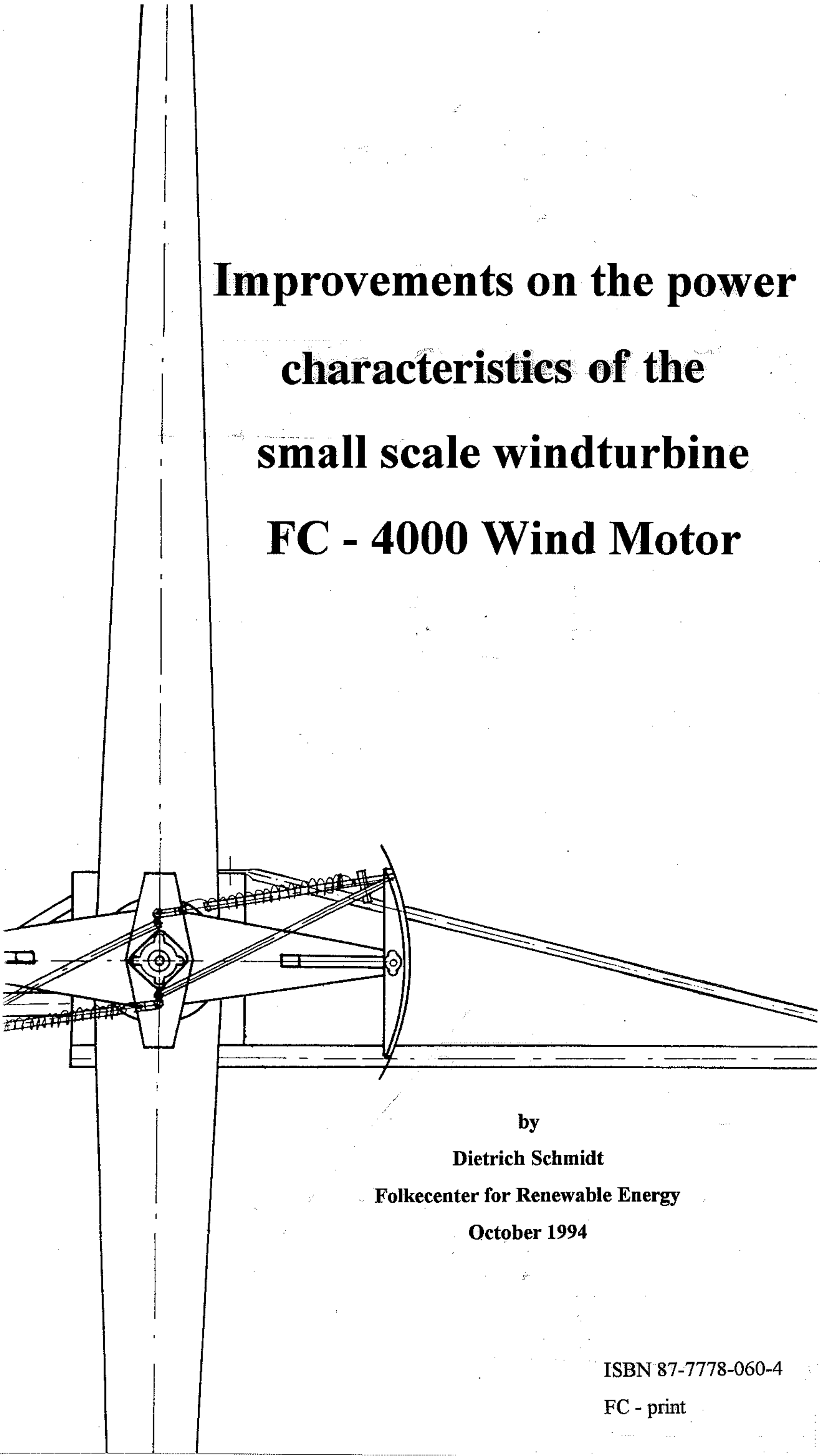
Improvements on the power characteristics of the small scale windturbine FC - 4000 Wind Motor



by

Dietrich Schmidt

Folkecenter for Renewable Energy

October 1994

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FC - print

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Tak for mig.

Dietrich Schmidt

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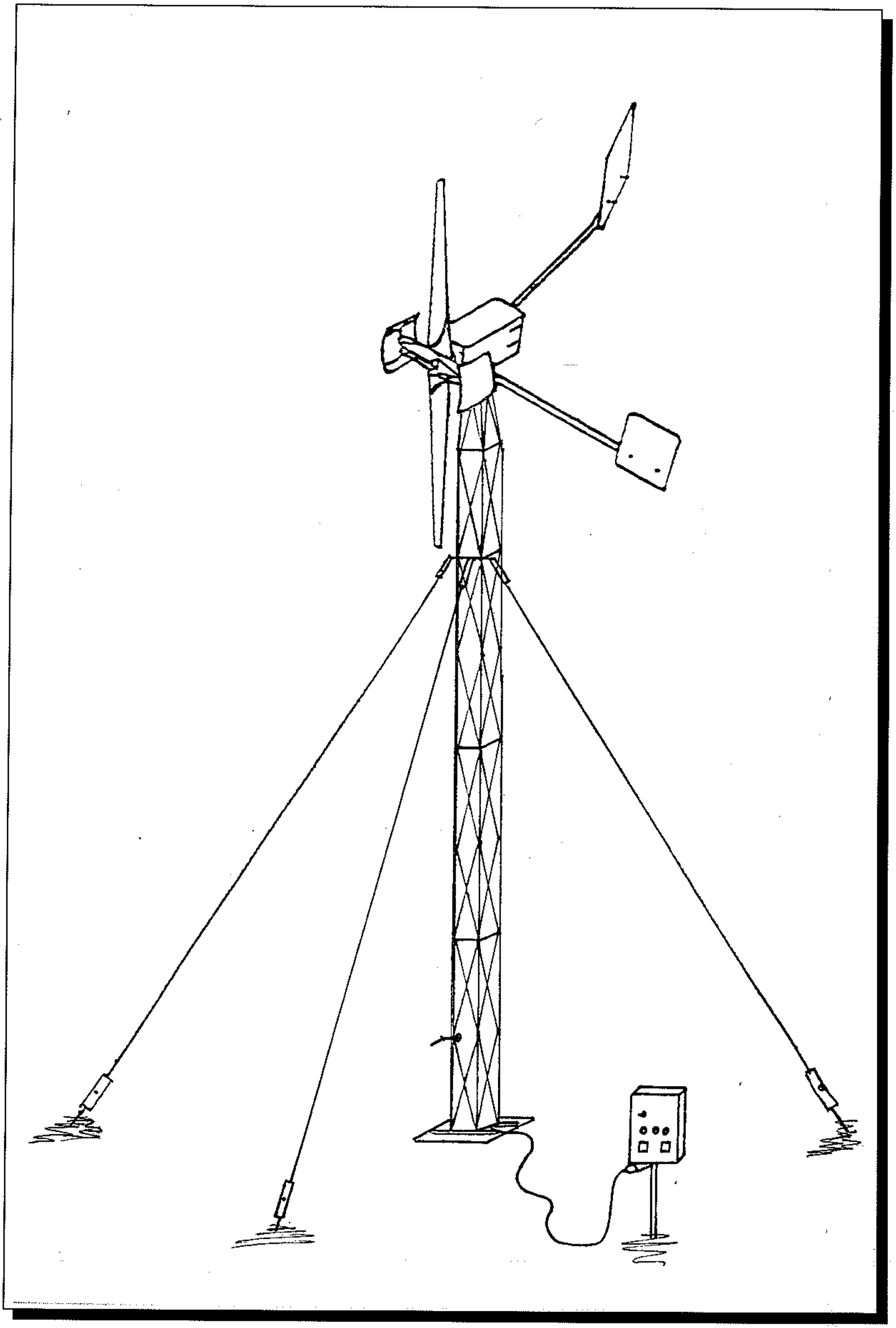

Fig. 1: The FC - 4000 Wind Motor

1. Introduction

The following report is a extract from my german report "Verbesserung der Leistungscharakteristik der Kleinwindkraftanlage FC - 4000 Wind Motor", witch is written during my work in Folkecenter for Renewable Energy / Denmark from April 11 to October 1 1994.

If there is some special interest in the FC - 4000 in general, I recommend the reports about the FC - 4000 mentioned in reference of this report.

2. The FC - 4000 Wind Motor

The FC - 4000 Wind Motor belongs to the series of small scale wind turbines, developed by the Folkecenter for Renewable Energy for application under different climatic conditions, like the extremely high wind regimes in the Arctic, the low wind regimes in the Tropics and the medium wind regimes like in Denmark.

The development of small scale wind turbines dates back to the mid 1970's, where a wide range of mechanical and electrical systems were developed and tested. The systems were developed for different purposes such as water pumping, battery charging and heating.

2.1 The PMG - design

Based on the experiences from this development, the Folkecenter has developed the wind motor series, a series of small multipurpose electric wind turbines. The wind motors are equipped with the most recently designed permanent magnet generators (PMG), and are thus very simple and reliable. The slow rotating PMG - generator is coupled directly to the rotor of the wind turbine. Gearbox are not applied and the design is more simple, has a better efficiency, a longer lifetime and is close to maintenance - free. Furthermore, the electric control system is more simple than on other electrical wind turbines.

2.2 Multi - purpose application

The wind motors can be applied for a wide range of purposes. The fluctuating voltage and frequency of the electricity can be converted directly in centrifugal pumps, in compressors and in standard electrical motors used for e.g. grinders, electric machinery etc..

One more delicate applications, requiring a higher quality of electricity, like e.g. light, computers, television, radios, the electricity can be converted, stored and later tapped from e.g. lead / acid car batteries.

2.3 The FC - 4000 Wind Motor

The FC - 4000 Wind Motor is a 1.5 kW wind turbine, designed for low wind regimes. It has a wide range of applications such as grinding, water pumping, cooling or battery charging.

2.4 The Rotor

Low solidity 2 bladed rotor, one beam, made of wood or fibreglass. For the FC - 4000 the NASA LS(1) 417Mod. airfoil is used.

2.5 The hub and airbrakes

Due to the one beam - rotor, the hub has a simple design. A set of airbrakes, mounted on the hub, controls the rotational speed when the generator is unloaded.

2.6 Generator and nacelle

The permanent magnet generator is the main component of the nacelle, featuring main shaft, bearings etc. in the same unit. Besides, the nacelle consists of mountings for the wind vanes and a simple roller bearing for yawing.

Generator specifications:

1.5 kW permanent magnet generator, 3 x 220 V at 428 rpm and 50 Hz, 14 poles, efficiency 89 to 94 %.

2.7 The yawing and safety system

The yawing and safety system consists of a side vane and a hinged main vane, held in position by a spring. In case of critically strong winds, the pressure on the side vane will outbalance the tension of the spring, the main vane will start turning and the rotor will yaw out of the wind. The maximum wind speed can be adjusted by changing the pre - tension of the spring.

2.8 The tower

The tower is made of a four section steel construction, supported by four guy wires or optional made of an iron pipe supported by tree guy wires.

2.9 Main Data

Rated output:	1.5 kW
Rotor diameter:	4 m
Hub height:	12 m
Rotations:	0 - 500 rpm

Wind speeds:

Cut in:	3 m/s
Rated:	10 m/s
Cut out:	15 m/s
survival:	45 m/s

price:	50 000 DKK

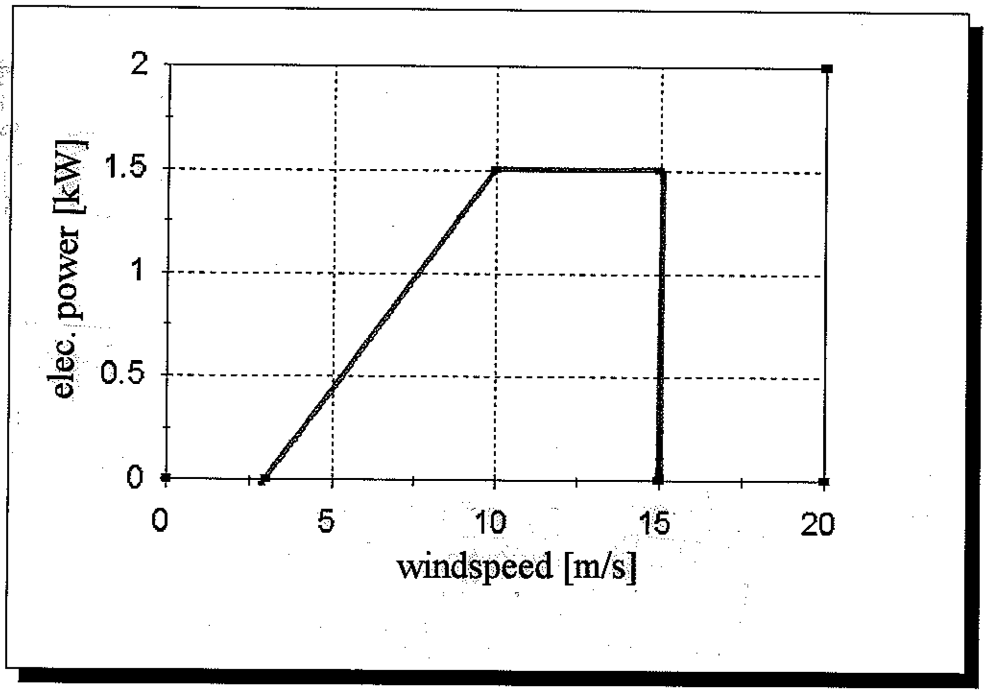

Fig. 2: The ideal powercurve of the FC - 4000

2.10 Production rates

Mean wind speed	Annual production
3 m/s	1185 kWh
4 m/s	2599 kWh
5 m/s	4123 kWh
6 m/s	5470 kWh

3. Motivation

The FC - 4000 is a small scale wind turbine and is going to become a basic component for different applications e.g. a sun - wind - battery - hybrid small scale power plant. In figure 2 the ideal powercurve of the FC - 4000 is shown, witch is a calculation base for following applications. But as shown in figure 3 the FC - 4000 never reaches the rated power output of 1.5 kW. That could be caused of to different influences. One is the yawing system witch may causes a powerloss and on the other hand there are the airbrakes causing a powerloss.

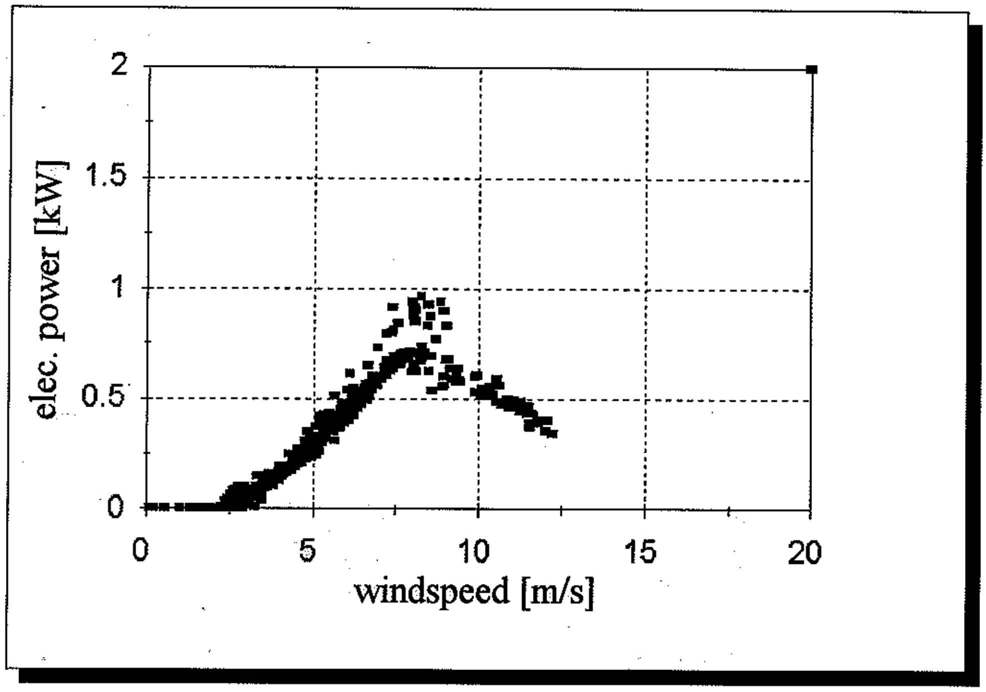

Fig. 3: The powercurve of the FC - 4000 with hub airbrake

3.1 The hub airbrakes

As shown in figure 1 there are to big airbrakes near the hub. This airbrake system is quiet big and heavy. It is also complicated to maintain the airbrake and so the hole brakesystem is quiet expensive. It costs app. 2500 to 3000 DKK. In the past were there also some problems with fractions in the construction.

One the other hand it is a very reliable construction and the brake power curve, as shown in figure 4, is very close to the optimum.

But already in summer 1991 the work for a new airbrake system started. The idea was to put the airbrakes on the tip of the blade.

3.2 The prototype of the Tip - Air - Brake

Because of the higher airspeed at the tips, the brakingplates could be build much smaller than the hub airbrake. Because of the brake force (power) is related to (Gasch 1993):

$$F_d = \frac{\rho}{2} \bullet v^2 \bullet A_B \bullet c_d$$

F_d : brake force

ρ : airdensity

v : air speed

A_B : Area of airbrake

c_d : drag factor

The centrifugal force witch forces the brake plates to move into braking position is also much higher at the bladetip.

$$F_c = (2\pi n)^2 \bullet r \bullet m_{plate}$$

F_C : centrifugal force

n : rotationspeed

r : radius of the blade

m_{plate} : mass of the brake plate

So in summer 1993 a prototype of a tip brake is been build (Grohs 1993). But as shown in figure 4 the power output reaches not the rated value of 1.5 kW. By comparing figure 3 and figure 4 a improvement is clear shown.

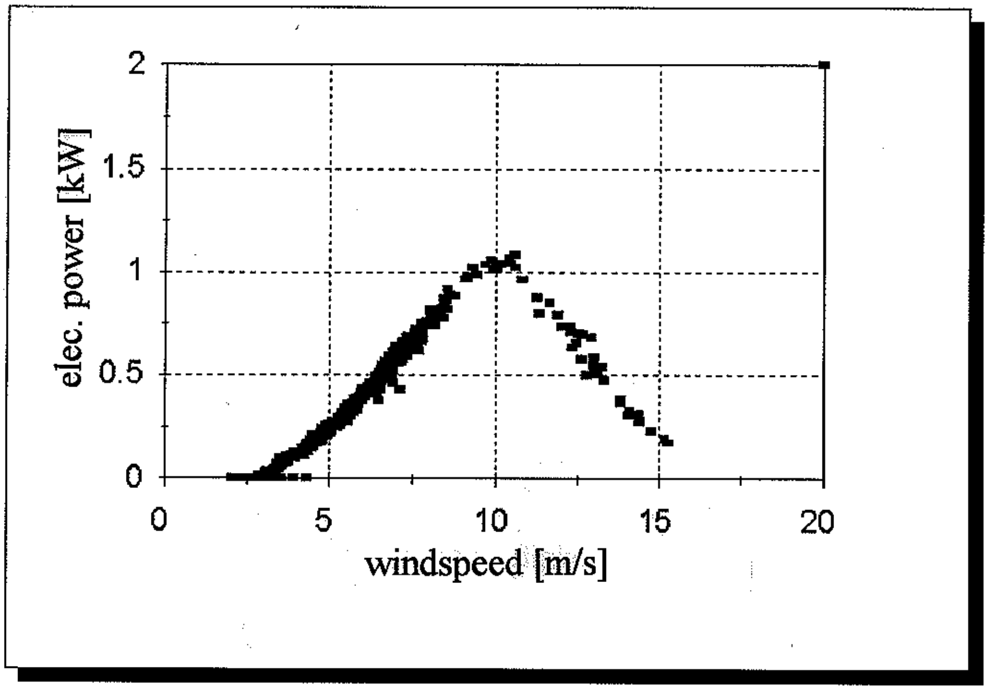

Fig. 4: powercurve of FC - 4000 with prototype tip - air - brakes

The maximum of the power curve is with the hub airbrake at 1.0 kW at 8 m/s, with the tip airbrake at 1.1 kW at 10 m/s. So still not high enough. Another problem of this airbrake is the aerodynamic noise of the braking plates and that the brake are not strong enough. They are destroying theirselves after a short time.

3.3 The yawingsystem

During the measurements for the power curves (fig. 3 and fig. 4) the observation was made that the windmill is already at a windspeed of 7 m/s yawing out of the wind. That is much to early, so at first some investigations about this have to be done.

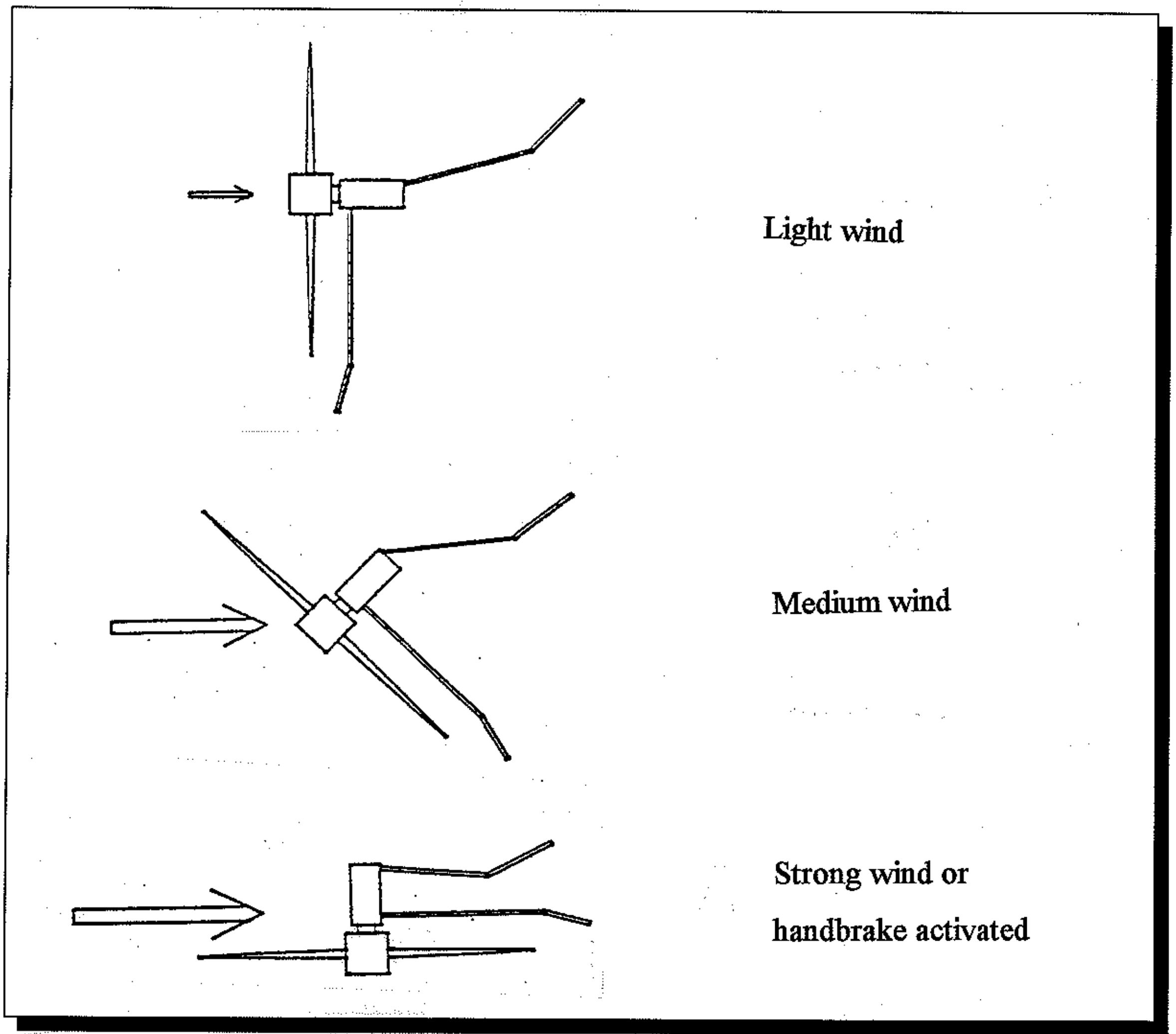

Fig. 5: The yawing system of the FC - 4000. Top view.

4. Improvement of the yawingsystem

For the FC - 4000 a very easy controlsystem is used. The yawing system is also working as a safety system for protection against to high windspeeds. Figure 5 shows the function principle of this system (Yde 1993).

In normal conditions the to vane controlsystem is following the equation (Gasch 1993):

$$l_S \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d = l_T \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{TV} \bullet c_l(\beta)$$

l_S : bar arm of sidevane

ρ : airdensity

v : windspeed

A_{SV} : sidevane area

c_d : drag factor

l_T : bar arm of talevane

A_{TV} : talevane area

c_l : liftfactor

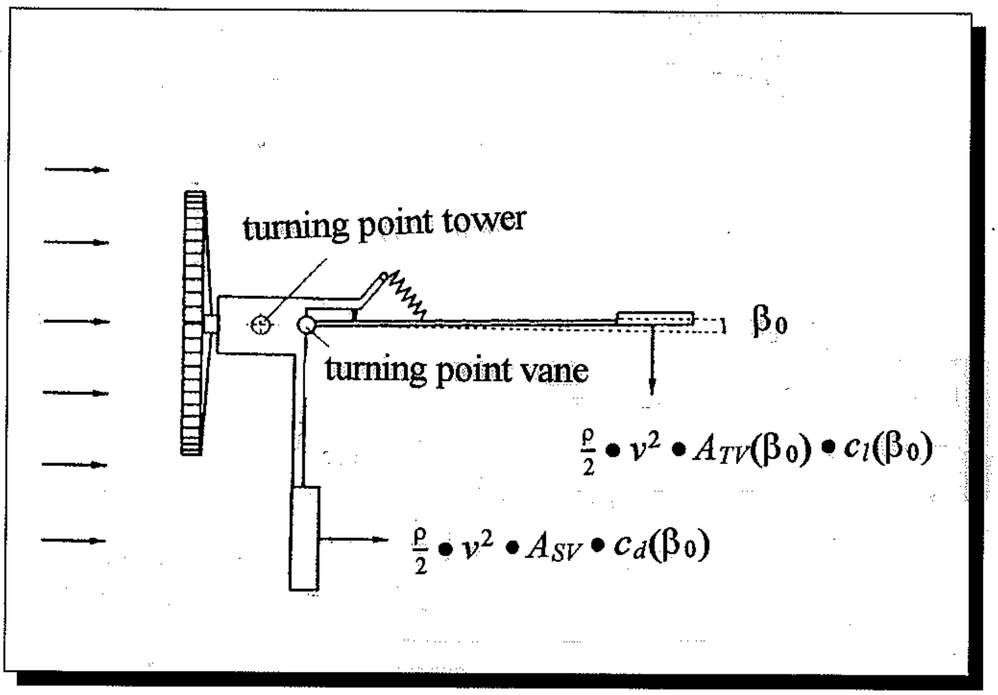

Fig. 6: The to vane control system (Gasch 1993)

In addition to that the pretension of the torsion spring (in figure 6 a normal screw spring is shown) has to be taken into the calculation.

4.1 Ascertainment of the data in the beginning

Measured area of sidevane:

$$A_{SVr} = a \bullet b$$
$$= 0.54m \bullet 0.58m$$
$$A_{SVr} = 0.3132m^2$$

because of the sidevane is inclined about 11° to the rotorplane follows for the resistance area:

$$A_{SV} = \cos 11 \bullet A_{SFr}$$
$$= \cos 11 \bullet 0.3132 m^2$$
$$A_{SV} = 0.3074 m^2$$

For the arm of the sidevane l_s=2.4 m is measured.

Measured pretension of the torsionsspring:

5 kg with a arm of 0.44 m are measured with a spring balance. So the pretension is :

$$M_{pre} = F_{pre} \bullet l$$
$$= 5kg \bullet 9.81 \tfrac{N}{kg} \bullet 0.44m$$
$$M_{pre} = 21.58 Nm$$

M_{pre} : pretension moment

F_{pre} : measured force

l : measured lever arm

That correspond to a pretension angle (inc. pretension element) with a spring constance of , $c = 1129 \frac{Nmm}{°}$ linear (corresponding to the manufacturer) of:

$$M_{pre} = c \bullet \alpha_{pre}$$
$$\alpha_{pre} = \frac{M_{pre}}{c}$$
$$= \frac{21.58 \bullet 10^3 Nmm}{1129 Nmm}$$
$$\alpha_{pre} = 19.12°$$

α : spring angle

The measured air density is at the present time $\rho = 1.225 \frac{kg}{m^3}$.

The drag factor of the sidevane (squared plate;11°) is following (Pinegin 1994) $c_d = 1.13$.

The windspeed of the first turning of the talevane into the sidevane:

That leads to:

$$M_{SV} = M_{TV} = M_{pre}$$

=> $F_{d,SV} \bullet l_S = M_{pre}$

with: $F_{d,SV} = \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d$; (Eduard 1988)

$$\frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d \bullet l_S = M_{pre}$$
$$v = \sqrt{\frac{M_{pre} \bullet 2}{\rho \bullet A_{SV} \bullet c_d \bullet l_S}}$$

$$= \sqrt{\frac{21.58Nm \bullet 2}{2.4m \bullet 1.225\frac{kg}{m^3} \bullet 0.3074m^2 \bullet 1.13}}$$

$$v = 6.50\frac{m}{s}$$

$F_{d,SV}$: drag force sidevane

l_s : bar arm sidevane

A_{SV} : area of sidevane

v: windspeed

c_d : drag factor

This windspeed is much to low to get the rated power output of 1.5 kW at 10 m/s!!!!!

Check of the torsionspring at beginning conditions

The maximal torsion angle of the spring is $\alpha_{max} = 120°$ (measured).
That leads to:

$$M_{tor} = c \bullet \alpha_{max}$$
$$= 1129\frac{Nmm}{\bullet}120$$
$$M_{tor} = 135.48Nm$$

M_{tor} : spring moment because of torsion

So the spring is maximal loaded with:

$$M_{max} = M_{tor} + M_{pre}$$
$$= 135.58Nm + 21.58Nm$$
$$M_{max} = 157.06Nm$$

Following (Matek 1986) the tension in the spring relates to:

$$\sigma = \frac{32 \bullet M \bullet q}{\pi \bullet d^3}$$

σ : tension

M : moment

q : tension factor

d : diameter of spring wire

with $w = \frac{D_m}{d}$; D_m : mean diameter of torsion spring

$$= \frac{90mm}{12mm}$$
$$w = 7.5$$

=> $q = 1.12$; corresponding the diagram in (Matek 1986); see Appendix 2

$$\sigma_{max} = \frac{32 \bullet 157.06 \bullet 10^3 Nmm \bullet 1.12}{\pi \bullet (12mm)^3}$$

$$\sigma_{max} = 1036.91 \frac{N}{mm^2}$$

The maximal allowable tension is according to the manufacturer:

$$\sigma_{allo} = 950 \frac{N}{mm^2}$$

=> $\sigma_{max} > \sigma_{allo}$!!!! That means the spring is already in normal conditions overloaded!!!

4.2 Calculation of an improved adjustment

As it has been observed the windspeed interval for the yawing out of the wind is okay. So just the pretension of the torsionspring should be increasedand the torsion angle of the spring should be limited.

4.2.1 Pretension adjustment at a windspeed of 15 m/s

$$F_{d,SV}(15\tfrac{m}{s}) = \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d$$

$$\begin{aligned} M(15\tfrac{m}{s}) &= F_{d,SV} \bullet l_S \\ &= \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d \bullet l_S \\ &= \frac{1.225kg}{2m^3} \bullet (15\tfrac{m}{s})^2 \bullet 0.3074m^2 \bullet 1.13 \bullet 2.4m \end{aligned}$$

$$M(15\tfrac{m}{s}) = 114.89Nm$$

$F_{d,SV}$: resistence force of sidevane

v : windspeed

M : moment of sidevane

l_S : bar arm of sidevane

That leads to a pretension angle of:

$$\begin{aligned} \alpha(15\tfrac{m}{s}) &= \frac{M(15\tfrac{m}{s})}{c} \\ &= \frac{114.89 \bullet 10^3 Nmm}{1129Nmm} \end{aligned}$$

$$\alpha(15\tfrac{m}{s}) = 101.76\,^{\circ}$$

α : angle of spring

c : spring constance

This adjustment of a pretension angle is unrealistic with the given material!!!

4.2.2 Pretension adjustment at a windspeed of 12 m/s

$$M(12\tfrac{m}{s}) = F_{d,SV} \bullet l_S$$
$$= \tfrac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d \bullet l_S$$
$$= \frac{1.225kg}{2m^3} \bullet (12\tfrac{m}{s})^2 \bullet 0.3074m^2 \bullet 1.13 \bullet 2.4m$$
$$M(12\tfrac{m}{s}) = 73,53Nm$$

That leads to a pretension angle of

$$\alpha(12\tfrac{m}{s}) = \frac{M(12\tfrac{m}{s})}{c}$$
$$= \frac{73.53 \bullet 10^3 Nmm}{1129Nmm}$$
$$\alpha(12\tfrac{m}{s}) = 65.13^\circ$$

This angle seems to be realistic.

Check of the spring for this adjustment

$$\sigma_{allo} = \frac{32 \bullet M_{allo} \bullet q}{\pi \bullet d^3} \text{ ; (Matek 1986)}$$
$$M_{allo} = \frac{\sigma_{allo} \bullet \pi \bullet d^3}{32 \bullet q} \text{ ; } \sigma_{allo} \approx 1000\frac{N}{mm^2} \text{ for a short calculation}$$
$$= \frac{1000N \bullet \pi \bullet (12mm)^3}{32 \bullet 1.12mm^2}$$
$$M_{allo} = 151.47Nm$$

σ_{allo} : maximal allowable tension of spring material

M_{allo} : maximal allowable moment of spring

$$M_{tor} = M_{allo} - M_{pre}$$
$$= 151.47Nm - 73.53Nm$$
$$M_{tor} = 77.94Nm$$

M_{tor} : maximal moment on the spring because of torsion

$$\alpha_{tor} = \frac{M_{tor}}{c}$$
$$= \frac{77.94 \bullet 10^3 Nmm}{1129Nmm}$$
$$\alpha_{tor} = 69.04^\circ \approx 70^\circ$$

α_{tor} : maximal bending angle of the spring

To limit the load of the spring the maximal torsion angle has to be limited on 70° instead of 120°.

Check of the calculated and done adjustment

13 kg on a bar arm of 0.64 m have been measured with a spring balance:

$$M_{pre} = F \bullet l$$
$$= 13kg \bullet 9.81\tfrac{N}{kg} \bullet 0.64m$$
$$M_{pre} = 81.62Nm$$

M_{pre} : pretension moment of the spring

Equivalent to a start windspeed for the first yawing out of the wind:

$$F_{d,SV} = \frac{M_{pre}}{l_S}$$
$$\frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d = \frac{M_{pre}}{l_S}$$
$$v = \sqrt{\frac{M_{pre} \bullet 2}{A_{SV} \bullet c_d \bullet \rho}}$$
$$= \sqrt{\frac{81.62Nm \bullet 2}{0.3074m^2 \bullet 1.13 \bullet 1.225\frac{kg}{m^3}}}$$
$$v = 12.64\tfrac{m}{s}$$

v : windspeed of start yawing

Figure 7 shows the results of the measurements with the calculated adjustments.

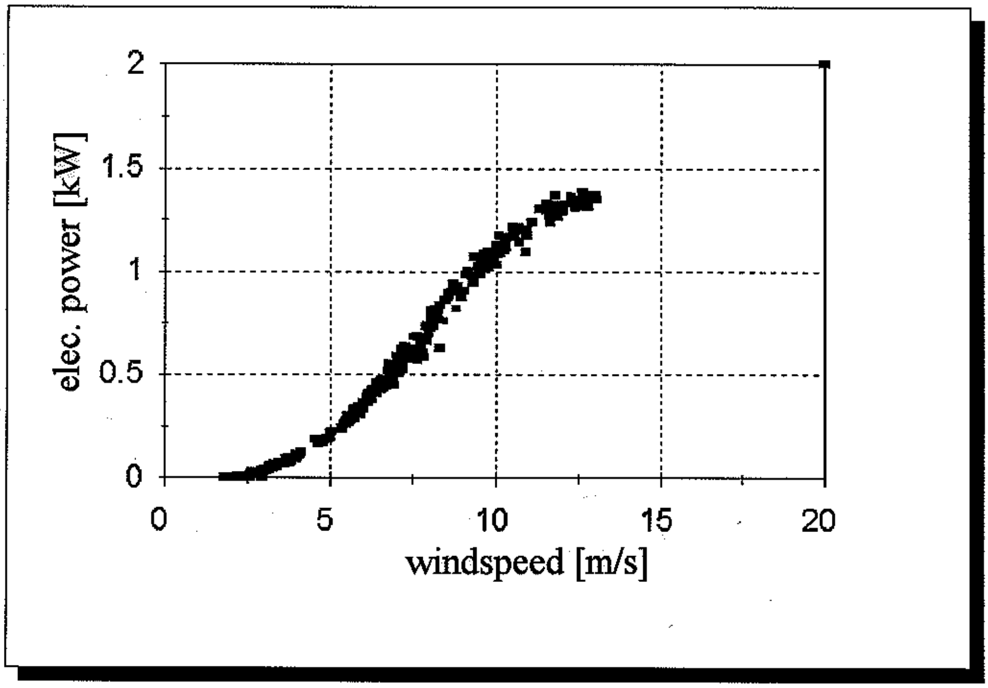

Fig. 7: powercurve of FC - 4000 with new spring adjustment (page 13)

It has been observed that the talevane starts moving from the stop at a windspeed of v = 10 m/s, but returns fast when the windspeed decreasing a little bit.

4.3 Variation of size and position of the side - and tale vane

Like established in 4.1 (page 9) the spring is quiet heavy loaded, with the adjustment calculated in 4.2 (page 12) even the maximal torsion angle has to be limited.

An other possibility to improve the output is to change the position and size of the side - and tale vane instead of to change the adjustment of the spring.

Under normal conditions the to vane control system follows (Gasch 1993)

$$l_S \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d = l_T \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{TV}(\beta) \bullet c_l(\beta)$$

ρ : airdensity

v : windspeed

c_l : lift factor

β : angle between wind and talevane

The lenght of the bars and the area of the talevane shall not to be changed.

$l_S = 2.4$ m : bar arm sidevane

$l_T = 2.0$ m : bar arm talevane

$A_{TV_r} = a\ b$: area talevane

$= 0.905\ m\ \ 0.92\ m$

$A_{TV_r} = 0.8326\ m^2$

$c_d = 1.13$: drag factor, (Penigin 1994) Appendix 2

The pretension of the spring has to be taken into the calculation:

$$M_{pre} = 21.58 Nm$$

$\alpha_{pre} = 19.12^{\circ}$; (see 4.1 ; page 9)

To find a solution of this problem, the talevane shall start moving from the stop at a windspeed of v = 12.5 m/s, the balance of the tree moments has to be found. All the components of these equations are influencing each other.

Moment sidevane: $M_1 = l_S \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d$

Moment talevane: $M_2 = l_T \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{TV}(\beta) \bullet c_l(\beta)$

$$M_2 = l_T \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{TV_r} \bullet \cos(\beta) \bullet c_l(\beta)$$

Moment of the spring: $M_3 = c \bullet \alpha$

$$M_3 = c \bullet (-\beta + 64.12^{\circ}) \quad \text{; see figure 8}$$

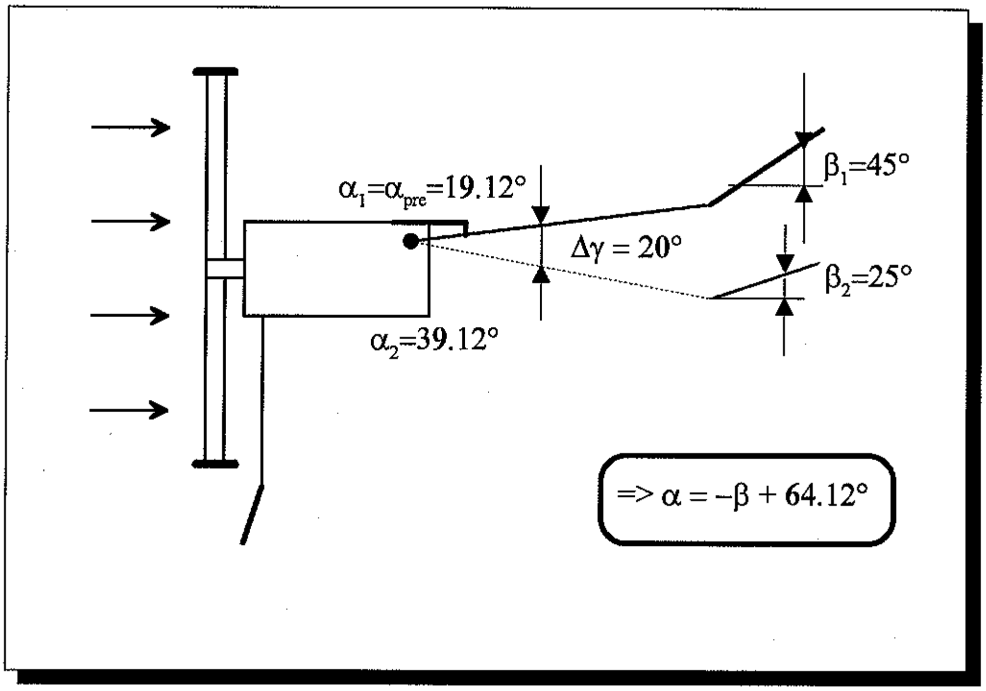

Fig. 8: Angles on the vanes of the FC - 4000

The value of $c_l(\beta)$ is only available in a diagram (Appendix 2), so the graphical way to solve the problem seems to be a god one.

M_2 and M_3 are calculated with a windspeed of v = 12.5 m/s and drawn into the diagram.

Trough the point of intersection M_1 is calculated and put into the diagram.The solution is shown in figure 9.

The solution is $M_1 = M_2 = M_3 = 60Nm$ at a angle of $\beta = 10^{\circ}$

according to: $M_1 = l_S \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d$

$$A_{SV} = \frac{M_1 \bullet 2}{l_S \bullet \rho \bullet v^2 \bullet c_d}$$

$$= \frac{20Nm \bullet 2}{2.4m \bullet 1.225\frac{kg}{m^3} \bullet (12.5\frac{m}{s})^2 \bullet 1.13}$$

$$A_{SV} = 0.2311m^2$$

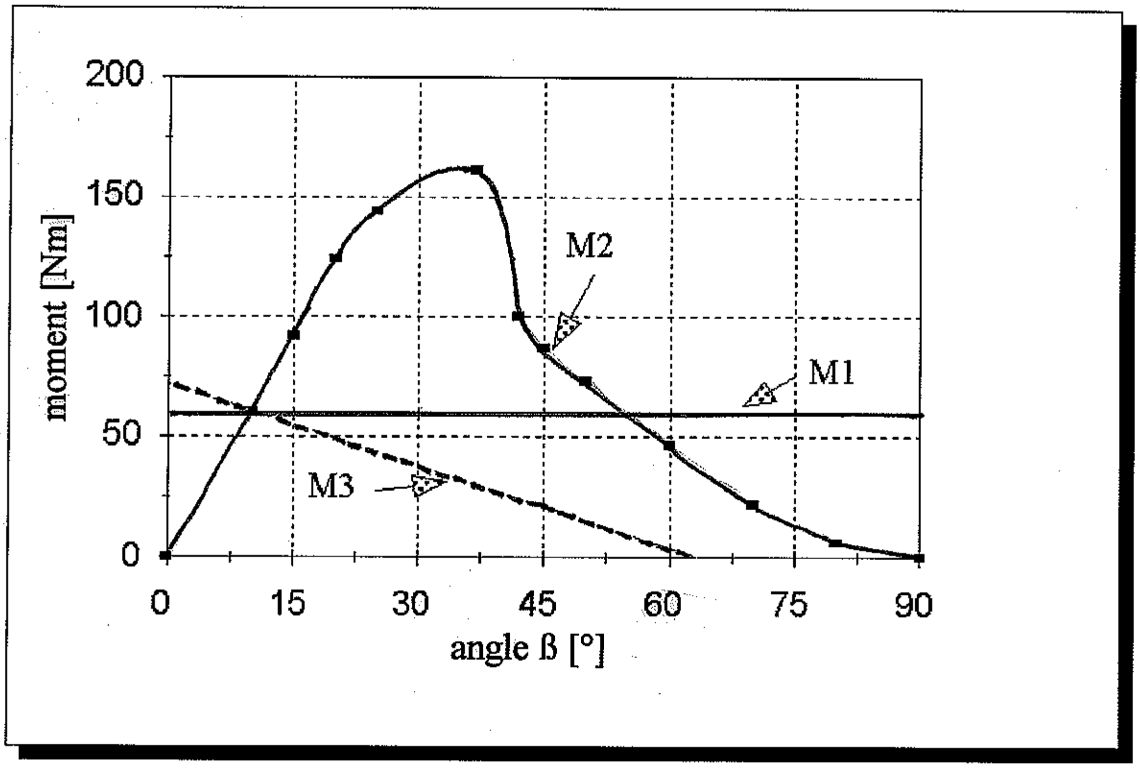

Fig. 9: Moments of torsion spring, tale- and sidevane

because of the sidevane is inclined about 11° to the rotorplane follows for the real sidevane area:

$$A_{SVr} = \frac{A_{SV}}{\cos 11} = \frac{0.2311 m^2}{\cos 11}$$

$$A_{SVr} = 0.2355 m^2$$

A_{SVr} : real sidevane area

A_{SV} : effective sidevane area

The bar arm of the sidevane shall stay at a value of $l_S = 2.4m$, so the breath of the sidevane shall also stay at a value of $b = 0.58m$. So the new height is:

$$A_{SVr} = b \bullet h$$

$$h = \frac{A_{SVr}}{b} = \frac{0.2355 m^2}{0.58 m}$$

$$h = 0.4060 m \approx 0.40 m$$

A new sidevane 0.58 m x 0.40 m has been made and the angle between the talevane and wind direction has been changed from $\beta = 45°$ to $\beta = 10°$.

The results of the measurements are shown in figure 10.

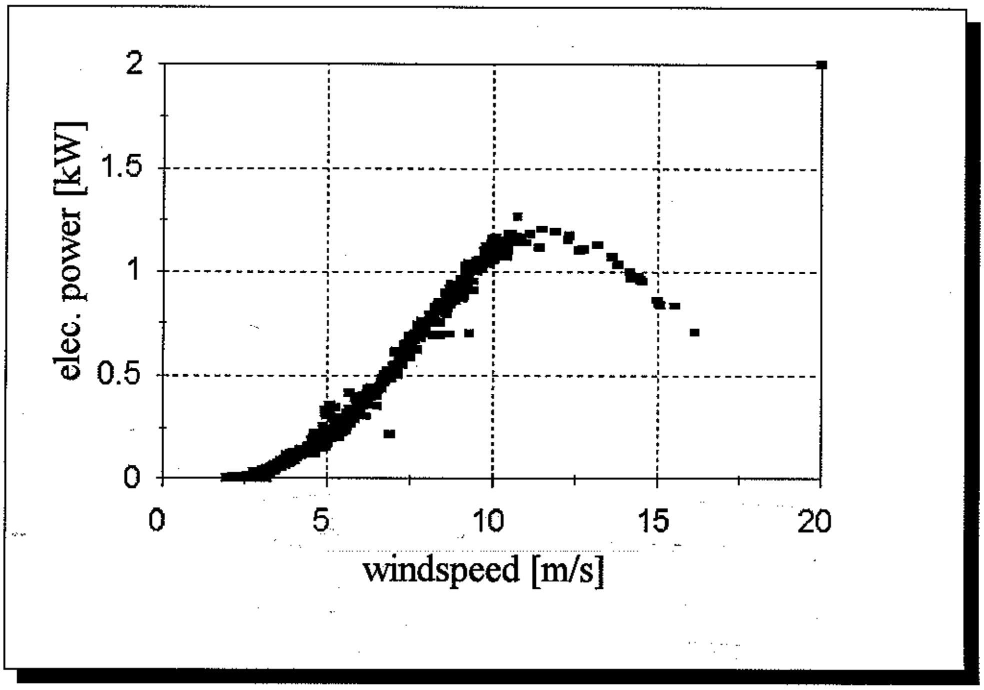

Fig. 10: power curve of FC - 4000 with new sidevane and talevane position

4.4 calculation of a future construction

Aim of this construction is an improved construction witch takes all proposals from the former chapters into consideration.

Like established in 4.1 (page 9) the spring is heavy loaded, already under normal conditions. So the pretension element is removed from the vane construction and the new following pretension is measured.

$$M_{pre2} = 18.25Nm$$

=> $$M_{pre2} = \alpha_{pre2} \bullet c$$

$$\alpha_{pre2} = \frac{M_{pre2}}{c}$$

$$= \frac{18.25 \bullet 10^3 Nmm}{1129 Nmm}$$

$$\alpha_{pre2} = 16.16^\circ$$

M_{pre2} :	new pretension moment of the torsion spring
α_{pre2} :	new pretension angle of the spring
c :	spring constance

The bar arms and the area of the talevane shall stay constant.

$l_S = 2.4m$: bar arm sidevane

$l_T = 2.0m$: bar arm talevane

$A_{TVr} = 0.8326m^2$: real area talevane

$c_d = 1.13$: drag factor

The talevane is about 30° inclined from the talevane arm. For to simplify the construction the talevane shall have no angle to the talevane arm. So the torsion angle (α) relates to the angle between wind direction and talevane (β) to:

$\alpha = -\beta + 31.16^\circ$; see figure 11

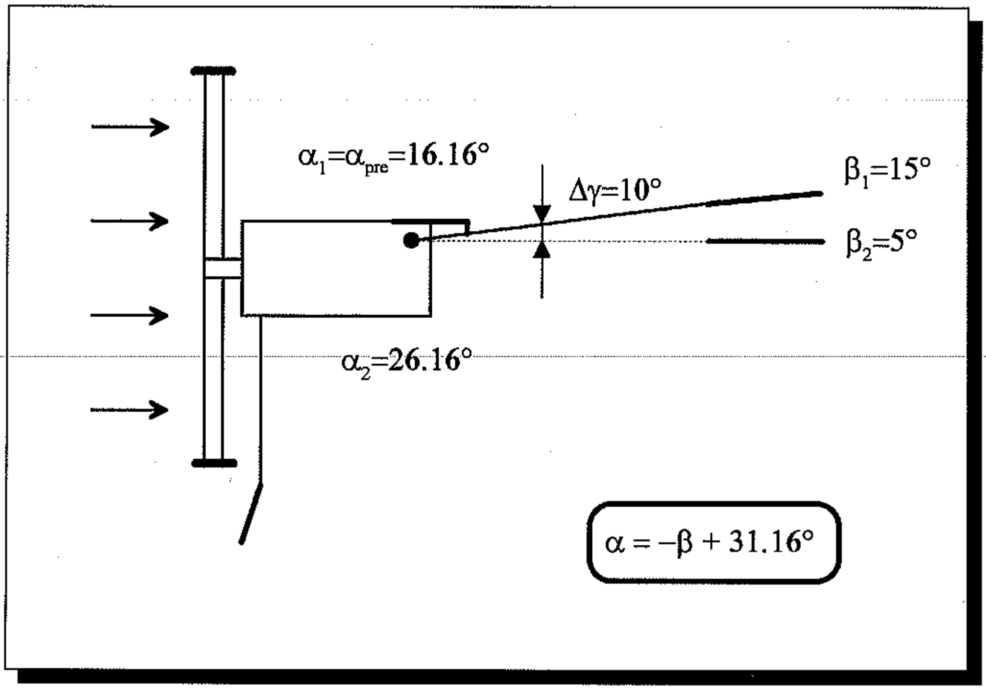

Fig. 11: angles on the vane arangement of the new construction

Corresponding to 4.3 the solution of this problem is searched in a graphical way. The balance of the three moments has to be found.

Moment of the sidevane : $M_1 = l_S \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d$

Moment of the talevane : $M_2 = l_T \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{TVr} \bullet \cos(\beta) \bullet c_l(\beta)$

Moment of the spring : $M_3 = c \bullet (-\beta + 31.16^\circ)$

M_2 and M_3 are calculated with a windspeed of v = 12.5 m/s and drawn into the diagram. Trough the point of intersection M_1 is calculated and also drawn into the diagram.

The solution is $M_1 = M_2 = M_3 = 29$Nm at an angle of $\beta = 5^\circ$

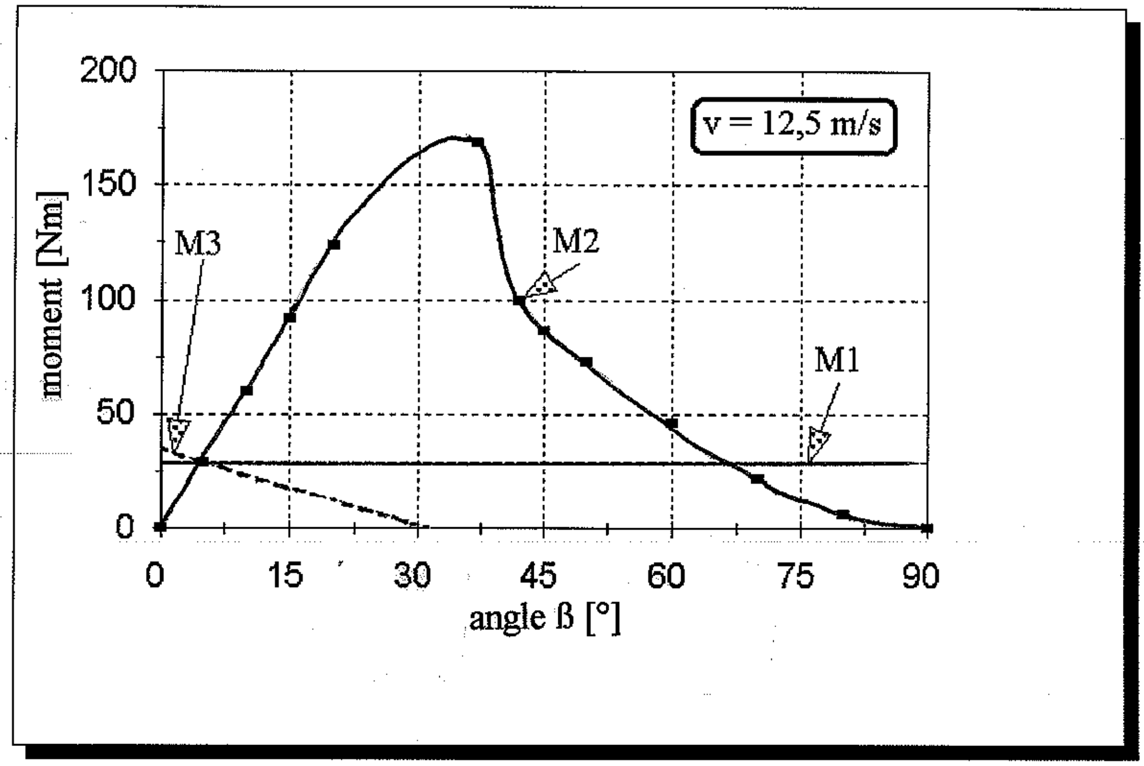

Fig. 12: Moments of torsion spring, tale- and sidevane

For the sidevane follows according to:

$$M_1 = l_s \bullet \frac{\rho}{2} \bullet v^2 \bullet A_{SV} \bullet c_d$$

$$A_{SV} = \frac{M_1 \bullet 2}{l_s \bullet \rho \bullet v^2 \bullet c_d}$$

$$= \frac{29Nm \bullet 2}{2.4m \bullet 1.225\frac{kg}{m^3} \bullet (12.5\frac{m}{s})^2 \bullet 1.13}$$

$$A_{SV} = 0.1117m^2$$

because of the sidevane is inclined about 11° to the rotorplane relates the real new sidevane area to:

=> $$A_{SVr} = \frac{A_{SV}}{\cos 11}$$

$$= \frac{0.1117m^2}{\cos 11}$$

$$A_{SVr} = 0.1138m^2$$

The bar arm of the sidevane shall stay at a value of $l_s = 2.4$ m, so the breath of the sidevane shall also stay at a value of b = 0.58m. So the new height is:

$$A_{SVr} = b \bullet h$$
$$h = \frac{A_{SVr}}{b}$$
$$= \frac{0.1138m^2}{0.58m}$$
$$h = 0.1962m \approx 0.20m$$

A_{SVr} : real sidevane area

b : breath of sidevane

h : height of sidevane

Finally the spring shall be checked (see 4.1):

with $\sigma = \frac{32 \bullet M \bullet q}{\pi \bullet d^3}$

$$M_{allo} = \frac{\sigma_{allo} \bullet \pi \bullet d^3}{32 \bullet q} \; ; \quad \sigma_{allo} = 950\frac{N}{mm^2}$$
$$= \frac{950\frac{N}{mm^2} \bullet \pi \bullet (12mm)^3}{32 \bullet 1.12}$$
$$M_{allo} = 143.89Nm$$

σ_{allo} : maximal allowable tension of the spring material

M_{alllo} : maximal allowable moment of the spring

q : tension factor

d : diameter of spring wire

$$M_{tor,\max} = M_{allo} - M_{pre2}$$
$$= 143.89Nm - 18.25Nm$$; see 4.4 page 18
$$M_{tor,\max} = 125.65Nm$$

$M_{tor,max}$: maximal allowable moment of the spring caused of bending

$$\alpha_{tor,\max} = \frac{M_{tor,\max}}{c}$$
$$= \frac{125.65 \bullet 10^3 Nmm}{1129 \frac{Nmm}{°}}$$
$$\alpha_{tor,\max} = 111.29^\circ$$

$\alpha_{bend,\max}$: maximal allowable bending angle

That means that the maximal torsion angle of the spring and in the same way the maximal angle of the talevane has to be limited at 111° to the old stop. This relates to a maximal angle of 101° to the new stroke for to reduce the load on the spring to the allowable value.

The old and the new adjustments are shown in figure 13 and 14.

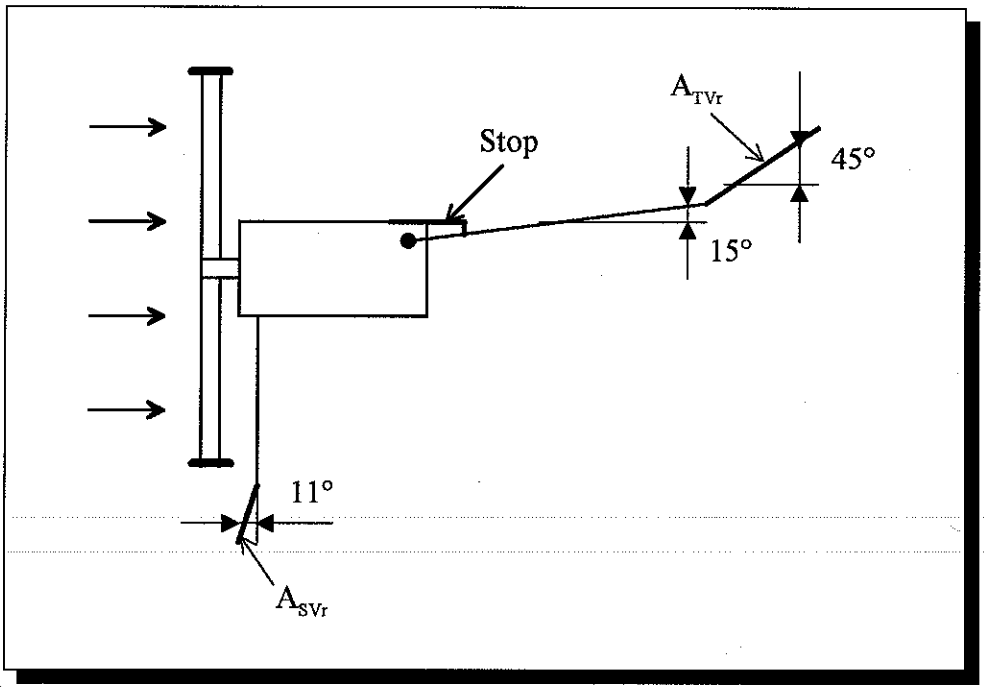

Fig. 13: The old adjustments of the vanes

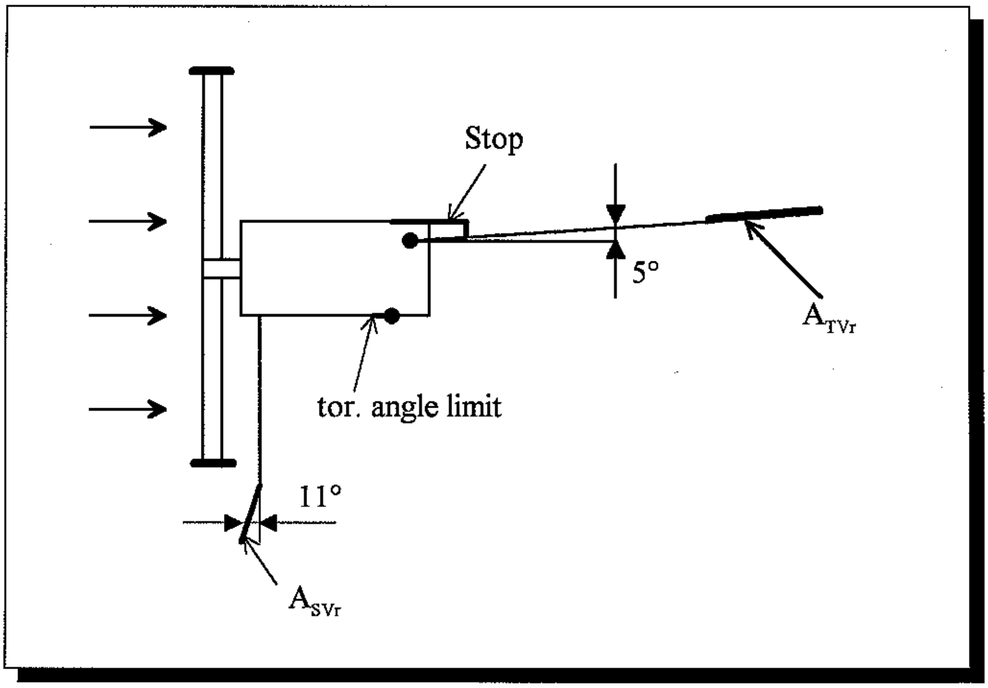

Fig. 14: The new adjustments of the vanes

5. Results

5.1 Presentation of the results

To check the quality of the different suggestions the energy production per has been calculated with a special computer program, using the measured power curves and different environmental conditions.

For the first table mean windspeed following the Rayleigh - distribution are used. This wind distribution is normally used for the dimension of wind turbines for the US marked. But it is exact enough to use this distribution also for the conditions in Denmark too.

mean windspeed	ideal powercurve (fig. 2)	with hub airbrake (fig. 3)	with prototype Tip - Air - Brake (fig. 4)	with new sidevane (fig. 10)
3 m/s	1.185	1.113	1.118	1.119
4 m/s	2.599	2.143	2.223	2.246
5 m/s	4.123	3.053	3.346	3.493
6 m/s	5.470	3.625	4.203	4.624

Fig. 15: Energy production per year [kWh/a]

For the second table danish roughness classes are used for the calculations. These classes relating to different mean wind speeds in different heights. For this table the hub height of the FC - 4000 of 12 m is used.

roughness class	ideal powercurve (fig. 2)	with hub airbrake (fig. 3)	with prototype Tip - Air - Brake (fig. 4)	with new sidevane (fig. 10)
0	6.455	3.760	4.647	5.520
1	4.992	3.337	3.853	4.232
2	3.826	2.821	3.100	3.254
3	2.269	1.891	1.957	1.980

Fig. 16: Energy production per year [kWh/a]

5.2 Interpretation

The interpretation is reduced to explain the production per year using the mean wind speeds in a hub height of 12m. The hole calculation is not very exact, because of the power curves are interpreted and put into the program by hand. So the calculations are more a tendency than a real calculation base.

It is also very important to mention that the hole construction of the FC - 4000 gets easier and cheaper with each proposal of a new adjustment or construction.

As shown in figure 15 the effect of improvement is nearly zero in low mean wind speeds. But it improves very much in higher mean wind speeds.

6. References

/1/ Beitz, W.; Küttner, K. - H.
Dubbel - Taschenbuch für den Maschinenbau
Springer Verlag; Heidelberg, Berlin 1990

/2/ Deng, Xingyong
Design of FC 4000 for Grid
FC - Print; Hurup / Denmark 1994

/3/ Fischer, Ulrich
Tabellenbuch Metall
Verlag Europa - Lehrmittel; Haan - Gruiten 1992

/4/ Gasch, Robert
Windkraftanlagen
B.G. Teubner Verlag; Stuttgart 1993

/5/ Ghosh, Kural
Design and construction of a Rotor for FC - 4000 Windturbine
FC - Print; Hurup / Denmark 1991

/6/ Grohs, Christian
FC Tip - Brake
FC - Print; Hurup / Denmark 1993

/7/ Hahn, Gunther
Battery - Charger for FC - 4000
FC - Print; Hurup / Denmark

/8/ Heier, Siegfried
Universitätsskriptum "Nutzung der Windenergie"
Gesamthochschule University of Kassel, FB Elektrotechnik 1993

/9/ Kragten, A.
The hinged sidevane as a savety mechanism for windmills
Eindhoven University of Technology; Eindhoven 1982

/10/ Linse, Hermann
Elektrotechnik für Maschinenbauer
B.G. Teubner Verlag; Stuttgart 1992

/11/ Meagård, Preben
Assisting the progress of soft technology to the market place
FC - Print; Hurup / Denmark 1994

/12/ Matek, Wilhelm; Muhs, Dieter; Wittel, Herbert
Maschinenelemente
Friedrich Vieweg & Sohn Verlag; Braunschweig 1986

/13/ Matek, Wilhelm; Muhs, Dieter; Wittel, Herbert
Maschinenelemente / Tabellen
Friedrich Vieweg & Sohn Verlag; Braunschweig 1986

/14/ Möller, Bernd
System for manufacturing wooden rotorblades for small windmills
FC - Print; Hurup / Denmark 1991

/15/ Møller, Troels - Kildemoes
Designværktøj for integreret luftbremse
FC - Print; Hurup / Denmark 1991

/16/ Schröter, Wolfram
Off - grid hybrid electric power supplysystem, using a combination of solar cells, small scale windturbine and batteries
FC - Print; Hurup / Denmark 1994

/17/ Shimizu, Y.; van Bussel, G.J.W.; Matsumura, S.
Studies on horizontal axis wind turbines with tip attachments
European Community Wind Energy Conference 1990
H.S. Stephens and Associates; Beford / England 1990

/18/ Vilsbøll, Nils; Rasmussen Peter
Beregning og skitser af langsomtløbende P - M - Generatorer til vindkraft
FC - Print; Hurup / Denmark 1992

/19/ Walther, Eduard
Technische Formeln
VEB Fachbuch; Leipzig 1988

/20/ Yde, Lars
A novel windturbine with multiple applications
FC - Print; Hurup / Denmark 1988

/21/ Yde, Lars; Gylding, Carsten; Schugmann, Monika
Manual on FC - 4000 Wind Motor
FC - Print; Hurup / Denmark 1993

/22/ Yde, Lars; Jagadeesh, A.; Rasmussen, Peter
FC - 4000 a stand alone windturbine with multiple applications for developing countries
FC - Print; Hurup / Denmark 1988

Appendix 1: Overview of the measurements

A 1.1 FC - 4000 with hub airbrake

The following diagrams are made with measurements data recorded from the 6.23. - 6.27.94 in Folkecenters test field. Thanks to Mr. Deng Xingyong for giving these data to me.
The rotor is manufactured by the DANPROP company using a NASA LS(1) airfoil. The wind has been measured with a Risø - anemometer.
By comparing the works of Wolfram Schröter (Schröter 1994) with the measurements it is quiet near to make the proposals described in 4.2.

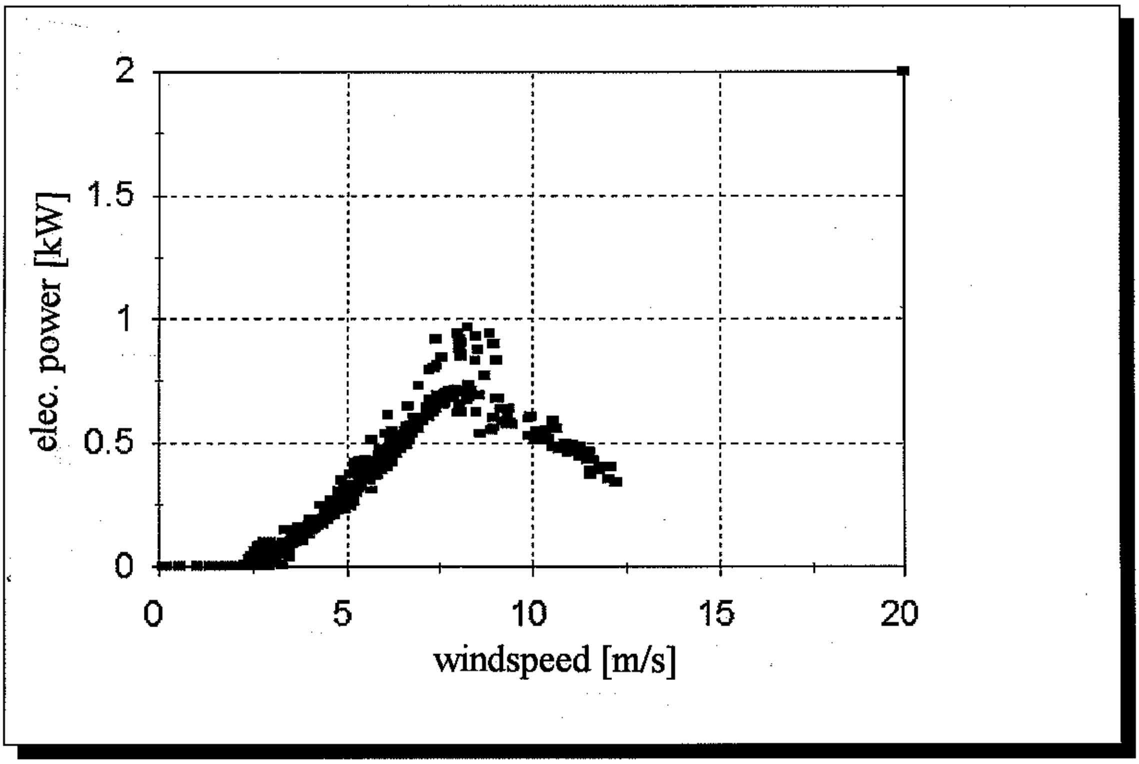

Fig. 17: power curve of FC - 4000 with hub airbrake

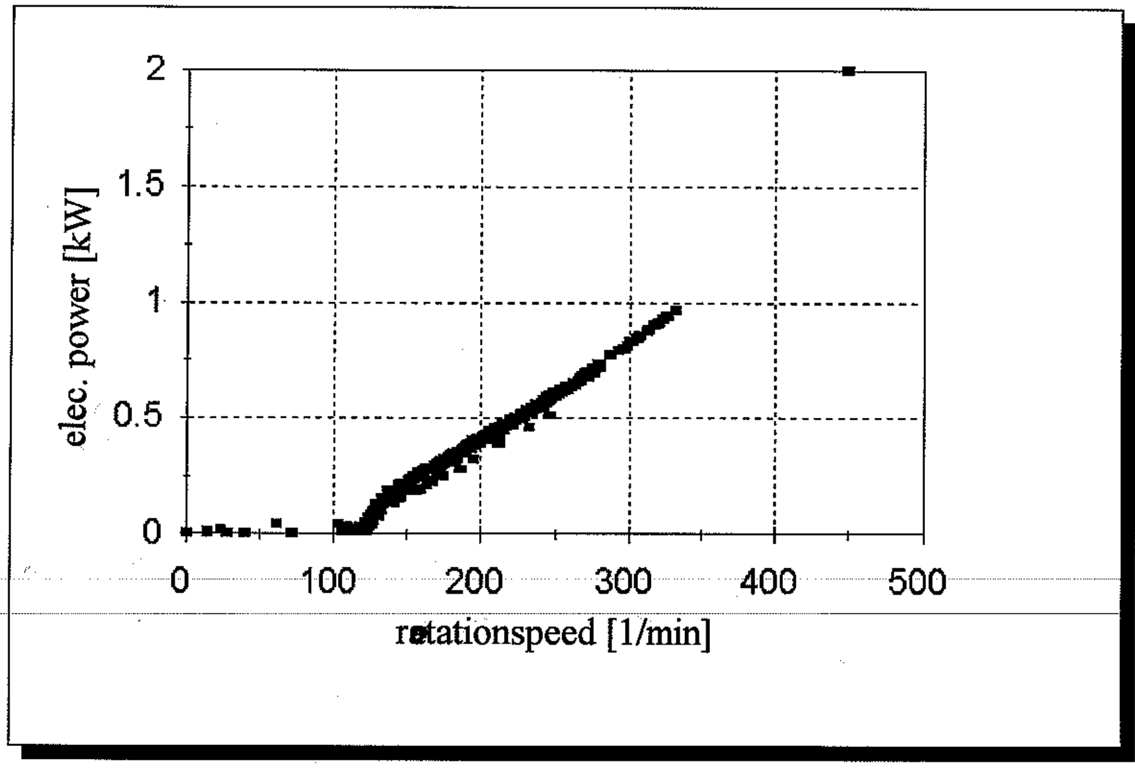

Fig. 18: generator power diagram

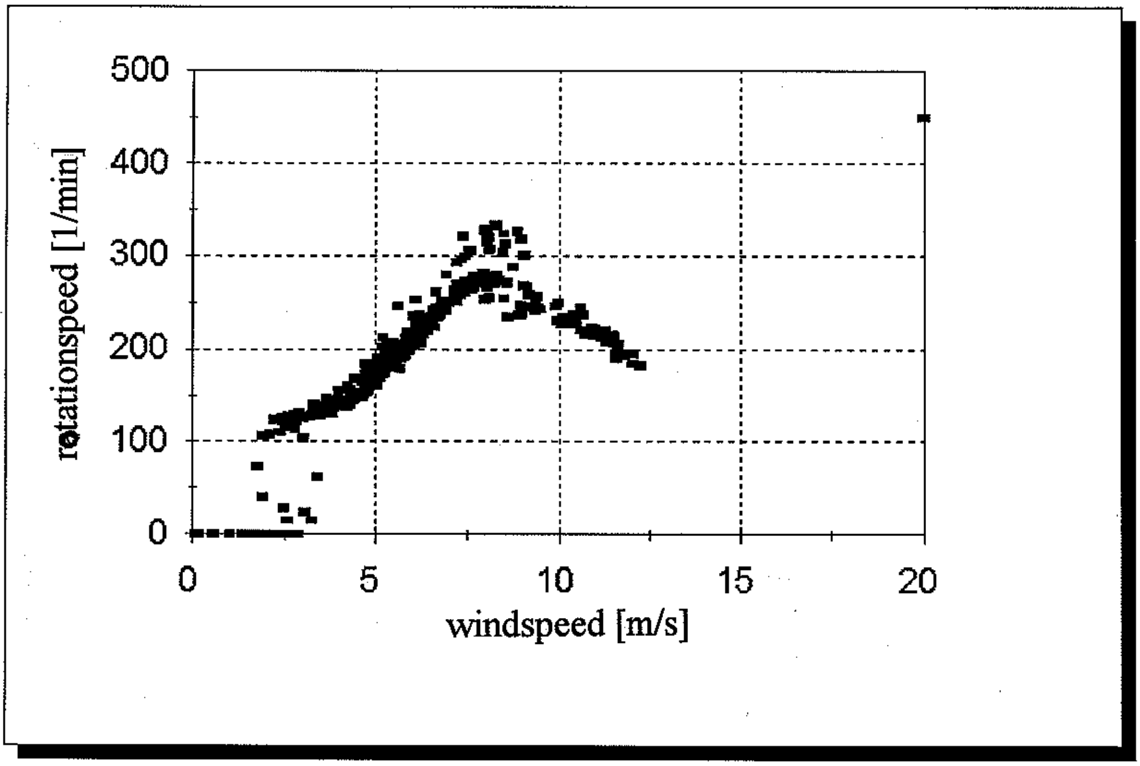

Fig. 19: rotation windspeed diagram

A 1.2 FC - 4000 with prototype tip - air - brake

The measurement data for the following diagrams are recorded from 4.24. to 4.30.94 in the Folkecenter test field.

The windspeed has been measured with a Helleskov - anemometer and the used rotor is an at Folkecenter made one with the NASA LS(1) airfoil.

The improvement to A 1.1 is obvious and the improvement could be even higher with a better rotor made by DANPROP.

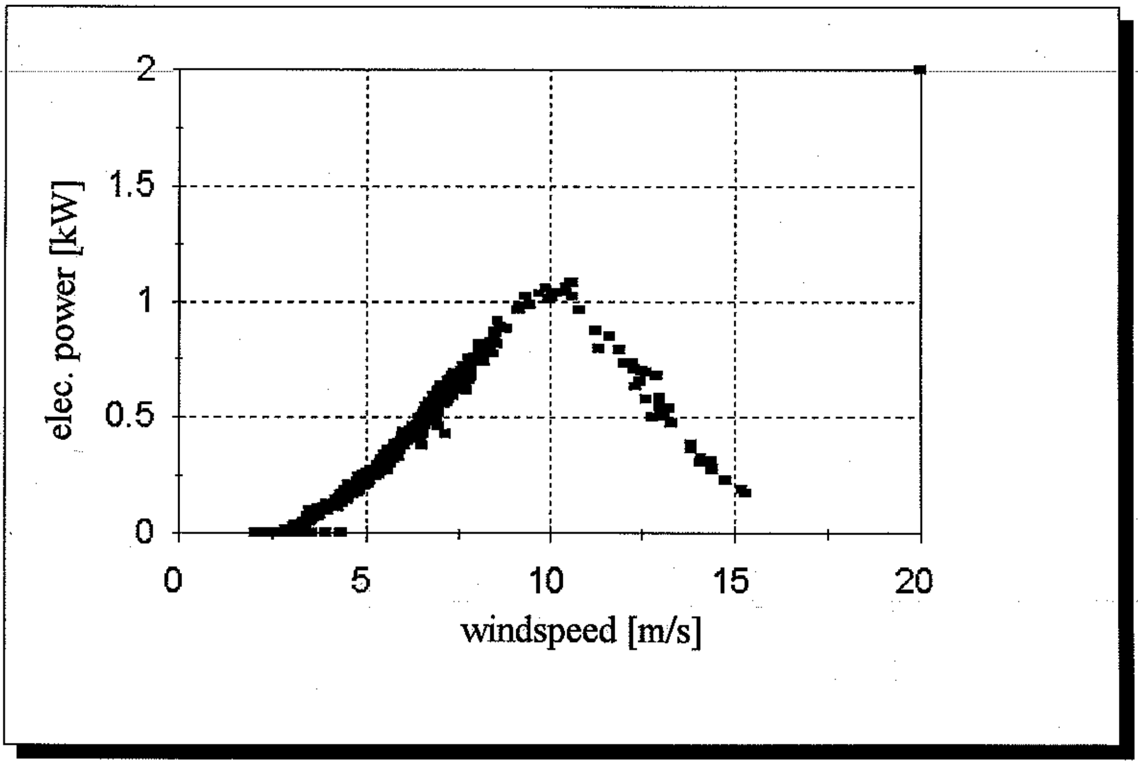

Fig. 20: power curve of FC - 4000 with prototype tip - air - brake

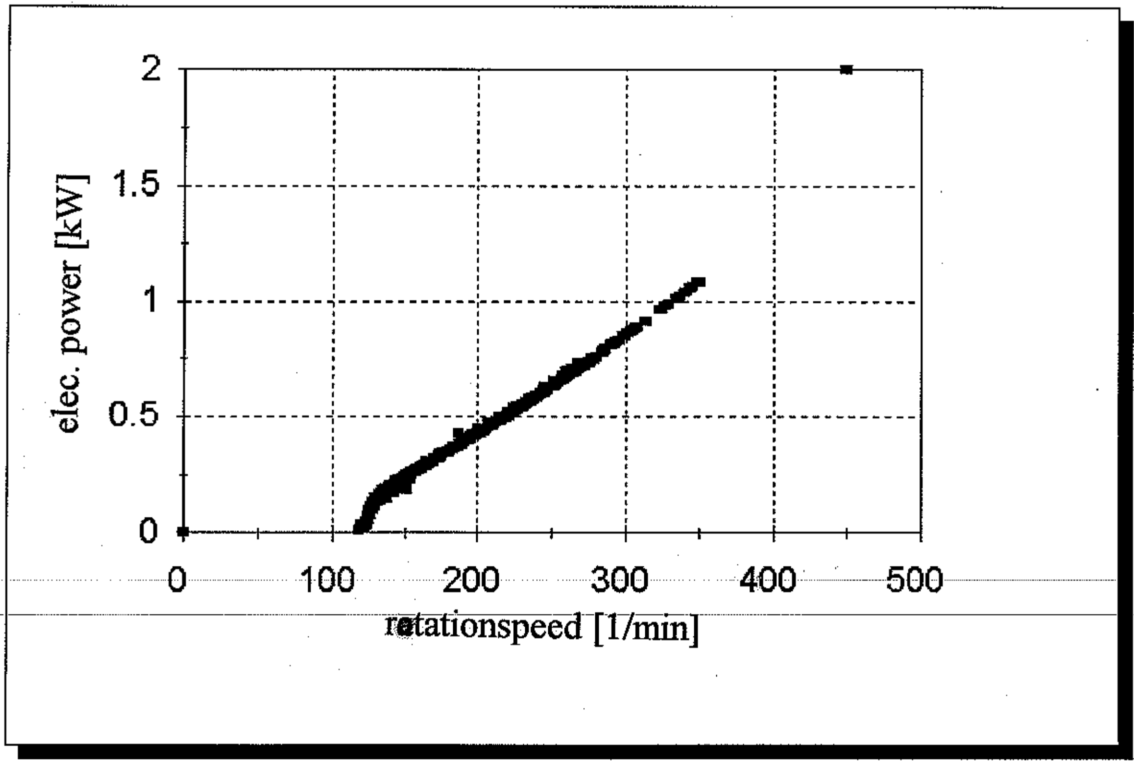

Fig. 21: generator power diagram

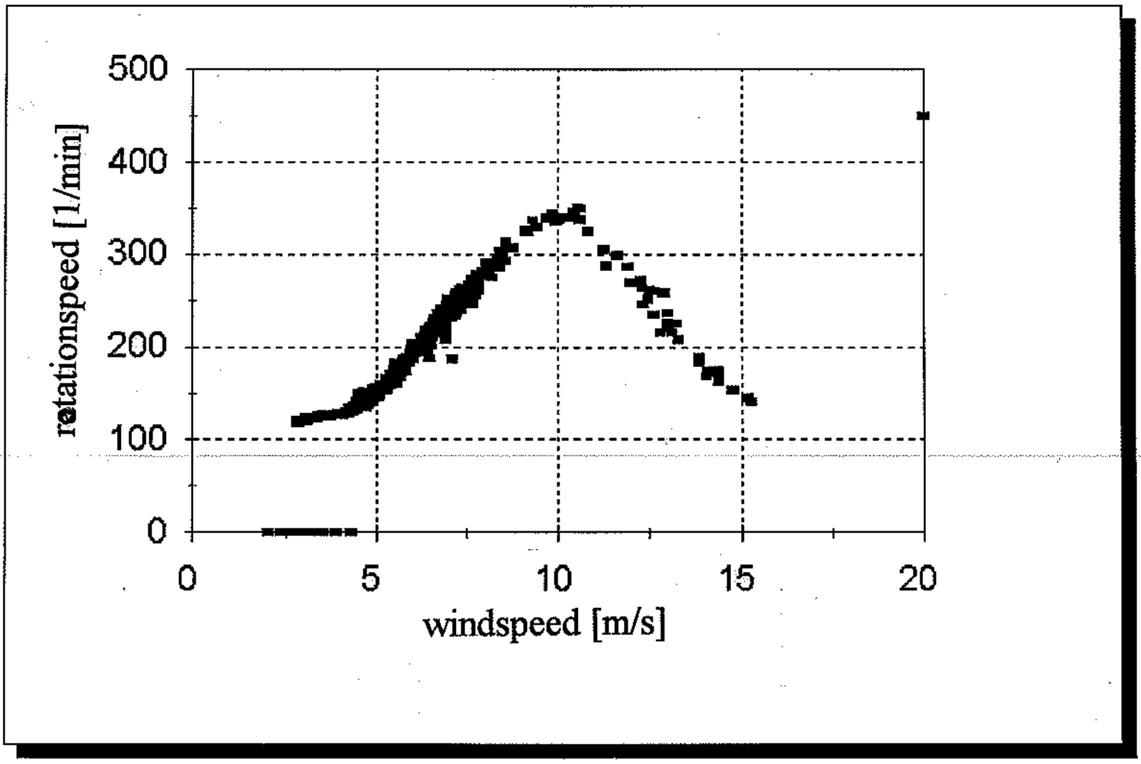

Fig. 22: rotation windspeed diagram

A 1.3 FC - 4000 with prototype tip - air - brake and an improved adjustment of the yawing system

The data for this measurements are recorded from 8.27. to 9.6.94 at Folkecenter.

The windspeed is also measured with a Helleskov - anemometer and the rotor is a in Folkecenter made one.

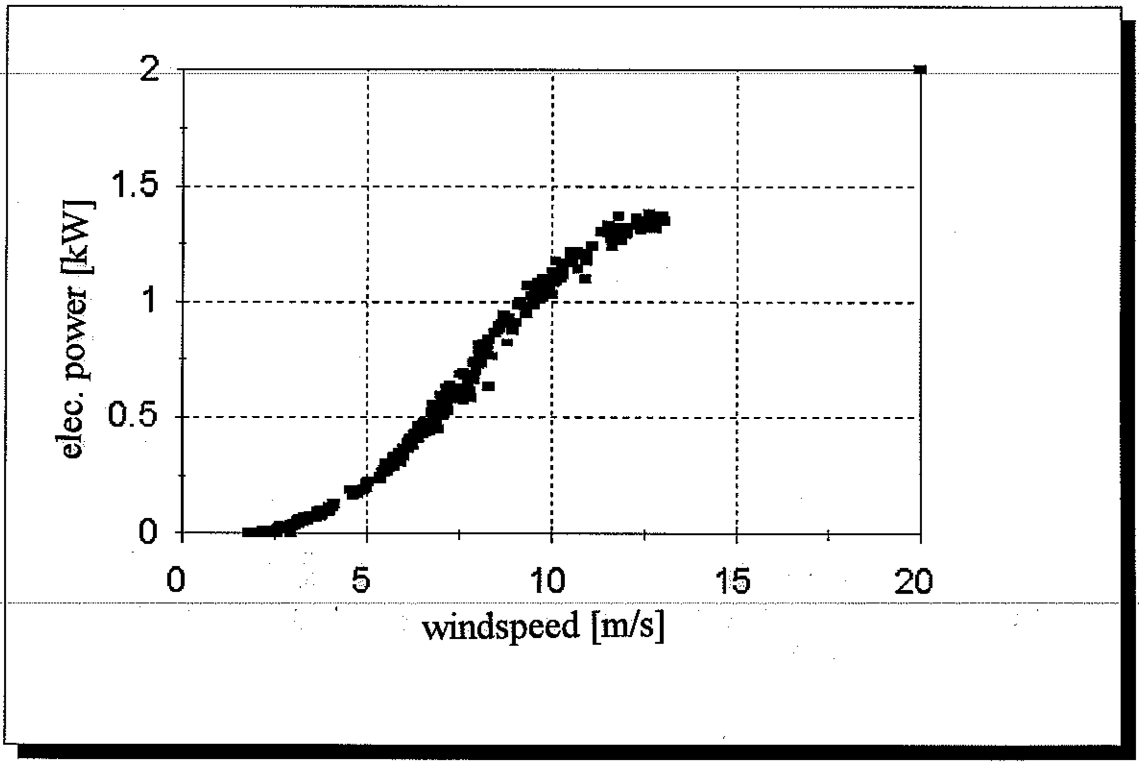

Fig. 23: power curve of FC - 4000 with prototype tip - air - brake and an improved adjustment of the yawing system

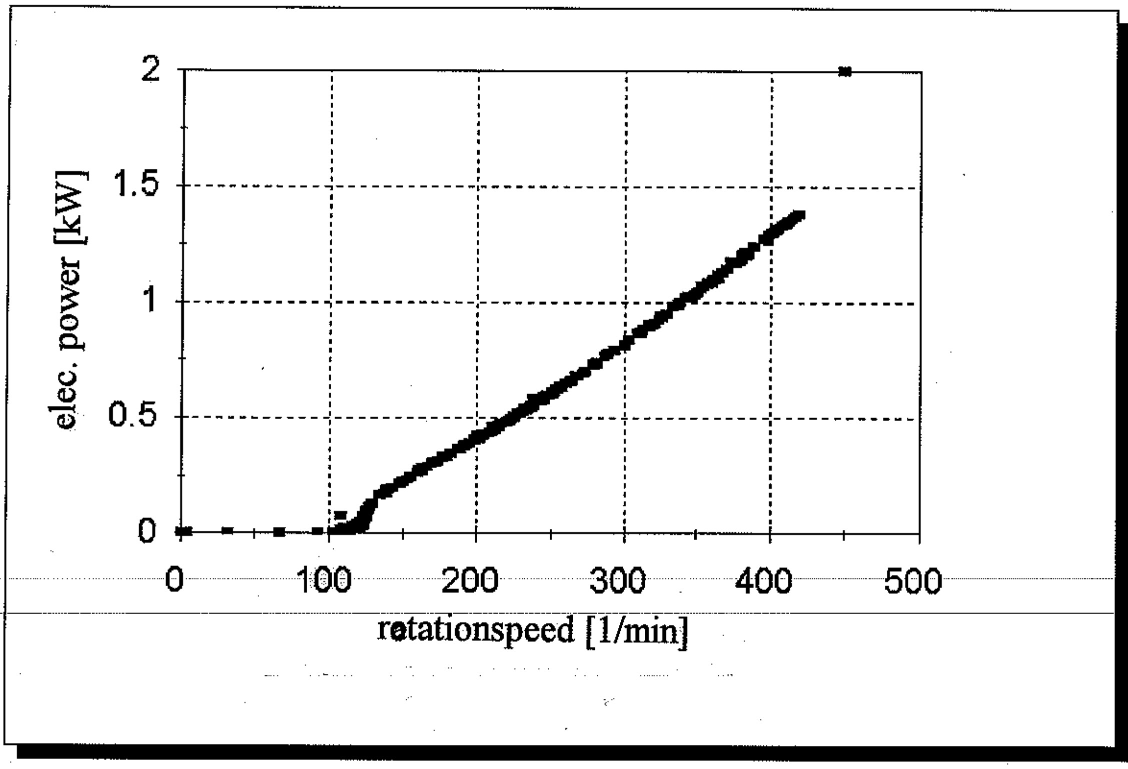

Fig. 24: generator power diagram

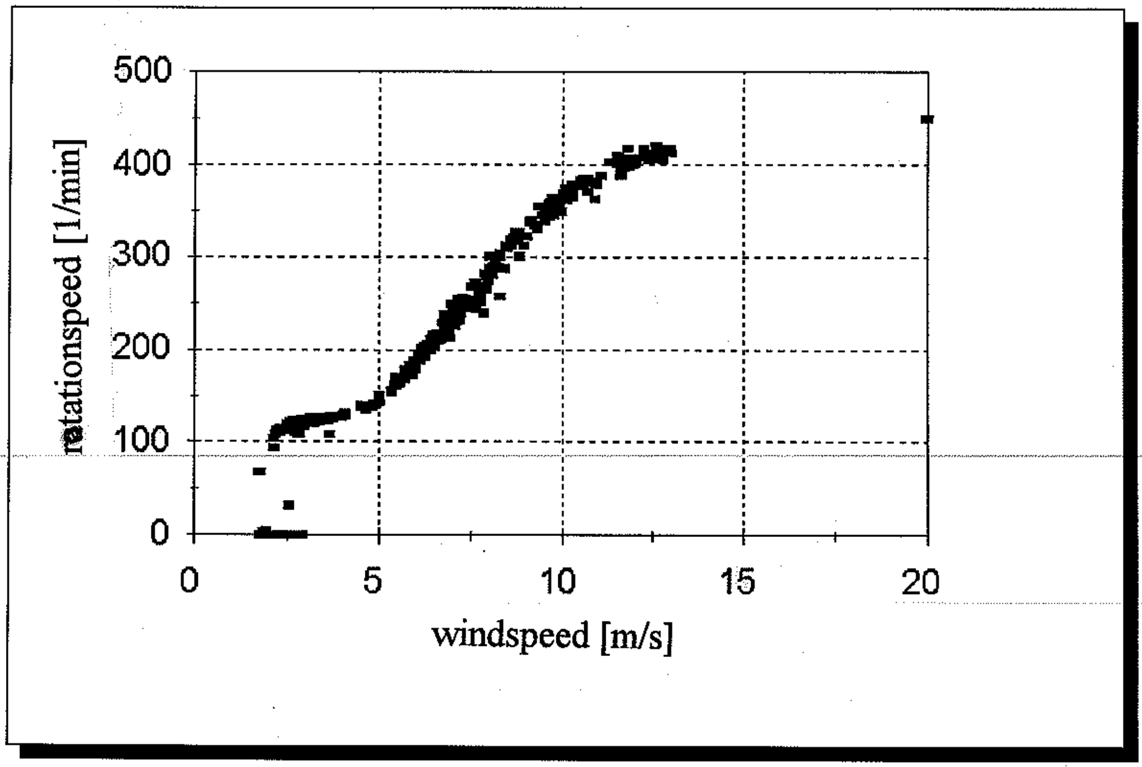

Fig. 25: rotation windspeed diagram

<u>**A 1.4 FC - 4000 with prototype tip - air - brake and new sidevane**</u>

The measurement data for these diagrams are recorded from 9.10 to 9.16.94 in the test field of Folkecenter.

The windspeed is measured with a Helleskov - anemometer and the rotor is a in Folkecenter made one.

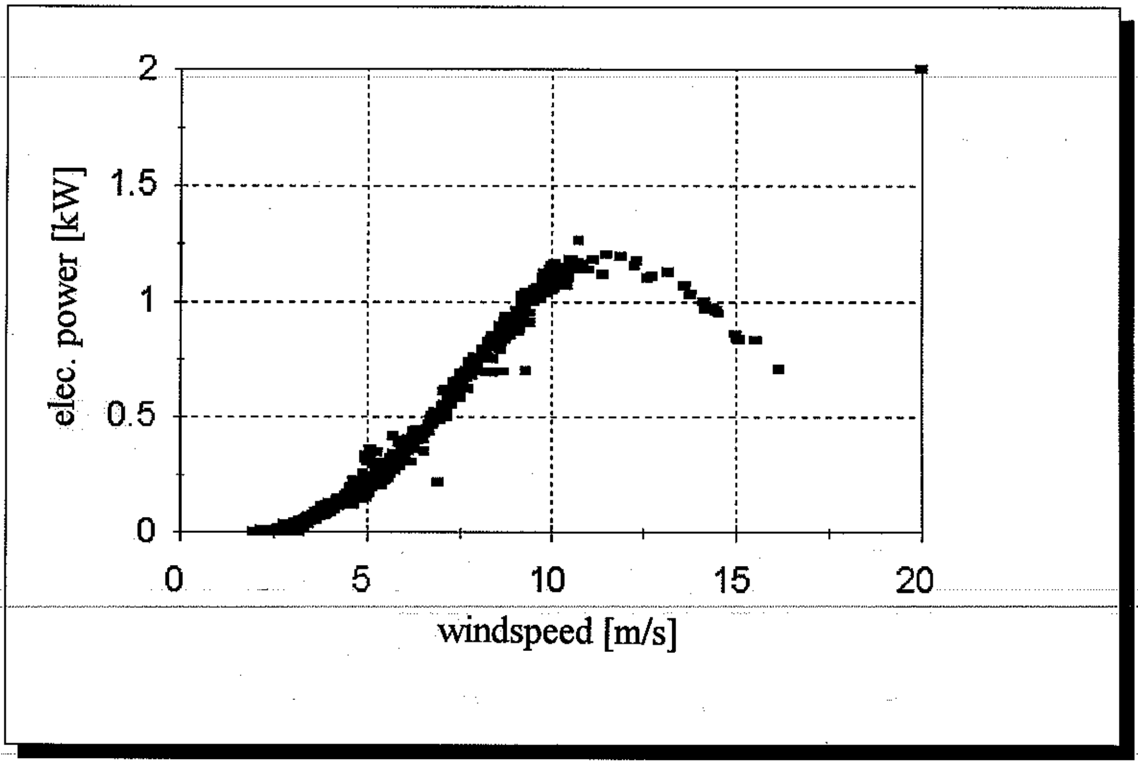

Fig. 26: power curve of FC - 4000 with prototype tip - air - brake and new sidevane

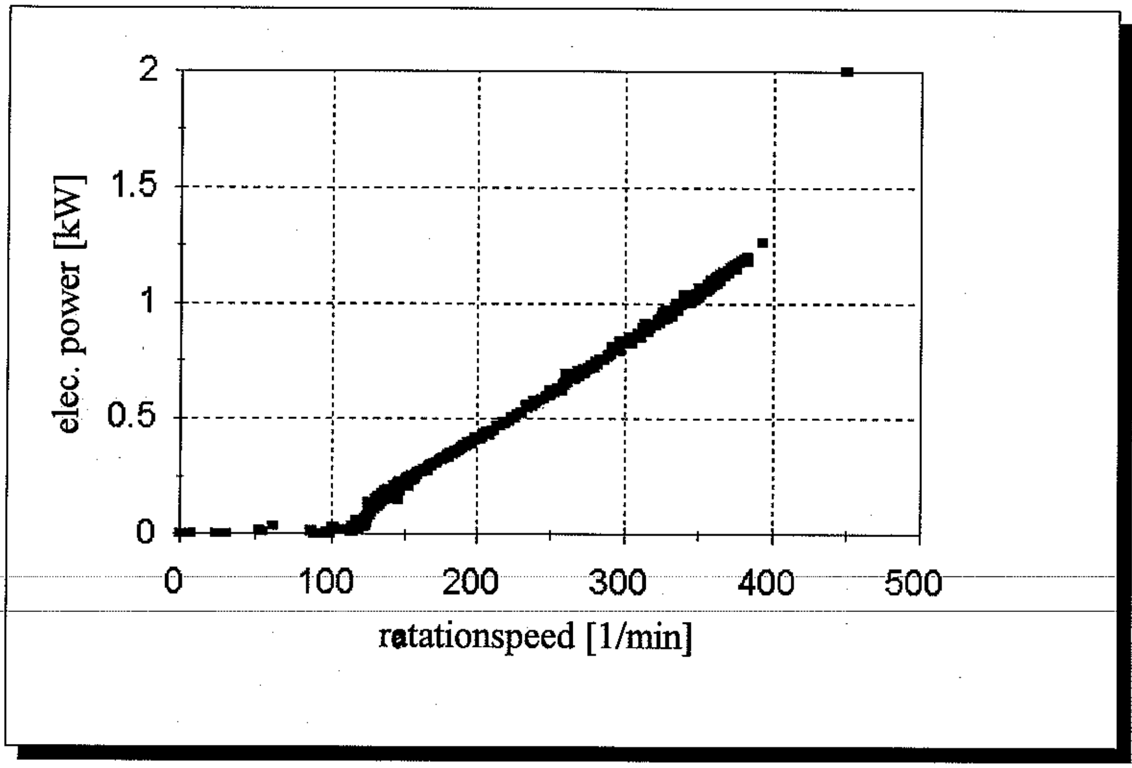

Fig. 27: gnerator power diagram

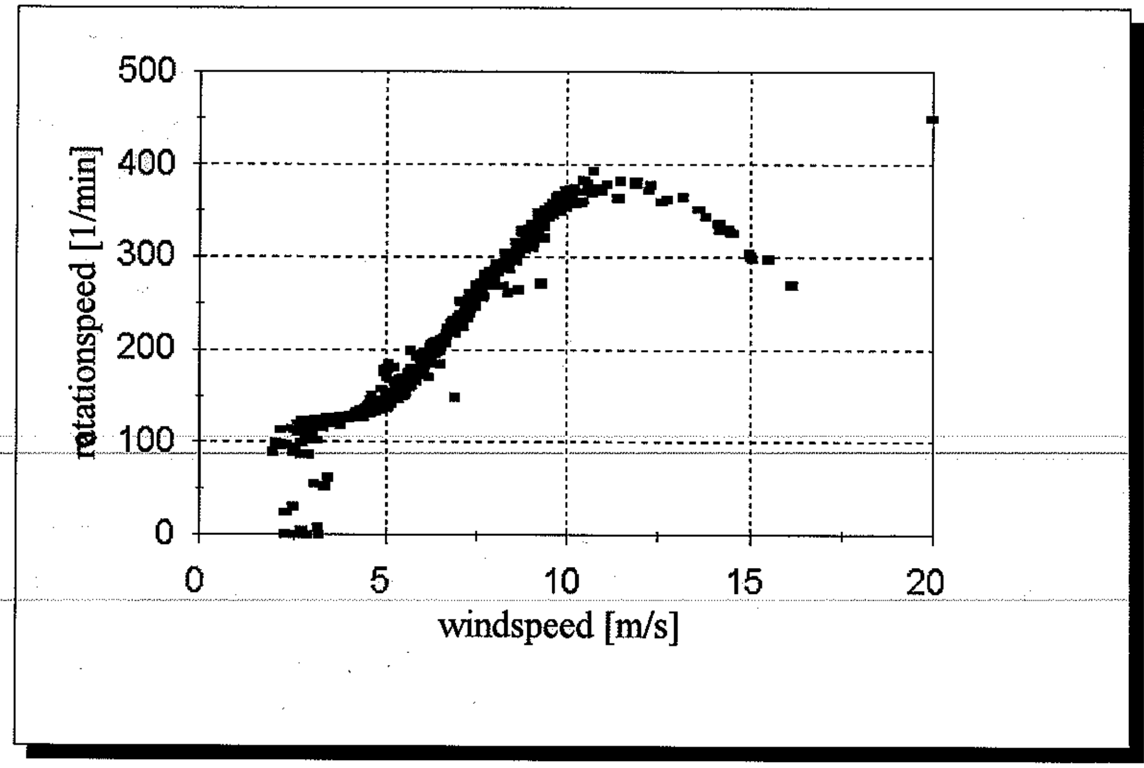

Fig. 28: rotation windspeed diagram

Appendix 2: Used diagrams

Figure 29 from (Matek 1986) page 79.
Tension factor q in relation to winding relation w or to the bending relation r/d

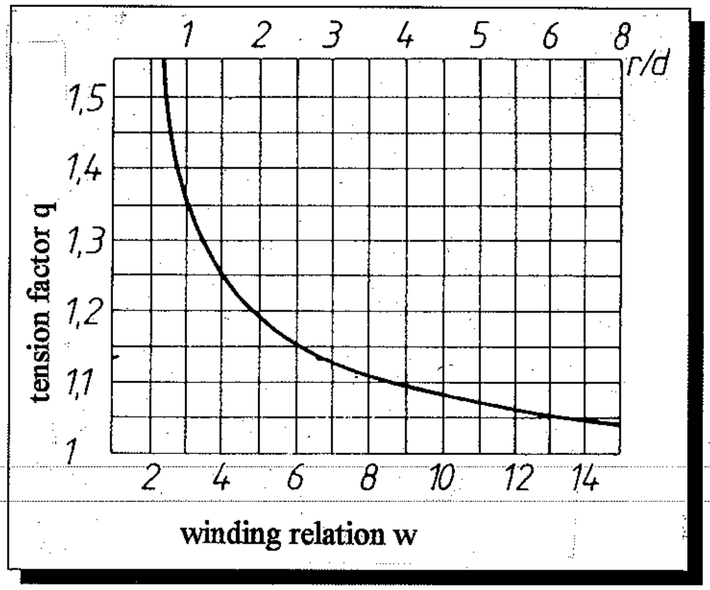

Fig. 29: tension factor diagram

Figure 30 from (Matek 1986) page 79.

Allowable bending tension for torsion spring wires. A, B and C following the german norm DIN 2076 and for rust - resistant wires (curve a) following the german norm DIN 17224.

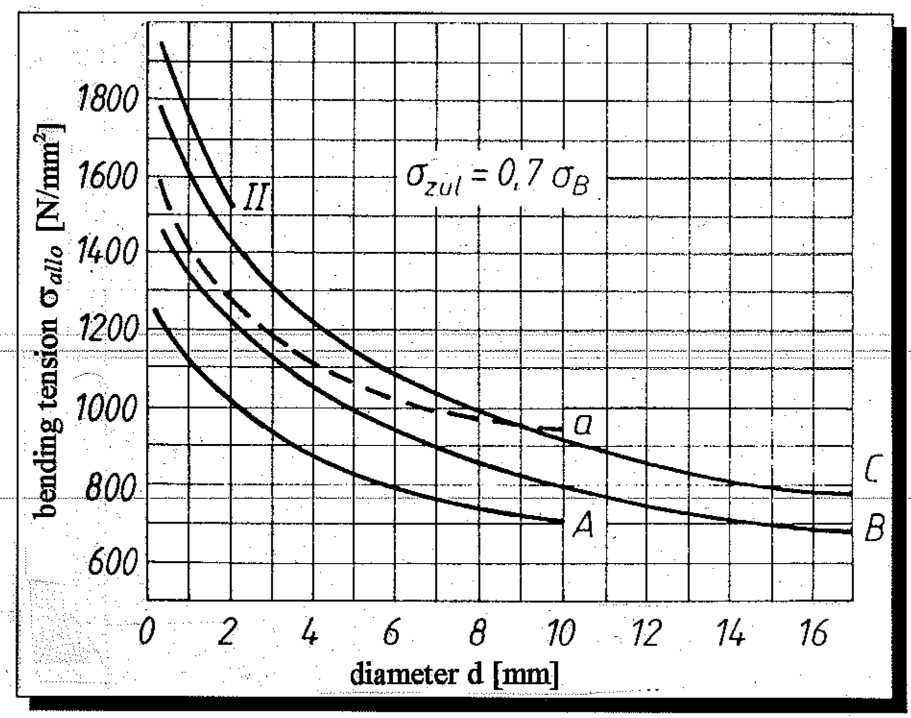

Fig. 30: allowable bending tension for springs

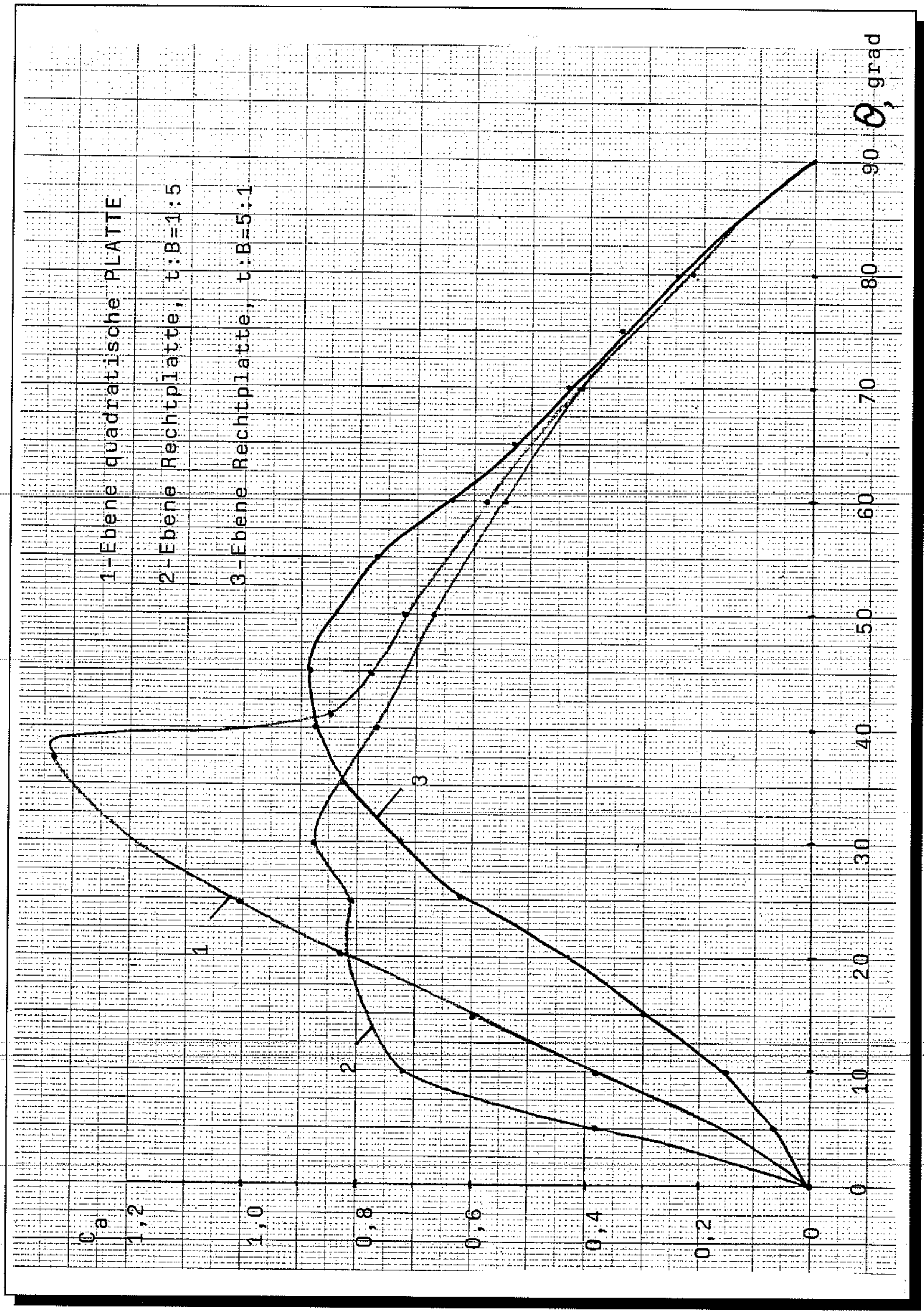

Fig. 31: lift factor for flat squared / rectangular plates (A. Penigin)

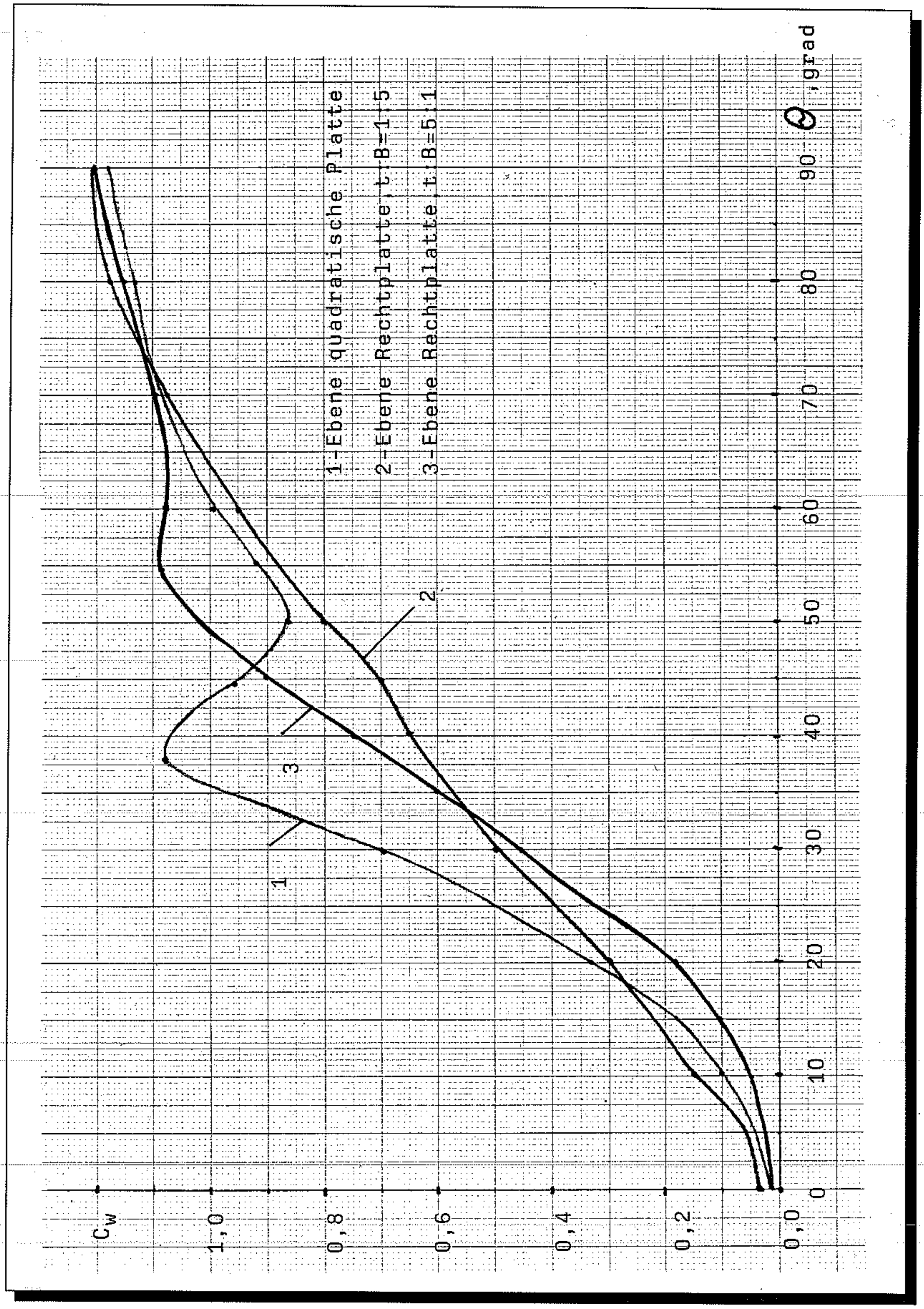

Fig. 32: drag factor for flat squared / rectangular plates (A. Penigin)