tower out-of-plane (1TO) does not show up in any of the many spectral plots examined thus far. The first blade edgewise mode (1BE) was underpredicted by 5% at zero rpm, but above 25 rpm the observed and predicted frequencies coincide. The first blade edgewise crossing of the 3P line shows up as a larger spike in the spectra of lead-lag gauges at 32 rpm, indicating a possible resonance condition at that rpm. The stresses are not high in this region in low winds, but increase significantly in winds above 13 m/s (29 mph). The first tower in-plane mode (1TI) tracks well except in the region where it crosses the second flatwise modes. This mode is predicted to cross the 3P line at 40.5 rpm. Strain guage signals reveal an excitation of this mode begins around 39.5 rpm, and the response is still increasing at 40 rpm. The tower-in-plane excitation, which includes blade edgewise motion, causes significant lead-lag RMS stresses, indicating a potentially destructive resonance condition.

Additional measured structural and aerodynamic data from the 34-m Test Bed may be found in Ashwill (1990, 1992).

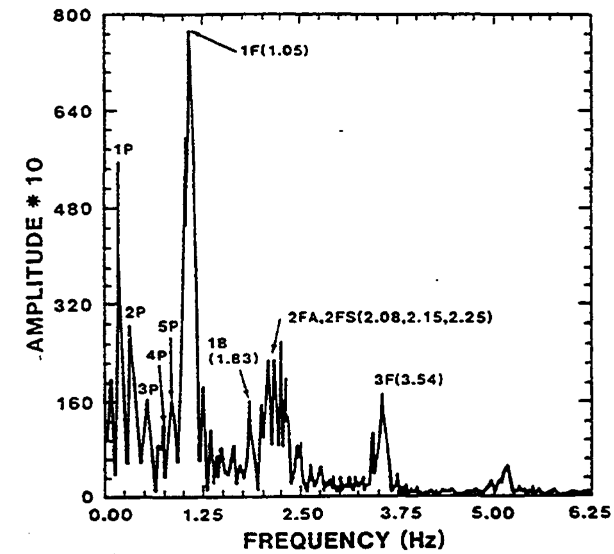


Figure 4. Strain Amplitude Spectrum at 10 RPM

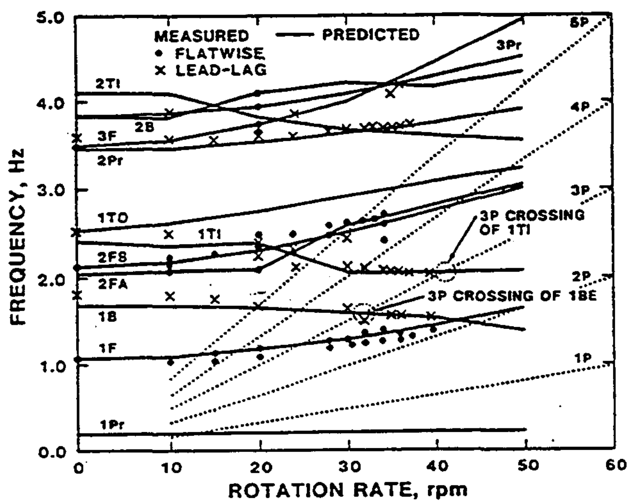


Figure 5. Rotating Modal Frequencies - Measured and Predicted

ROTATING STEP-RELAXATION TEST

Our normal techniques for analyzing the stress response of a VAWT utilize frequency domain codes. However, during variable speed operations or transient events, the structural equations of motion have time-varying coefficients, and frequency-domain techniques are no longer applicable. We have, therefore, developed an approach (Dohrmann and Veers, 1989) for integrating the equations of motion in the time domain to allow the simulation of wind turbine structural response to stochastic wind loading, control system inputs, and braking transients. A finite element based, time-domain, structural analysis computer program, which formalizes the approach for vertical axis wind turbines (VAWTs), has been developed at Sandia National Laboratories (Argüello and Dohrman, in preparation). This code is referred to as VAWT-SDS for Vertical Axis Wind Turbine - Structural Dynamics Simulator.

VAWT-SDS predictions have been compared to frequency domain techniques for the case of constant speed operation with near perfect agreement. Reasonable results have also been obtained for variable speed mode. However, we had no measured transient response test data with which to compare these predictions, so we conducted a test to acquire some rotating transient response data in the absence of significant wind-driven aerodynamic loading. Ideally, the test would be run in zero winds to eliminate the loading uncertainty which is introduced when we estimate the wind loads with an aerodynamic model. However, because perfectly still air is rare, especially in the Texas panhandle, testing was done in winds as low as possible (less than 5 mph, or 2.2 m/s). Very low winds were also desirable to avoid aerodynamic excitation levels which could overwhelm the excitation due to the applied load. During the low wind operation, the motor/generator was used to propel the turbine and maintain its speed at a constant preset level.

The step-relaxation or "pluck" test applied a force to the turbine structure and suddenly released it while the turbine rotated. This required the use of a light steel cable which was attached to one blade, looped through a pulley on the tower, as indicated by Figure 6, and was then tensioned with a pneumatic actuator mounted at the base of the rotor. After the turbine was rotating at the desired preset speed, Ω , the cable was slowly preloaded to 13.3 kN (3,000 lb.) and then suddenly released. The loading and release of the actuator were controlled remotely, using the turbine's slip rings to pass control signals, so several "plucks" could be performed without stopping the turbine.

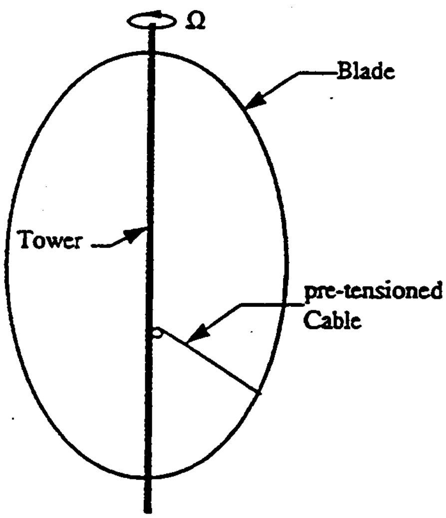


Figure 6. Step-Relaxation Test Schematic

The pneumatic actuator was a 10.2 cm (4-in.) diameter cylinder and piston which used compressed air canisters in the base of the tower to pressurize the cylinder and tension the cable. By simultaneously opening four valves to vent the cylinder and injecting compressed air behind the cylinder to drive the piston to its fully extended configuration, the load on the blade could be released in less than 0.14 seconds, thus providing a truly dynamic force and exciting substantial structural dynamics in the turbine.

VAWT-SDS was used to determine the amount of loading that should be applied to the blade and the effects of ambient wind on blade response. The effect of wind on blade bending stresses for a location near the lower root of the blade is illustrated in Figure 7. Figure 7a shows the stress history at this location for the 2.2 m/s (5 mph) wind load case. The cable is loaded instantaneously at time zero, and the dynamic effect on the blade is significant, but dies out quickly. The sudden release of the cable tension at 36 seconds results in an initial cyclic stress range of about 2.8 MPa (400 psi) which gradually diminishes with time to the wind-only level of about 0.8 MPa (110 psi) at about 120 seconds. The 1.3 m/s (3 mph) case is shown in Figure 7b. The importance of attempting to perform this test in minimum winds is clearly evident here, for the response due to the "pluck" is far more readily distinguishable for the lower wind case.

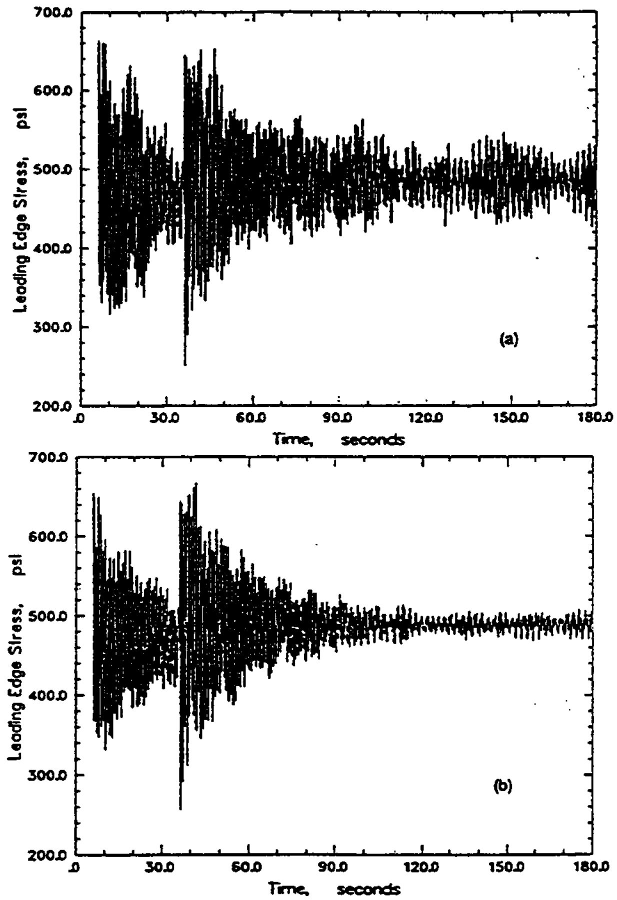


Figure 7. Predicted Lead Edge Stresses Near Lower Blade Root (a) 5 mph Wind, (b) 3 mph Wind

Figure 8 shows the computed response at the point on the blade where cable was attached, together with the measured response at a strain gauge about 21 inches away from that point. The offset between the responses is due mainly to the fact that the strain gauges do not reflect stress due to gravity. In addition, the wind-only effects are more pronounced in the measurements than in the computed values. Despite these differences, however, there is good agreement between computed and measured response. The difference in location contributes to the difference in response, for there are large stress gradients in the vicinity of the attachment point.

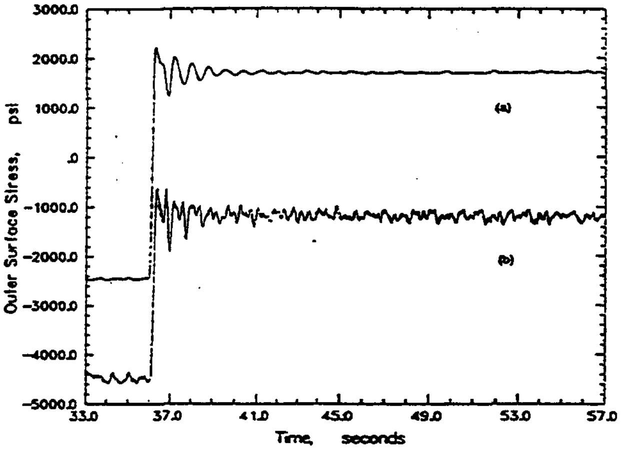


Figure 8. Outer Surface Streese Near Cable Attachment Point (a) Computed, (b) Measured

Figure 9 shows the computed leading-edge stress response at a node near the upper root of the blade and the corresponding measured response from a gauge about 30 inches away. The bending portion of this response component should not be influenced by gravity. This is indeed the case, with only a slight offset (0.9 Mpa or 125 psi) between the two response curves. In this case, however, the wind-only effects are extremely pronounced in the measurements.

Additional information on this test and comparison with analytical results may be found in Argüello, et al, 1994.

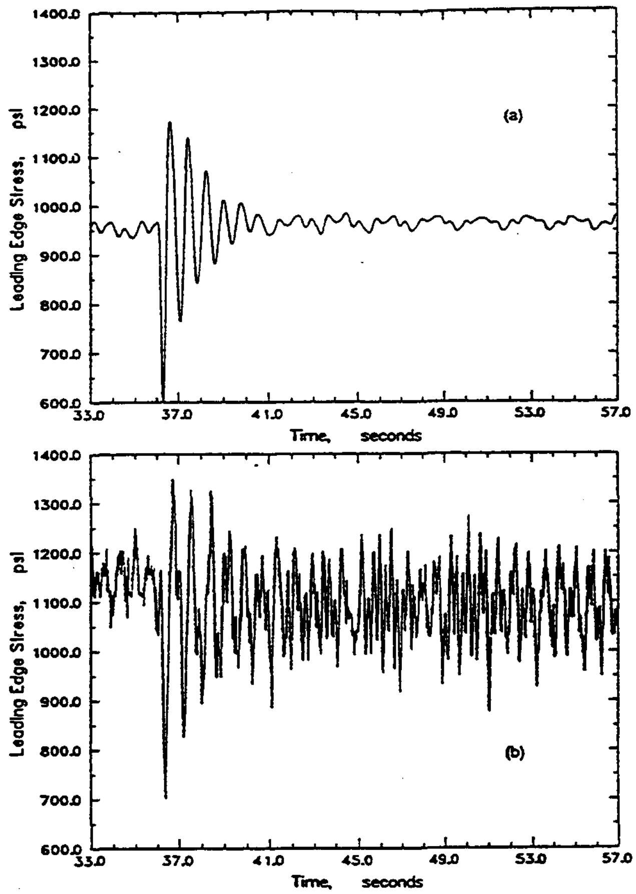


Figure 9. Leading Edge Stresses Near Upper Blade Root (a) Computed, (b) Measured

BLADE SURFACE ROUGHNESS

We were aware of the effect of bug debris on wind turbine blade performance (Yekutieli and Clark, 1987) and attempted to consider that in the design of the SNL 0018/50 blades by examining the design-code predicted effect of forced boundary-layer transition near the leading edge of the airfoil. The code predicted that the NLF blades would suffer some loss of performance with surface contamination, but would still outperform the NACA blades that had been used on all previous VAWTs (Klimas, 1984).

The Test Bed first rotated early in 1988, but for various reasons we ran it almost exclusively during the late fall and winter months in '88 and '89, generating performance characteristics and gaining significant operating experience. While operating the turbine in the spring of '90, we found that the turbine was producing higher than normal power under high-wind operating conditions-about 15% above what we had observed to be normal performance. A review of the recent performance data showed that the increase had occurred during late April and early May, when the insect hatch had started in earnest. An inspection of the turbine revealed insect debris build-up on the blades, leading us to conjecture that the insect debris was responsible for the increase in peak performance. This conjecture was confirmed by additional tests throughout the summer (Clark and Davis, 1991), summarized in Figure 10. Since this effect of blade surface roughness was contrary to what the design code had predicted, what had been observed on all other turbines, and what our performance codes had predicted based upon grit roughness tests in the Ohio State University wind tunnel, we decided to attempt to characterize the actual roughness. By characterizing the roughness, we hoped to then reproduce it and utilize that simulated roughness in wind-tunnel testing to gain an understanding of the underlying reasons for the increase in peak turbine performance.

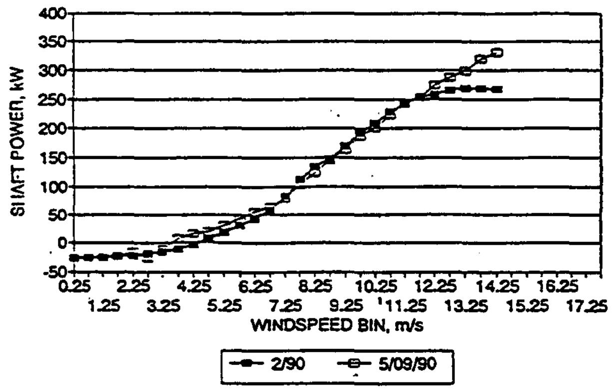


Figure 10. Test Bed Performance at 28 RPM with Clean and Dirty Blades

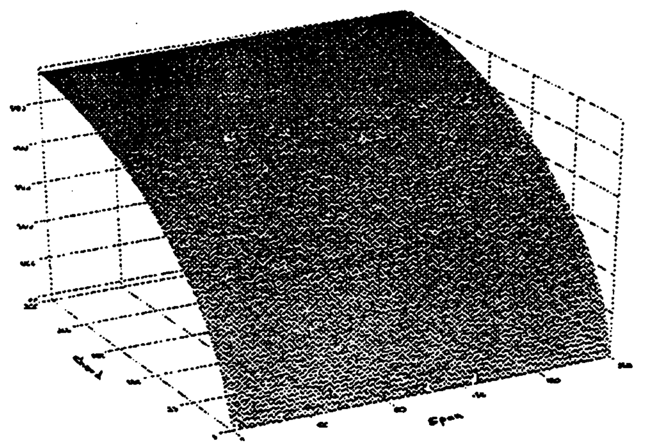
Traditional mechanical contact measurement techniques are not well suited to measuring bug debris or other types of surface contamination because the contamination is, in general, rather soft and very fragile and it is deposited on a curved surface. We have developed a portable blade mapping system utilizing a low-powered laser position sensor (Case, 1991; Von Voss, et al, 1991). It is a system that can be used in the field to scan areas of the blade - one that can be attached to a blade (in an inverted position, if necessary) by two workers in a man bucket and operated from the man bucket. The system is controlled by a personal computer that controls the traverse unit stepper motors, tracks the sensor head location, determines the distance of the surface from the laser head, stores the resultant data, and keeps the operator appraised of the system status at all times. Additional information on the system may be found in Berg, et al, 1992.

The completed system, which we refer to as the "spider", is approximately 61 cm (24 in) square and weighs just over 30 pounds. The entire system is designed for packing into two well-padded shipping containers for easy transportation.

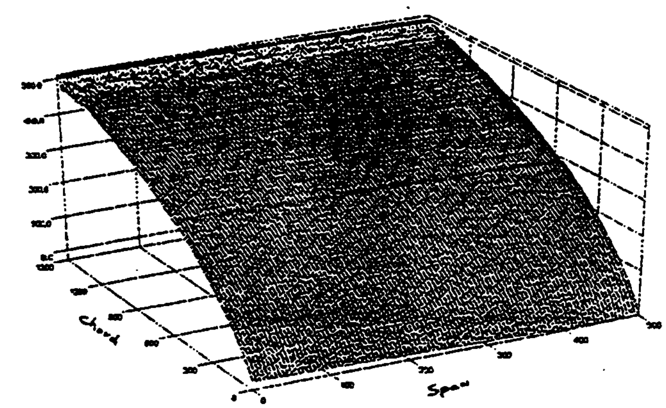
The data acquisition and presentation software for this system was developed and runs under National Instrument's LabView® for Windows environment on an IBM PC or compatible. LabView® is one of a number of new-generation integrated data acquisition, analysis, and presentation software systems that utilize state-of-the-art visual programming tools to allow the user to design complex real-time data collection and analysis routines using only icons, without typing a single line of code. The typical result is a high performance code which executes at speeds comparable to C code. LabView® has a very steep learning curve, but it is very powerful and complete, containing sophisticated debugging tools and all the modules needed for practically any data acquisition process. We are currently utilizing LabView® to develop a new generation of turbine control and data acquisition and analysis software.

While the spider meets our accuracy requirements, we have been somewhat disappointed in its performance. The laser sensor is capable of acquiring at least 100 data points per second, but our operating experience has revealed that the data acquisition rate is actually limited to a small fraction of that - 4 to 5 points per second. At that rate, scanning a one square inch section of blade with 0.13 mm (0.005 in.) steps requires 11 hours. This summer we discovered that we can effectively double that data acquisition rate to 8 points per second by changing the software to acquire surface range data while traversing, rather than acquiring data only while stopped. However, the limiting factor now is software, rather than hardware. While the LabView® software operates quite efficiently, there is a significant time delay whenever the program must communicate with the hardware. Actual hardware control is accomplished with a C code routine, and every call to that routine requires LabView and Windows to perform a large amount of bookkeeping before the routine is executed and after it terminates. The current software requires a call to a very simple C routine for each data point that is acquired. We will be rewriting the software to acquire data for the entire specified area with one call from LabView® to a much more complex C code or assembly language routine, and we anticipate increasing our data acquisition rate by a factor of 5 to 10.

We have used the spider to scan both the dirty blade on the Test Bed (field-type roughness) and the grit roughness used to simulate that surface contamination in wind-tunnel testing. The differences are hard to distinguish on Figure 11, but the character of the two types of roughness near the leading edge (bottom of the plots) differs significantly. We will be acquiring data from a number of commercial machines during insect hatching season to develop a more representative sample of true field-type blade roughness.



a) Grit Roughness



b) Field-Type Roughness

Figure 11. Comparison of Grit Roughness and Field-Type Roughness

CRACK GROWTH GAUGES

Fatigue of wind turbine blades has been shown to be an important factor in the economic viability of wind energy conversion systems. The design of the next generation of wind turbines must have fatigue life at the center of structural decision making. It is necessary, therefore, to possess simple methods of estimating component fatigue lives. While it may not be possible to conduct detailed fatigue analysis when the load and structural dynamics are poorly defined, even a crude life estimate would be very useful.

Fatigue life calculations can be separated into three mechanistic divisions: 1) crack initiation, 2) growth and coalescence of micro-cracks, and3) growth of a macroscopic cracks. Ideally, a fatigue analysis would include each of these mechanisms in the total estimate of time to failure. Originally, all three were lumped into a single analysis based on the S-n curve (a plot of the number of cycles to failure versus constant amplitude cyclic stress level) (Veers, 1989).

Wind turbine fatigue life estimation requires data on component fatigue characteristics and loading. Estimating fatigue life of wind turbine components, where the loading and structural response are random, can be a difficult task. In addition, the life estimate is sensitive to rare large loads and can be influenced by the sequence of load applications. The fatigue characteristics are obtained from component testing or from material test and careful component stress analysis. Loading may be determined using either strain gauge measurements for an operating wind turbine or numerical structural analysis. The fatigue life of wind turbine components can be estimated relatively quickly if the stresses are known.

Wind turbine stress histories are inherently non-stationary, but can easily be divided into stationary or constant segments over short periods of time. As the mean wind speed changes, the RMS stress level also changes. The rate of damage accumulation or crack growth during each stationary period can be estimated. The crack growth can be determined directly by summing the increments in crack growth due to each cyclic stress range.

Horizontal Axis Wind Turbines (HAWTs) and Vertical Axis Wind Turbines (VAWTs) have different blade orientations and operating conditions. They do, however, share some common loading characteristics. Both tend to have harmonic responses in the edgewise, or stiffer, blade bending direction - in HAWTs due to gravity loads and wind shear, and in VAWTs due to the cyclic orientation of the blades with respect to the wind. Both tend to have flatwise, or flapwise, loading that is more influenced by turbulence, resulting in significant responses at the blade natural frequencies.

The idea of damage gauges (Grant and Dumanis-Modan, 1983) was first brought to our attention by Bob Thresher at NREL. We subsequently decided to install these gages on the Test Bed.

To examine the fatigue damage accumulated in the blades on the Sandia 34-meter VAWT Test Bed, five damage gauges were installed on blade 2 along with several strain gauges. Figure 12 illustrates the relative location of these gauges. The locations (the blade-to-blade interfaces, the blade-to-tower interfaces, and the blade equator) were chosen because they were "hot spots" as indicated by our analytical analyses.

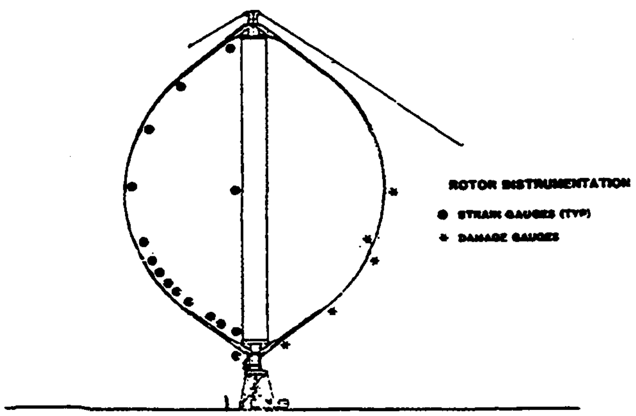


Figure 12. 34-meter VAWT Test Bed Instrumentation Layout

Each of the 5 damage gauges that were installed on the Test Bed were custom built as shown in Figure 13. The aluminum coupon was precracked and instrumented with a strain gauge and a KRAK gage (TTI Division). The damage coupons were glued into place using Hysol EA934NA Room Temperature Curing Adhesive (Hysol Division). The coupon was supported above the blade surface with an aluminum shim. The height of the damage coupon (from the blade to the top surface of the coupon) is approximately 0.07 inches. The initial crack length in each gauge was approximately 0.1 inches. After bonding and completing the electrical connections, the gauges and their respective completion units were coated with M-Coat D to provide an environmental seal. As the blade circuits had to be smoothed into the contour of the blade section with a minimal effect on the flow field, the entire installation was covered with Hysol EA-960F Fast Room Temperature Curing Adhesive (Hysol Division).

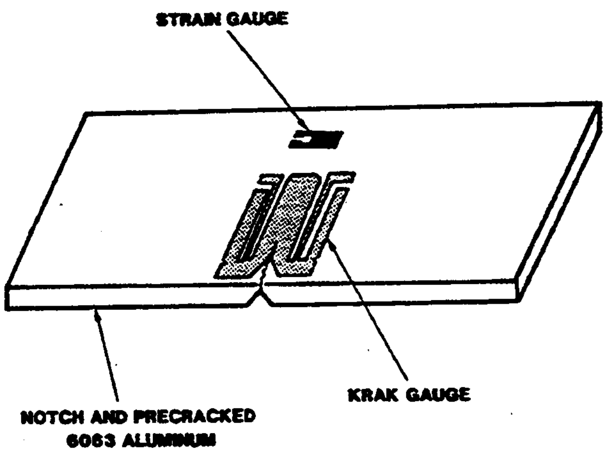


Figure 13. Diagram of a Damage Gauge

The first KRAK gauge readings were taken December 4, 1987 just after the Test Bed was erected. Since then 17 readings have been manually read at various turbine operating hours. The 34 meter VAWT as of August 11, 1994 has 1485 hours of operating time. All five gauges have exhibited a crack propagation trend. Two KRAK gauges failed around 690 and 812 turbine operating hours; three gages still appear to be working. Herb Sutherland at Sandia was responsible for the installation of the gages and will be doing the crack growth analysis. At this time a detailed analysis to correlate crack growth to fatique life has not been performed.

Damage gauges should be elegantly simple indicators of component damage due to cyclic fatigue. The damage gauge itself is very simple which should make it inexpensive to fabricate. Monitoring the gauge in the field simply involves taking a reading with a volt-ohm meter. The disadvantages of damage gauges are the need for characterization of the gauge material and the time required to perform the initial design. Many parameters and properties of the gauge and gauge material must be better understood before a successful design is mass produced.

ACKNOWLEDGMENTS

Portions of this paper have been extracted from Ashwill, 1990; Argüello, et al, 1994; and Berg, et al, 1992.

REFERENCES

Argüello, J. Guadalupe, and Clark R. Dohrmann, 1994, "Time Domain Structural Dynamics Simulator for Vertical Axis Wind Turbines", SAND93-XXXX, Sandia National Laboratories, Albuquerque, NM.

Argüello, J. Guadalupe, Clark R. Dohrmann, Tom G. Carne, and Paul S. Veers, 1994 "Analysis/Test Correlation Using VAWT-SDS on a Step-Relaxation Test for the Rotating Sandia 34-m Test Bed", *Proceedings of Wind Energy 1994*, New Orleans, LA, January 1994.

Ashwill, Tom D., 1990, *Initial Structural Response Measurements and Model Validation for the Sandia 34-Meter VAWT Test Bed*, SAND88-0633, Sandia National Laboratories, Albuquerque, NM.

Ashwill, Tom D., 1992, *Measured Data for the Sandia 34-Meter Vertical Axis Wind Turbine*, SAND91-2228, Sandia National Laboratories, Albuquerque, NM.

Berg, Dale E., William A. Stephenson, R. Nolan Clark, and Kenneth E. Mulh, 1992, "A Noncontact Blade Surface Mapping System", *Proceedings of Windpower '92*, Seattle, WA, October 1992.

Carne, Tom G., James P. Lauffer, Anthony J. Gomez, and Tom D. Ashwill, 1989 "Model Validation of the Sandia 34-Meter Test Bed Turbine Using Substructured Modal Testing", *Proceedings of the Eighth ASME Wind Energy Symposium*, Houston, TX, January 1989.

Case, S., 1991, "Laser Sensors for Precise Control of Hybrid Manufacturing", *Hybrid Circuit Technology*, January 1991.

Clark, R. Nolan, and Ron D. Davis, 1991, "Performance Changes Caused by Rotor Blade Surface Debris", *Proceedings of Windpower '91*, Palm Springs, CA., September 1991.

Grant, A.F. Jr., and A. Dumanis-Modan, 1983, *Evaluation of the Crack Growth Gage Concept as an Individual Aircraft Tracking Device*, Vol. II, AFWAL-TR-83-3082, AFWAL/FIBEC, Wright-Patterson AFB, OH 45433, September 1983

Hatch, Paul W., James A. Van Den Avyle, and John Laing, 1989, *Fatigue Crack Growth Automated Testing Method*, SAND 89-0778, June 1989

Hysol Division, The Dexter corp., 2850 Willow Pass Rd., Pittsburg, CA 94565

James, George H., 1994, "Extraction of Modal Parameters from an Operating HAWT Using the Natural Excitation Technique (NExT)", *Proceedings of Wind Energy 1994*, New Orleans, LA, January 1994.

Klimas, Paul C., 1984, *Tailored Airfoils for Vertical Axis Wind Turbines*, SAND84-1062, Sandia National Laboratories, Albuquerque, NM.

Sutherland, Herbert J., and William A. Stephenson, 1988, *Rotor Instrumentation Circuits for the Sandia 34-meter Vertical Axis Wind Turbine*, SAND 88-1144, Sandia National Laboratories, Albuquerque, NM.

Sutherland, Herbert J., and Larry L. Schluter, 1989, *Crack Propagation Analysis of WECS components using the LIFE2 Computer Code*, Proceedings of the Eighth ASME Wind Energy Symposium, Houston, TX, SED-Vol. 7, January 1989

TTI Division, Hartrun Corp., 125 Columbia Court, Chaska, MI 55318

Van Den Avyle, James A., and Herbert J. Sutherland, 1989, *Fatigue Characterization of a VAWT Blade Material*, Proceedings of the Eighth ASME Wind Energy Symposium, Houston, TX, SED-Vol. 7, January 1989

Veers, Paul S., 1987, *Fatigue Crack Growth Due to Random Loading*, SAND 87-2039, Sandia National Laboratories, Albuquerque, NM.

Veers, Paul S., *Simplified Fatigue Damage and Crack Growth Calculations for Wind Turbines*, Proceedings of the Eighth ASME Wind Energy Symposium, Houston, TX, SED-Vol. 7, January 1989

Von Voss, W., D. Lutrus, S. Case, and J. Bolkcom, 1991, "Measure Solder Paste in the Third Dimension", *Electronic Packaging and Production*, January 1991.

Yekutieli, Oded, and R. Nolan Clark, "Influence of Blade Surface Roughness on the Performance of Wind Turbines", *Proceedings of the 6th ASME Wind Energy Symposium*, Dallas, TX, February 1987.

NREL Blade Fatigue Testing

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Walt Musial
Senior Test Engineer

Structural Testing at The National Renewable Energy Laboratory

International Meeting of Test Stations - September 12, 1994
National Renewable Energy Laboratory
National Wind Technology Center, Golden CO

OBJECTIVES:

To operate a state-of-the-art structural testing laboratory at NREL for the purposes of conducting:

- Prototype blade design evaluation for NREL's Turbine subcontractors.
- Conduct cooperative research activities with industry partners.
- Conduct USDOE/NREL/SNL structural testing and research activities.

NREL BLADE TESTING FACILITIES:

TEST STAND #1 - Located in Building A-60 at the NWTC

- Hydraulic Fatigue Testing System - 12,727 kg (28 kip) max load, 1 m (40 in) max stroke
- Static Tests on Blades up to 19-m (60-ft)
- Maximum Moment of 1,356,000 n-m (1,000,000 ft-lbs)
- Maximum Deflections up to 3.65-m (12 ft)

TEST STAND #2 - Located in Building 251 at the NWTC (Highbay)

- Static Tests on Blades up to 19-m (60 ft)
- Maximum Load of 1,356,000 N-m (1,000,000 ft-lbs)
- Maximum Deflections of 9.14-m (30 ft)

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STRUCTURAL TESTING PARTNERS

KENETECH WINDPOWER INC.	56-100 / 33M-VS
ATLANTIC ORIENT CORPORATION	AOC 15/50
PHOENIX INDUSTRIES	PHOENIX 7.9M
NORTHERN POWER SYSTEMS	NW 250
ZOND SYSTEMS INC.	Z-40

Zond Blade Testing:

Test #1 - Fatigue Test of Full Blade / Blade Root	6/1 - 7/30
Test #2 - Modal Test of Blade	6/1 - 7/1
Test #3 - Fatigue Test of Aileron Linkage	8/5 - 8/26
Test #4 - Static Test of Full Blade	8/26 - 10/3

FUTURE GOALS

- Duplicate fatigue testing capability on Test Stand #2.
- Build larger facility to accomadate larger blades.
- Enhance current fatigue facilities to accept different blade configurations, different load spectra, and multi-point loading.
- Testing for certification.

NREL Anemometer Field Calibration

Neil Kelley
National Renewable Energy
Laboratory

NRWL Anemometer Calibration

Neil D. Kelley

Wind Technology Division

Calibration Philosophy

- **Wind Tunnel Calibration Reference**
  - Strive to maintain ±0.1 m/s transfer accuracy over a range of 5-25 m/s
  - Compare wind tunnel calibration via round-robbin intercomparisons as often as possible
- **Atmospheric Intercomparisons**
  - Intercompare both mechanical and sonic anemometry at the NWTC on a regular basis

Topics of Discussion

- Wind Tunnel Calibrations
- Field Intercomparisons

Wind Tunnel Calibrations

NCAR Anemometer Calibration Wind Tunnel

- Tunnel designed by Gerald Gill (U of Mich) and Harold Bayton of NCAR in 1971
- ≈ 1 meter circular cross-section, open loop tunnel
- Operating speed range 0-30 m/s
- Automatic, closed-loop speed control
- Took part in national round-robbin calibration tunnel inter comparison

NREL Tunnel Velocity Data System

Pitot-based system optimized for range of 5-25 m/s

- Computer-controlled data acquisition
- Instrument complement:
  - » MKS Barotron 0-10 Torr Differential Pressure Transducer
  - » Rosemount 4-wire RTD & millivolt linear bridge
  - » AIR digital absolute pressure transducer
  - » Hewlett-Packard 3458A 8.5 Digit Digital Voltmeter
- RM Young Reference Polystyrene Reference Propeller with pitch of 0.2944 m/rev used as local standard

Results of Round-Robbin Comparisons

ROUND-ROBIN WIND TUNNEL EXPERIMENT	Test Date	RR No.	Error to ETP (%)	Rank on Error	Std. error of Y est. (m/s)	a bias (m/s)	b slope (m/s)	Pitch Est. (m/r)
Savannah River Laboratory	2/23/89	16	+0.1	1	0.013	+0.211	+0.0088	0.2966
Nat. Ctr. for Atmos. Res./SERI	1/90	18	+0.1	2	0.045	-0.078	+0.0092	0.2967
National Bureau of Standards	5/24/83	5	+0.1	3	0.052	+0.000	+0.0093	0.2967
R. M. Young Company	7/20/86	13a	-0.2	4	0.016	-0.003	+0.0059	0.2957
R. M. Young Company	10/06/82	1	+0.2	5	0.009	-0.005	+0.0102	0.2970
R. M. Young Company	8/12/86	13b	-0.3	6	0.017	+0.016	+0.0049	0.2954
National Weather Service	8/09/83	6	+0.4	7	0.021	+0.024	+0.0116	0.2974
AES of Canada	4/12/83	3	-0.4	8	0.024	+0.068	+0.0042	0.2952
University of Michigan	3/20/84	10	-0.4	9	0.204	+0.607	+0.0034	0.2950
Nat. Ctr. for Atmos. Res./SERI	8/25/88	15	-0.5	10	0.022	+0.005	+0.0030	0.2949
University of Washington	4/03/85	11	+0.8	11	0.070	+0.058	+0.0161	0.2987
R. M. Young Company	12/13/89	17a	+0.8	12	0.020	+0.038	+0.0163	0.2988
Savannah River Laboratory	1/31/90	19	-0.8	13	0.011	+0.225	-0.0008	0.2938
R. M. Young Company	12/14/89	17b	+0.9	14	0.018	+0.030	+0.0168	0.2989
University of Michigan	3/21/84	10'	+1.0	15	0.041	+0.286	+0.0182	0.2993
University of Washington	2/02/84	9	+1.1	16	0.082	+0.004	+0.0191	0.2996
NOAA - Data Buoy Office	11/03/83	7b	-1.1	17	0.021	+0.054	-0.0034	0.2930
NOAA - Data Buoy Office	10/27/83	7a	-1.2	18	0.101	+0.016	-0.0040	0.2928
University of Hawaii	12/10/83	8	+1.2	19	0.240	+0.177	+0.0203	0.3000
Meteorology Research, Inc.	4/25/83	4	+1.4	20	0.033	+0.001	+0.0223	0.3005
EPA Fluid Dynamics Lab.	11/04/82	2	-2.6	21	0.022	+0.015	-0.0184	0.2885
Dugway Proving Ground	12/08/87	14	+4.4	22	0.035	+0.038	+0.0555	0.3093
Brookhaven National Laboratory		12	+5.9	23	0.110	-0.028	+0.0669	0.3137

Source: *Meteorological Standards Institute*
Fox Island, Washington

Atmospheric Intercomparisons

- Intercomparison exposure at NWTC
  - Tower at Site 1.1 allows exposure to both mountainous and rolling terrain upwind fetches
  - Computer-controlled, 16-bit data acquisition system
  - System allows for pre-programmed data collection sequences
- Used only for Sonic/Bivane Intercomparisons So Far

Future Plans

- Re-activate wind tunnel calibration capability using NCAR Tunnel
- Re-establish NWTC Anemometer Intercomparison Facility at Site 1.1
- Enter into new series of Round-Robin tunnel intercomparisons

What This Means

- Goal is to maintain well-documented data base for wind resource measurements and characterization of the NWTC
- Documented wind speed measurements with accurate estimates of error limits for both power curve and dynamic testing activities at the NWTC

NREL Certification Program

C. (Sandy) Butterfield
National Renewable Energy
Laboratory

NREL ORGANIZATION AND CERTIFICATION PROGRAM

C.P. (SANDY) BUTTERFIELD

Presented at the International Meeting of Test Stations
September 12-13, 1994

NREL Activity:

- Applied Research Program
  - Inflow Research
  - Resource Assessment
  - Unsteady Aerodynamics
  - Structural Dynamics Codes
  - Advanced Components

    Aerodynamic Devices
    Electrical and Controls
    Advanced Blades
    University Research

C.P. Butterfield
IMTS Meeting, September 12-13, 1994
Boulder, Colorado

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NREL Activity (continued):

Utility and Industry Programs

- Turbine Development Programs

  - Turbine Development Contracts

    Cost shared contracts with US companies to assist in the development of advanced wind turbines. Major goal is to reduce the Cost of Energy (COE) to $0.04 k/W at Great Plains sites by 2000.

NREL Activity (continued):

Utility and Industry Programs (continued)

- **Supporting Research and Testing**

NREL and SNL provide direct support to companies under contract.

Analysis
Field testing
Fatigue testing
Dynamometer testing

C.P. Butterfield
IMTS Meeting, September 12-13, 1994
Boulder, Colorado

NREL Activity (continued):

Utility Integration Programs

- CCAP Windfarms
- U*WRAP
- Avian Interaction
- TVP
- Utility Analysis
- Systems Analysis

NREL Activity (continued):

- Technical Assistance
  - International Programs
  - International Resource Assessment
  - Wind/Hybrid Systems

- Cooperative Technical Development
  - Industry Support
  - Industry Cooperative Research
  - Industry Testing and Operations Support
  - *Wind Turbine Certification*

NREL

Certification Testing Program Plan:

Develop certification testing procedures

- Calibration procedures
- Documentation procedures
- Testing procedures
- Reporting procedures
- Proprietary data security procedures

C.P. Butterfield
IMTS Meeting, September 12-13, 1994
Boulder, Colorado

Certification Testing Program Plan (continued):

Test the Testing procedures

Round Robin test of reference anemometer with Risø

Round Robin Turbine Test (AOC 15/50) with Risø

Report results of:

Anemometer Round Robin Test
Round Robin Turbine Noise Test
Round Robin Turbine Performance Test
Round Robin Turbine Loads Test

Offer Certification testing services to Industry

C.P. Butterfield
IMTS Meeting, September 12-13, 1994
Boulder, Colorado

Certification

Carsten Skamris
Risø National Laboratory

(Unavailable at time of printing)

Lloyd's Certification Assessment

Ray Hunter
NWTC

14th International Meeting of Test Stations Boulder, Colorado, USA

Conformity Assessment System for Wind Turbines

Raymond S Hunter

&

Allan G Johnston

National Wind Turbine Centre

UK

Standards & Certification

Certification is a means of assessing conformity to standards.

Standards have many benefits including:

- improved management control
- consistency
- improved productivity

The benefits of certification are different and include:

- improved tendering ability
- marketing (PR benefits)
- increased market share

- Lloyd's Register (LR), project management & certification input

- Garrad Hassan & Partners (GH), design review and specialist input

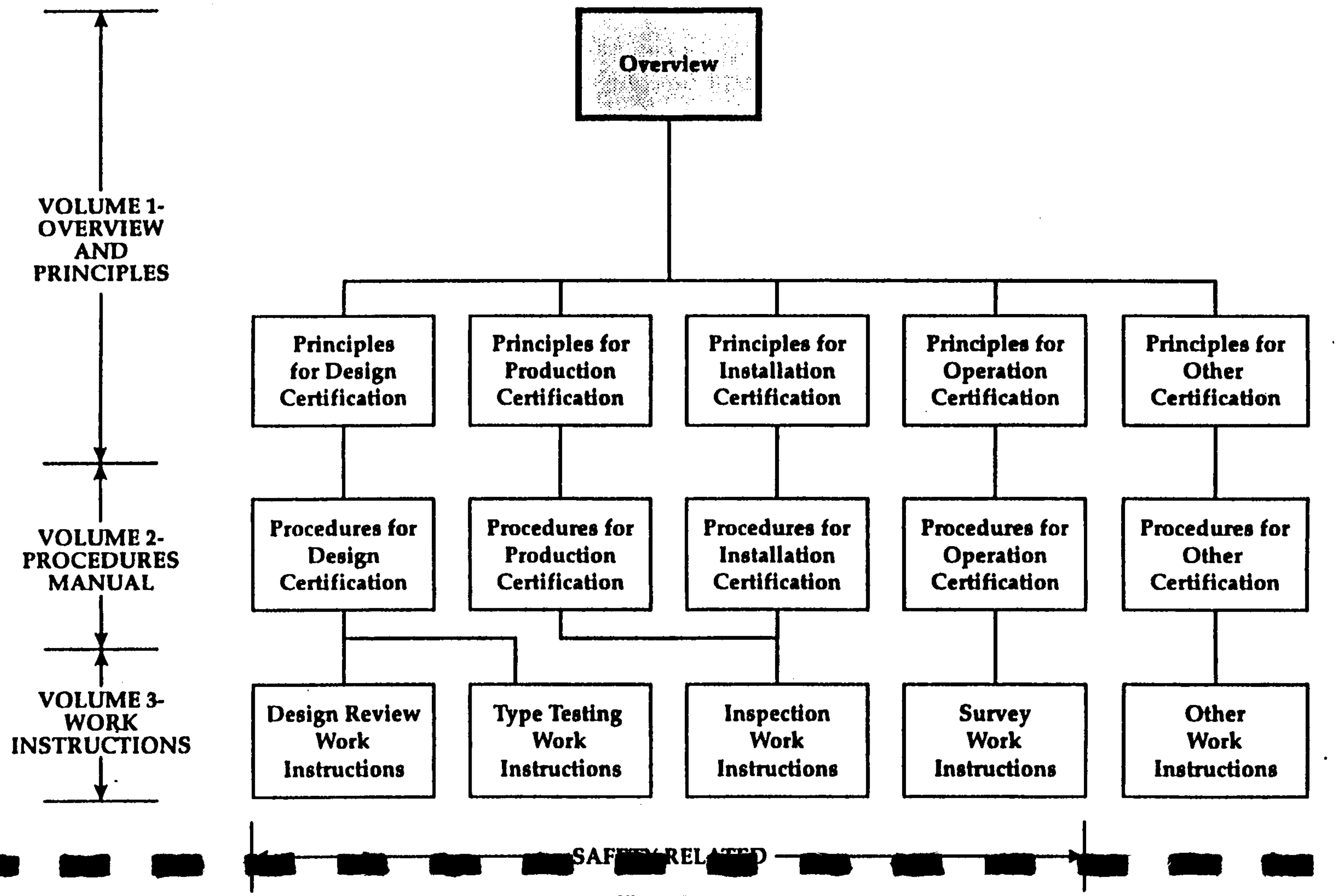
- NEL, testing input

- Wind Energy Group (WEG), manufacturer input and provision of test bed

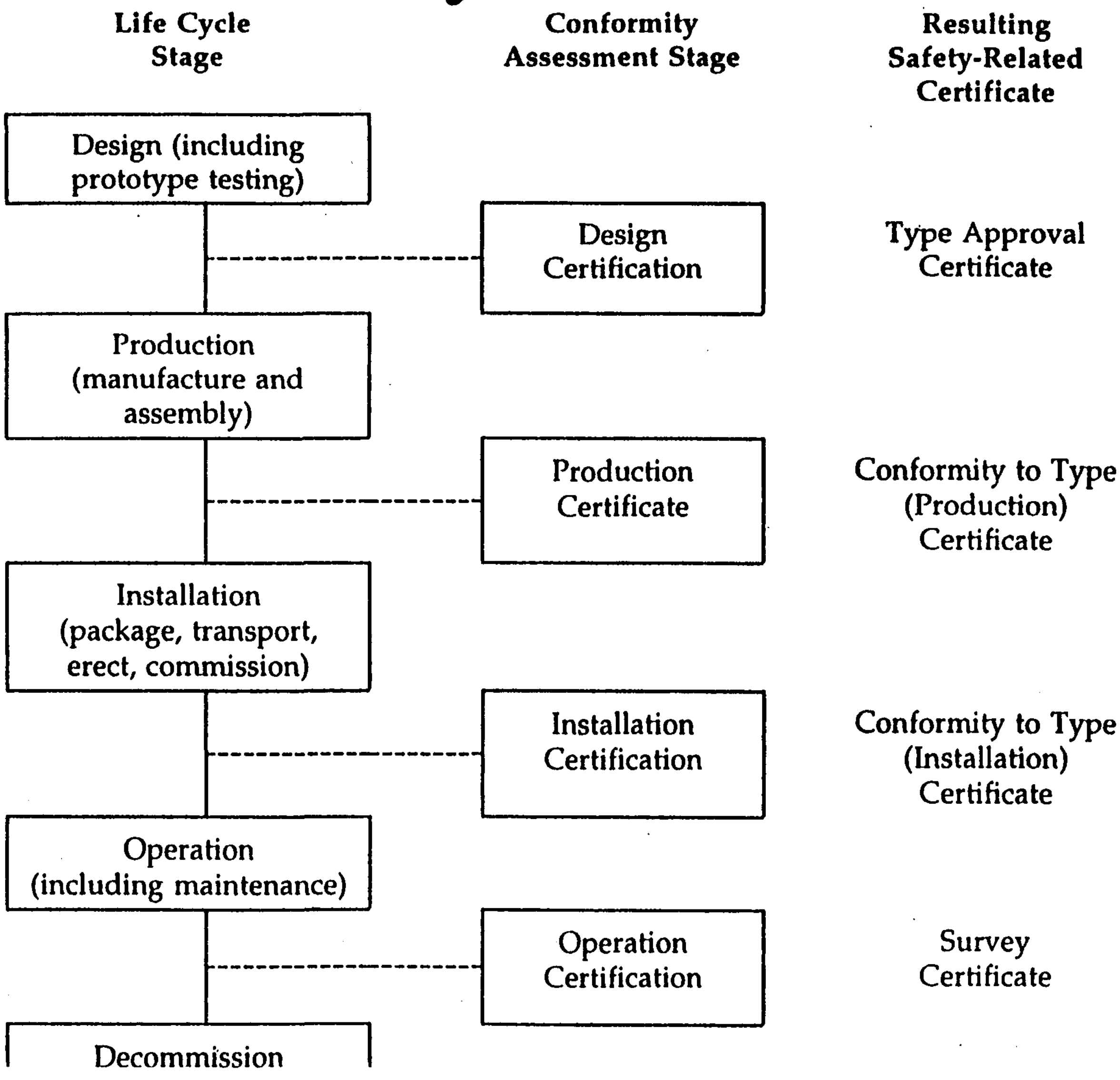
- Formal launch of the LR Conformity Assessment System will be launched at the EWEA Conference in Greece, 10-14 October 1994

- Project Deliverables - Documentation in 3 volumes
  - Volume I: Overview & Principles
  - Volume II: Procedures Manual
  - Volume III: Work Instructions

Conformity Assessment of Wind Turbines Overview



Life Cycle Model



Life-Cycle Phase	Phase Number
Design (including prototype testing)	1
Production (manufacture and assembly)	2
Instalation (package, transport, erect, commission)	3
Operation (including maintenance)	4
Decommission	5

Design Certification

CLIENT

Wind turbine designer/ manufacturer

Operating to ISO 9001 (or a similar approved) standard (Ref. 4)

LR

Type Approval project manager

Operating to EN 45011 or equivalent standard (Ref. 5)

Design Review Group

Named experts

Type Testing Group

Production Certification

CLIENT Wind turbine manufacturer	*Operating to ISO 9002 (or a similar approved) standard (Ref. 7)*
LR Project manager	*Operating to EN 45012 or equivalent standard (Ref. 8)*
INSPECTION TEAM Named member(s) plus other member(s)	Named Inspectors

Operation Certification

CLIENT Wind turbine manufacturer	*Operating to ISO 9002 (or a similar approved) standard (Ref. 7)*
LR Project manager	*Operating to EN 45012 or equivalent standard (Ref. 8)*

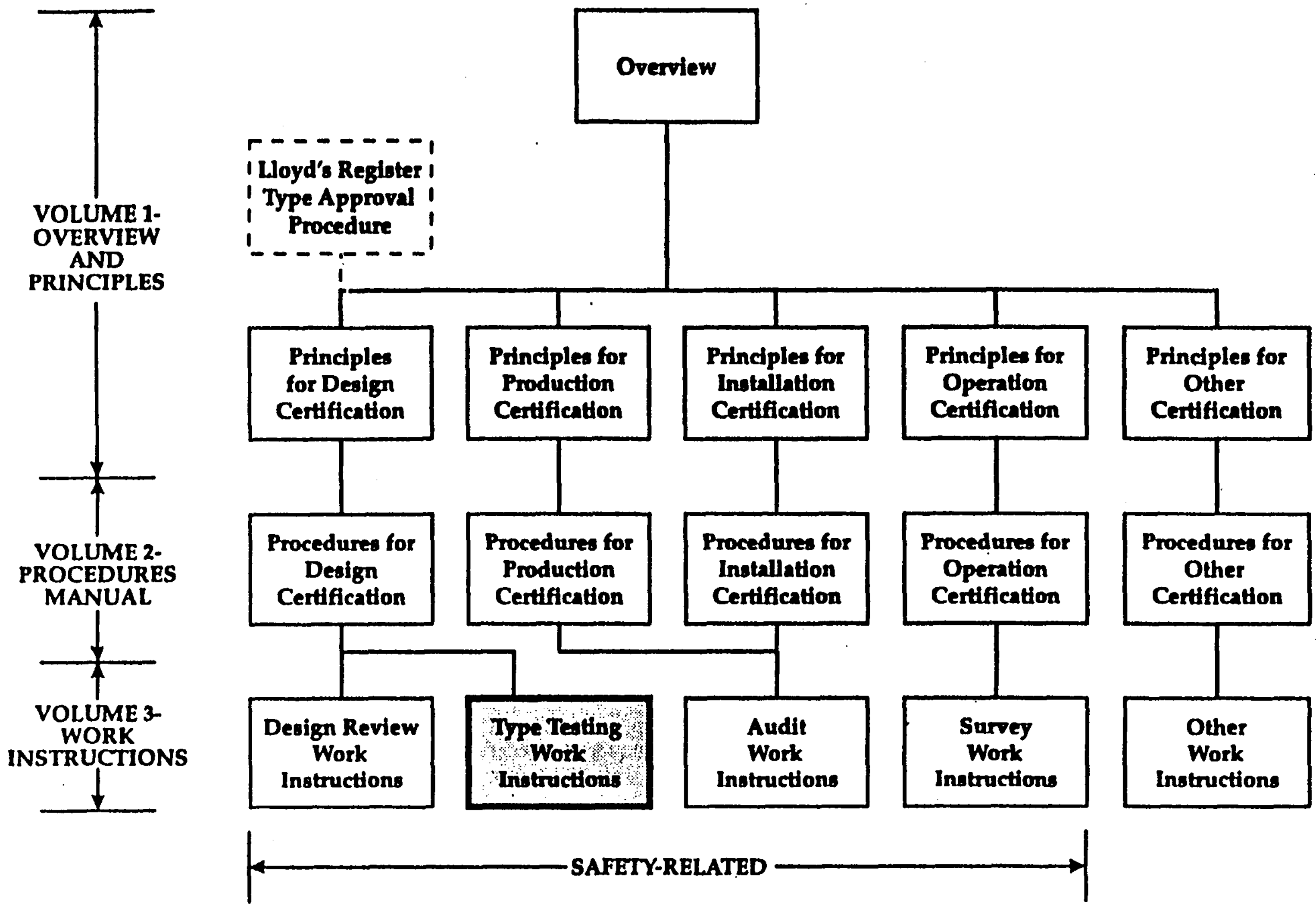
SURVEY TEAM

Named surveyor(s)
plus
other surveyor(s)

Installation Certification

CLIENT Wind turbine installer	*Operating to ISO 9002 (or a similar approved) standard (Ref. 7)*
LR Project manager	*Operating to EN 45012 or equivalent standard (Ref. 8)*
INSPECTION TEAM Named member(s) plus other member(s)	Named Inspectors

Conformity Assessment of Wind Turbines Overview



Testing Philosophy

Reasons for Mandatory Testing

- Confirm the function and integrity of a safety critical component or system where one or more of the following is applicable:

- Where legislation or institutional frame works require specific testing

Selection of Mandatory Tests

- If for a given test, one or more of the above reasons will always definitely apply to all turbines then that test should be made mandatory
- If it is highly unlikely that any of the above reasons will every apply to a given test for any turbine then that test should not be mandatory

Selection of Mandatory Tests

- However, if there is a probability that for some but not all turbines a given reason might apply then an assessment of whether the given test is mandatory should be made based on the design appraisal of the specific turbine being considered

Scope

- These type testing procedures, as the name implies, relate to testing and not to inspection. However, the procedures do include verification of function of safety critical systems by witnessing.

Scope

- There is no requirement that any of the tests have to be carried out by an independent body. However, should a manufacturer choose to carry out the tests in-house, then the results and documentation submitted for inspection by the approval body should provide enough information for an adequate independent appraisal to be conducted. As a minimum this will require an audit trail to be established in accordance with ISO 9000

Hierarchical List of All Tests

- ROTOR
- TRANSMISSION
- SUPPORT STRUCTURE
- ELECTRICAL CONVERSION
- TURBINE
- CONTROL AND PROTECTION
- PERSONNEL SAFETY

ROTOR

- Rotor blades
- Connections and Interfaces
- Hub
- Pitch Mechanism
- Air Brake System
- Teeter Mechanism Components

TRANSMISSION

- Low Speed Shaft
- Gearbox
- High Speed Shaft
- Mechanical Brake
- Bearings
- Compliant Couplings
- Generator
- Connections and Interfaces
- Blocking Devices

SUPPORT STRUCTURE

- Mountings and Housings (Drivetrain)
- Bed Plate
- Yaw Bearing
- Tower
- Foundation
- Connections and Interfaces

ELECTRICAL CONVERSION

- Generator
- Transformer
- Down-Cable
- Slip Ring
- Switch Gear
- Power Factor Correction
- Power Conversion System
- Electrical Connections and Interfaces

TURBINE

- Complete turbine

CONTROL AND PROTECTION

- Processors
- Transducers
- Actuators
- Brakes
- Yaw
- Power Regulations
- Blade Pitch
- Synchronisation Hardware
- Circuit Breakers
- Lightning
- Fire

PERSONNEL SAFETY

- Access, Access Prevention and Escape
- Blocking Devices
- Electrical
- Interlocks

List of Mandatory Safety Related Tests

The following tests apply to applications for type approval and are mandatory

- ROTOR
- TRANSMISSION
- SUPPORT STRUCTURE
- ELECTRICAL CONVERSION
- TURBINE
- CONTROL AND PROTECTION
- PERSONNEL SAFETY

List of Environmental Related Tests

The following tests relate to the issue of an environmental certificate

- Turbine - (Complete System)
  - Acoustic Noise Emission
  - Visual Appearance

List of Quality of Performance Related Tests

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- Power Conversion System
- Turbine - (Complete System)
  - Power Performance

Format for Work Instruction Sheet

- Title
- Justification for Test
- List of Possible Reference Procedures
- Recommended Selection and Amendment of Procedure
- Interpretation of Test Results

Certification

Bob Sherwin
AOC

(Verbal presentation only)

ECN Certification Activity

Wim Stam
ECN

EUROPEAN WIND TURBINE STANDARDS

JOULE-II PROJECT : CT93-0387

MAIN CONTRACTOR : EUREC AGENCY

TECHNICAL COORDINATION : ECN

PROJECT BUDGET : 1.450.000 ECU

DURATION : 2 YEARS

EUROPEAN WIND TURBINE STANDARDS

PARTICIPANTS

* EUREC AGENCY

- CIEMAT	(SPAIN)
- CRES	(GR)
- DEWI	(GER)
- ECN	(NL)
- NEL	(UK)
- RISØ	(DK)

* ASSOCIATE CONTRACTORS

- Det Norske Veritas	(DK)
- Germanischer Lloyd	(GER)
- Teknikgruppen	(S)

ECN

EUROPEAN WIND TURBINE STANDARDS

Objectives

SUPPORT TECHNICAL HARMONIZATION OF EUROPEAN WIND TURBINE MARKET

* **Development of guidelines and recommendations.**
- **Address key issues.**
- **Not (properly) covered yet.**
- **Implement Probabilistic Reliability Analysis.**
- **Integrate available information.**
- **Generate new information (if necessary).**

ECN

EUROPEAN WIND TURBINE STANDARDS

Objectives (cont)

* **Establish a expert network.**
  - **Identification of constraints.**
  - **Screening of directives.**
  - **Tracking standardization activities.**

* **Report to interested parties.**
  - **CEN/CENELEC.**
  - **National Standardization committees.**
  - **Manufacturers.**
  - **IEC-88/IEA.**
  - **Others.**

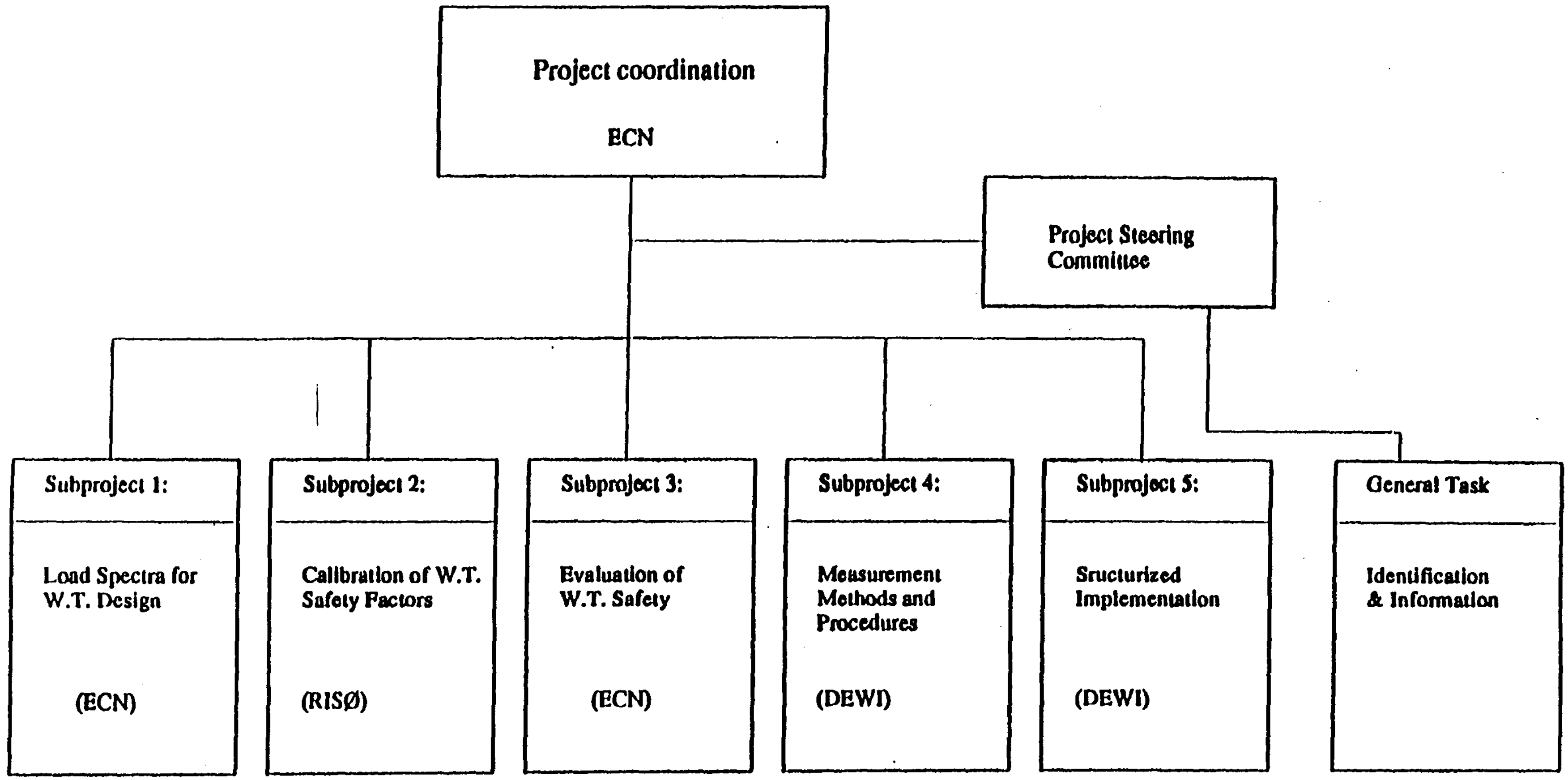
ECN

EUROPEAN WIND TURBINE STANDARDS

AVAILABLE DOCUMENTATION

* European Council Directives.
* IEA Recommendations.
* IEC Draft Standards.
* Results of JOULE studies.
* Europa-recommendations (DG17-studies)
* National Standards/criteria (DK, GER, NL).

ECN


Project coordination
ECN
Project Steering Committee
Subproject 1:
Load Spectra for W.T. Design
(ECN)
Subproject 2:
Calibration of W.T. Safety Factors
(RISØ)
Subproject 3:
Evaluation of W.T. Safety
(ECN)
Subproject 4:
Measurement Methods and Procedures
(DEWI)
Subproject 5:
Sructurized Implementation
(DEWI)
General Task
Identification & Information

EUROPEAN WIND TURBINE STANDARDS

Deliverables

* **Methodology for W.T. design Load spectra.**
* **Procedures for safety factor calibration.**
* **Methodology for W.T. safety evaluation.**
* **Measurement techniques and procedures.**

ECN

EUROPEAN WIND TURBINE STANDARDS

PROJECT STRUCTURE

* Sub projects
  I Load spectra [ECN]
  II Safety factor calibration [RISØ]
  III Safety evaluation [ECN]
  IV Measurement procedures [DEWI]
  V Implementation plan [DEWI]

* General Task [PSC]

ECN

EUROPEAN WIND TURBINE STANDARDS

Sub project I:
Load spectra for Wind Turbine Design

Objective

Uniform methodology for design load spectra
- based on existing information;
- include increased loads in wind farms;
- allow for use of load measurement results.

Coordination : ECN

Participants : CIEMAT, CRES, DEWI, ECN, NEL, RISØ, TAB

ECN

EUROPEAN WIND TURBINE STANDARDS

Sub project II:
Calibration of Partial Coefficients

Objective

- **Development of a calibration procedure based on probabilistic structural reliability analysis.**
- **Calibration of some central partial coefficients.**
- **Drafting of guidelines for comparison of structural safety levels in (inter)national standards.**

Coordination : RISØ

Participants : DNV, ECN, RISØ

ECN

EUROPEAN WIND TURBINE STANDARDS

Sub project III: Evaluation of Wind Turbine Safety

Objective

Practices for evaluation and assessment of safety concepts and systems.

- Including probabilistic system reliability analysis;
- based on and supplementary to present rules;
- applicable for designers, developers and certification bodies;
- allow for more quantative assessment of safety and risk.

Coordination : ECN

Participants : ECN, GL, RISØ

ECN

EUROPEAN WIND TURBINE STANDARDS

Sub project IV:
Evaluation of Wind Turbine Safety

Objective
Recommendations to harmonize test, measuring, calibrating and evaluating techniques.
- Wind speed measurements;
- site calibration;
- mechanical load measurements;
- electrical power quality.

Technical Coordination : DEWI

Participants : CRES, CIEMAT, DEWI, ECN, NEL, RISØ

ECN

EUROPEAN WIND TURBINE STANDARDS

Sub project V:
Structural Implementation of Standardized W.T. Measurement

Objective

Action plan for implementation in EUREC Agency measurement network.

- **State-of-the-art techniques;**
- **voluntary mutual accreditations;**
- **acceptation of results**

Coordination : **DEWI**

Participants : **DEWI, ECN, RISØ (CRES, NEL, CIEMAT)**

Status : **Preliminary draft plan**

ECN

EUROPEAN WIND TURBINE STANDARDS

GENERAL TASK: IDENTIFICATION AND INFORMATION

* Identification of constraints and bottle-necks.

* Screening of E.C. Directives on technical suitability.

* Drafting of custom made documents for interested parties.

ECN

EUROPEAN WIND TURBINE STANDARDS

PROJECT STATUS

* PSU; March 10-11, 1994, ECN
* Kick-off S.P. I : May, 1994
* Kick-off S.P. II : April 26, 1994
* Kick-off S.P. III : April 26, 1994
* Kick-off S.P. IV : April 18-19, 1994
* Kick-off S.P. V : April 7, 1994

ECN

Meeting Minutes

International Meeting of Test Stations
(September 12-13, 1994)

MEETING MINUTES

Attendees:

D. Ancona, DOE, USA
A. Fragoulis, CRES, Greece
D. Dodge, NREL, USA
H. Klug, DEWI, Germany
N. Kelley, NREL, USA
M. Rumsey, Sandia, USA
N. Clark, USDA, USA
D. Berg, Sandia, USA
T. Petersen, Riso, Denmark
V. Minim, IN, Russia
G. Dmitriev, IEN, Russia
P.H. Jensen, Riso, Denmark
C. Skamsis, Riso, Denmark
S. Butterfield, NREL, USA
R. Sherwin, Atlantic Orient, USA
W. Stam, ECN, The Netherlands
Magnus Ellsen, Chalmers Univ.,

The issue discussions in these minutes record dialogues which occurred during or immediately following the various presentations; which would not be included in the copies of vu-graphs.

A. Fragoulis
Testing Activities at Center for Renewable Energy Sources (CRES), Greece

Calibration Accuracy

A.Fragoulis — In calibrating blade strain gages; can introduce errors if you don't calibrate from more than one point (one for flap another for edge bending moment.)

R.Hunter — Are you saying you can't avoid crosstalk in blade strain gage calibrations?

A.Fragoulis — Yes. Test engineers must account for the cross talk effect by making flap and edgewise measurements. Otherwise can have an error in loads up to 10%.

Performance Testing

Dr. Fragoulis suggests the use of turbine power and noise level to measure the wind speed, given the difficulty with calibrating anemometers and accounting for terrain effects..

P. Jensen: Questioned assumptions made about wind shear, sayed that these are difficult to make in complex terrain.

T. Pedersen: How does CRES mount anemometers on turbine to avoid wind interference?

Fragoulis: They mount on nacelle at center line of tower.

Jensen: Expressed opinion that one needs to correlate with a separate mast-mounted anemometer first

Fragoulis Proceudres are based on need to certify power performance rapidly (in 2 months)

S. Glocker, WINDTEST, Kaiser Wilhelm-Koog.
Certification Situation in Germany

Germany has a new format for certification test reports which includes an uncertainty analysis according to S Frandsen's IEA recommendations

H. Klug (Comment) It is important that power and noise curves are public once manufacturer applies for a subsidy

S. Glocker (In response to a question on turbulence intensity) WINDTEST throws out all data collected when the calculated turbulence intensity is over 15%.

Issue - Power Quality Measurements

P Jensen What drives power quality measurements?

S.Glocker WINDTEST doesn't discriminate among effects, but flicker is most imporant, as induced by voltage and current variations

R. Sherwin How discriminate between what turbine is producing and what the grid is doing? On an induction based machine, what you measure is what's going on in the grid.

S.Glocker They try to measure with and without turbine to determine this

Issue - Comparison of tip shapes using wind tunnel and field data

W. Stam &
A. Fragoulis: Work is being done on discrepancies between results in the tunnel and in the field right now. There is a real difference between the results and the physics are complex.

Ray Hunter and Alan Johnston, NEL
IEC TC88 Noise and Performance Testing at NEL

No issues discussed.

Magnus Ellsen, Chalmers Univ.
Hono Test Site Activity

Comparison of synchronous generator with diode rectifier with induction generator with transistor rectifier

Question: What are the relative costs for synchronous and induction generators?

M. Ellsen We use a factor of 3.7 for a synchronous generator, compared with a factor of 5.7 for an induction generator.

R.Hunter Are there limitations to the loads that can be handled?

S.Butterfield Pointed out that the two types of generatorss assume different types of control (Synchronous: frequency control; induction: rpm control)

T. Pedersen How are the costs of the rectifier losses calculated?

M.Ellsen Losses are related to the cost of the entire turbine

Wind turbine of the future? Direct drive turbine with control system that monitors flap loads with a smart control linked to the grid through a transister inverter.

Peter H. Jensen, Riso

See CFD as major work area in the future; trying to optimize CFD models; using commercial and inhouse codes.

W. Stam (Commenting on P. Jensen's claim of increased efficiency for larger turbines):

Increase in rotor efficiency can be misleading if increased hub height (and resulting higher winds) is not factored in.

Troels Pedersen, Riso

T. Pedersen Riso is testing blades up to 24 meters (their facilities will be too small to service industry by the end of this year).

S.Butterfield Can control system compensate for changes in eigen frequency? Yes.

T. Pedersen Looking at flow around hills and other complex terrain and effect on performance; they have categorized such structures and have calculated adjustment factors. Even very small hills can create very large speedups at 30-meters of elevation. Increase is greater at 4D than at 2-3D. (calculations done with WASP)

Wake Effects

T. Pedersen Need to be 30-40 rd away to be outside the wake. will be fully in wake within 18-20 r.d.

(In response to question from A. Fragoulis) These figures take turbulence into account.- turbulence level of 10%

Issue - Correction of power for a pitch regulated wind turbine when close to rated power: Cp is constant divided by wind speed to the one-third power

T. Pedersen Instead of this, should be proportional to wind speed (not raise wind speed to any power)

Issue - Positioning anemometer on wind turbine so that wind speed does not change

Need to find a place where the anemometer will not be shadowed by the nacelle if the wind is coming uphill or downhill relative to the machine.(T. Pedersen showed areas where anemometer could be located)

S.Butterfield Are there any effects of blade passsage with nacelle-mounted anemometer?

T.Pedersen No, the wind speed effects average out.

V. Minin, Russian Academy of Sciences, Murmansk

Map of Northern Russia shows concentrations of wind near coast of 7.7 m/s - 9 up to 10-12 m/s

The Murmansk test station is located 60 meters above sea level.

Russian-made windsets (from 200 W to 6 kW) are under test at their facility

Test results have been used to improve turbines; as a result of success, will be considered for large scale tests

Total Russian wind capacity is about 5MW

G Dmitriev, Russian Academy of Sciences, Murmansk

Power grids are very small therefore potential is for small scale power sets. The potential for Kola penisula is 12×10^9 kWh/year; potential capacity is 40×10^6 kW

Hydro and wind are compatible; availability for hydro in spring and summer, availability for wind in winter.

Icing is not a problem because winter winds blow from SW toward the warmer sea.

There is little interference with human habitation in the area; best wind areas are unpopulated.

Nolan Clark, U.S. Department of Agriculture, Bushland
Testing Activities at the USDA

A Fragoulis — Did you have lightning problems with instrumentation

N.Clark — Had a spike and it blew a fuse on the power coming in but didn't have problem with computer installed

Dale Berg, Sandia Laboratories
Test Activities at Sandia

Question: With regard to the application of KRAK gauges, can they be applied to other types of materials other than aluminum?

D. Berg — Yes. Herb Sutherland at Sandia has used them for composites. He can be contacted at Sandia.

N. Kelley, NREL
NREL Anemometer Field Calibration

W. Stam	Could European wind tunnels be included in a round robin test involving U.S. facilities?
N.Kelley	Yes they could be.
S.Butterfield	Mentioned that NREL and Riso were planning to conduct a round robin anemometer test in conjunction with the round robin turbine test that will be conducted next year.
N.Kelley	Discussed problems with accuracy of propeller vanes in some cases: turbulence causes improper tracking; vertical component causes anemometer to read up to 20% low. NREL no longer uses propeller anemometers in windfarm situations. Cups are not affected in this way by turbulence.
T.Pedersen	Has this been documented?
Response:	No. The question was raised at TC-88 but only according to rumors by the Americans. This should be formally documented in some way.
N.Kelley	Certainty that this problem was happening is high: 1) happened on more than one level; 2) could be predicted as small-scale turbulence increased.
H. Klug	DEWI has had to calibrate sonic anemometers for many directions due to their characteristics. Does Kelley have a problem with this?
N.Kelley	Did not notice this effect at a very turbulent site; would be more important at a non-turbulent site. At NWTC turbulence averages 30%.
R. Hunter	In Europe have been doing round robins for a long time. Still get small differences beween tunnels due to difficulty in defining blockage areas. We are identifying "super teunnels" with limited blockage errors; this has caused criticism, but now we can identify specific errors between test stations.
N. Kelley	It is important to cross check with tests in the atmosphere. Aeronautical tunnels are too laminar. Scatter is greater with cups when they are tested in a tunnel.
A.Fragoulis	CRES has used propeller, cup and sonic in wind tunnel and test site: They have found the same thing with propellers (they introduce effects designed into them and are "second order instruments") The Gill sonic instrument seems to be directional but this doesn't matter at the test site due to higher turbulence. They

have used a 3-dimensional propeller ("you get a lot of [extraneous] information if axis is up to 45 degrees").

H. Klug — Should really directly compare a cup and a propeller anemometer. We can include this in harmonization process.

P.Jensen — We have already talked about this

H.Klug — Should have one from the States also.

R Hunter — Is this under development?

T.Pedersen — No. it is being developed

S. Butterfield
NREL Plans for Certification Testing

A Fragoulis — What is schedule for NREL's round robin with Riso?

S.Butterfield — Test the AOC 15/50 turbine by Spring (the turbine is already installed at NREL's facility). Start anemometers sooner. Riso will test in the Autumn

Question: — Why do modal testing?

S.Butterfield — Natural frequencies are needed to validate dynamics codes like ADAMS and other models like YAWDYN, FAST and FLAP that use distributed properties.

C. Skamris — Why doesn't NREL include type approval in its program?

R.Thresher: — Primarily legal reasons - DOE and NREL are not certified to do this through legislation or other means. Are not insured to handle liability questions arising from certification.

Alan Johnston, National Engineering Laboratory
Overview of Certification Activities at NEL

Conformity Assessment of Wind Turbines - with LR, will be launched at EWEC in October 1994

Mandatory Testing - where regulations require it and where needed to confirm function and integrity of a safety critical component or system when: a. calculation is not posible, b. design information is not known, c. there is lack of confidence in calculations.(e.g., airbrakes at low V)

Manufacturer can do the test himself, but tests have to be open to scrutiny; an audit trail such as ISO-9000 is required. However, Safety Systems require independent testing.

NEL defines a hierarchy of 40-50 tests (defined by discrete output data) in the areas of safety, environment, and performance.

Work Instruction Sheet:

- Title
- Justification ofr Test
- List of Possible Reference Procedures
- Recommended Selection and Amendment of procedure
- Interpretation of Test Results

A full NEL test could cost a great deal of money; approach has been to get manufacturer to assess his own conformity; Lloyd's Register will randomly sample the data that has been produced. LR will ask what tests have been done; LR will then delve into greater depth of tests and analyses that have been done.

T. Pedersen Does this guanaratee a role for Garrad Hassan

R.Hunter No

T.Pedersen What is an "appearance test"?

R.Hunter This is related to blade reflectivity

C. Skamris
Type Approval of Wind lTurbines at Riso Laboratory

History of certification in Denmark:

1979 - 1st evaluation

1981 - system approval attached to subsidy system

1994 - open market with certified accreditation bodies (DEA doesn't want to do all type approvals, RISO must now compete with other companies)

Organization: DEA asked Test Station to develop the system

Limits:

Concrete Foundation - assure that foundation matches planned soil conditions at site

Electrical System - limited at utility interconnect if not a part of the turbine
Control System - safety aspects only - look at components of system and assure that it matches the principles of the turbine's control

S.Butterfield How do you track possible flaws?

C.Skamris We don't have separate tests of the control system, but do simulate failure of components; look into opertion and maintenance of the wind turbine.

Type Approvals:

1. Safety Systems (mechanical, personnel safety (installation & operation, follow rules for othersimilar equipment; these are under local jursidiction in Denmark)

2. Documentation Quality (lifetime, efficiency/power curve, reliability [more related to general design integrity], and noise)

Three Levels of Type Approval:

A - highest, all must be documented & installation certificate according to ISO-9002 (1 year)

B - non-safety related components may not have to bedocumented. There can be one ortwo outstanding points (such as power curve) Can accept a product certificate (1 year)

C - prototypes only - for demonstration, 3-year period, after which turbine must be taken down or obtain higher level of approval

Question: What about renewals?

C. Skamris Renewals require reports on all accidents and product changes or improvements

Approval Methods:

Control of documentation (red pencil approach) - has advantage of providing a check of design methods used by manufacturer. Design is verified through test and analysis performed by Riso.

W. Stam Can manufacturer have verification without doing his own calculations?

C.Skamris No. Manufacturer must have made his own calculations.

Manuals have to be in Danish for approval by Riso

Conditions:

Type approval is a commercial activity; therefore the manufacturer must pay. At the same time, Riso must accept approvals by other bodies in Denmark. They obtain Det Norske Veritas cooperation for working outside Denmark (they are accredited in The Netherlands and Germany)

S.Butterfield Is Riso ISO-9000 certified?

C.Skamris No, but we are working on it. EN - 45000 45011 are aspects of ISO-9000 in Europe, they are more specific for laboratories and certification agencies (similar to ASQC in United States)

DEA requires that Riso be accredited,but they are working under a grace period

R. Hunter (In response to question) NEL is midway through ISO-9000 accreditation. NAMAS has certified them in UK for test quality.

W.Stam ECN is accredited according to EN-45000 and 45011.

S. Glocker WINDTEST is accredited according to EN - 45000.

R.Thresher Guiding Principles in U.S. are that any process meet economic, political and market realities in U.S.

1. Industry Driven with consensus approach
2. Voluntary progrm in the U.S. (market forces will drive companies to participate)
3. Concentrate capability in one place
4. Not compete with industry (e.g., certification agencies)
5. Work for acceptance in other countries on a broad international basis.
6. Independent Testing must be maintained separately from turbine development- (NREL is also direct administrator of R&D funds).

Wim Stam - ECN
Discussion of European Certification Activities

Certification in Europe has been governmentally driven, but this will change to inudstry driven

European Project to support European wind turbine standards involves Joule II - EUREC, and European renewable energy centers (CRES, DEWI, Riso, ECN, etc.)

This project is not designed to develop new standards; rather aimed at developing guidelines and recommendations.

Issues not (properly) covered by existing standards

W. Stam (In response to question from R. Thresher): There is no formal relationship between this and IEC. Documents will be distributed to the U.S. (first document will be available at the end of 1994). Makeup of the commiteess is almost the same as the IEC participation in Europe.

We try to avoid duplication of on-going IEC activity; i.e., not must inerest in aoustics, but a lot of focus on anemometery, which is not covered under IEC. Recommendations will be provided to the IEC working group 7

S.Butterfield Should groups operate in closer participation?

W.Stam Many members are the same among these two groups.

R.Hunter This project is establishing the technological basis for the European participants.

D.Dodge Very similar to the technical work that is going on between NREL, University of Utah, and U.S. industry participants.

A.Fragoulis Should work together to form a common baseline (don't know how contractually do this, but this should be a high priority on the agenda)

S.Butterfield Between U.S. and Europe and other countries, formal harmonization is more difficult than informal harmonization.

D.Ancona No way to enforce harmonization other than to let the market enforce it. each country has their own set of internal philosophies and procedures. The world economy will harm those counries that are too restrictive.

W.Stam Hope that this project will eliminate additional rquirements in Europe.

D.Ancona Want to start an IEA annex for the round robin test; US and Riso should continue, but this offers an opportunity for others to participate.

R.Sherwin IEC has an observer on the IEA and there are already procedures for transferring documents between the two groups (e.g., acoustics has involved IEC use of an IEA document)

Group Consensus: Frame round robin in terms of making it an IEA annex; let others look at it and see if they want to participate . Riso needs a description to give to the Daniah Energy Agency.

NREL and Riso will draft a proposal.

NREL has its own goals; to establish certification test credibility

R.Thresher	We don't understand different test results from different wind regimes and using diffrent data systems. We will find sources of error and learn how they are created.
W.Stam	This scientific reason should be the rationale for the IEA annex
R.Sherwin	We should leave certification issues out of the IEA agreement
A.Fragoulis	CRES has started something similar to this with a Vestas 225 turbine and a Nordtank machine operating in Greece, Spain, and Sky River.
T.Pedersen	Need a small turbine to send around to various countries participating in the round robin.
W.Stam	Suggest that we restrict the loads measurements so that they don't get too expensive for the various laboratories.
S.Butterfield	Staged tests were envisioned for the NREL-Riso round robin so that people could do what they want to; but a loads program is critical to eventual agreement and harmonization.
T.Pedersen	The ultimate goal is how to use these data to harmonize testing
R.Thresher	Would be desirable to develop a very abbreviated load test, such as one flap and one edgewise measurement or do a rainflow count. This would be advantageous to defining turbine design issues for harmonization. Even "identical" turbines may not behave in the same way.

Wrap Up Discussion

The group discussed the format of subsequent meetings, agreeing that there should be more discussion time and fewer formal presentations. The group also agreed that presentatioins should be more focussed and address specific technical topics.

The next IMTS is tentatively planned for Monday and Tuesday, October 2-3, 1995 at the National Engineering Laboratory in East Kilbride, Scotland, UK.

Topics for the next meeting (half day focus):

1. Load measurements
2. Power quality
3. Uncertainty of measurement results in relation to the IEC standards documents

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