Field measurements on the WEU 1/3 water pumping windmill

FIELD MEASUREMENTS ON THE WEU I/3 WATER PUMPING WINDMILL

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SUMMARY

In this report the measurements are described, which have been performed on the WEU I/3 windmill. They concern the 10 minutes mean measurements only.

All measurements are processed via a so-called bin method. This method showed to be very attractive for output measurements.

Although the windmill showed some defects (leaking pump) an overall power coefficient of the system was reached of 0.32 at a design wind speed of about 3 m/s.

ACKNOWLEDGEMENTS

The authors would like to thank A. Prijt for his technical advices and his assistance.

CONTENTS

1 INTRODUCTION

In 1979 an apparatus was developed and built by two students of a Technical College [1] to measure, to store and to process the data measured from a (water pumping) wind mill.
This apparatus was built according to the requirements given by the Wind Energy Group, which was in need of such an apparatus to do field measurements.
In the summer and automn of 1981 this system was used for performance measurements on the WEU I/3 wind mill.
In the beginning, the sample period of the measurments was one hour; later this was decreased to ten minutes. Only the ten minute measurements are reported here.

2 WIND MILL MEASURING EQUIPMENT AND REGISTRATION

2.1. The WEU I/3 wind mill in Eindhoven

In the automn of 1979 the WEU I/2 wind mill which had been developed in the Sri Lanka project was built at the testfield of Eindhoven. In a cooperative effort between SWD and WEU this wind mill was modified in the summer of 1980. The result was the so-called WEU I/3 wind mill [2]. The wind mill consists of a 3.05 m diameter rotor directly coupled to a pistonpump via an adjustable crank. During our measurements this crank diameter was not changed. The pistonpump used in Eindhoven is still the pistonpump as described in [2] (this was based on the WMP I/2 pump, also developed in Sri Lanka). Differences with the pump in Sri Lanka are the airchambers which are inside the pump instead of outside and the pistondiameter, also with the revision of the windmill an iron pumprod was used instead of a PVC ons. In Eindhoven it was necessary to make a sealing at the top of the pumprod because a pressure simulation was built instead of a well. An overview is shown in Figure 1.

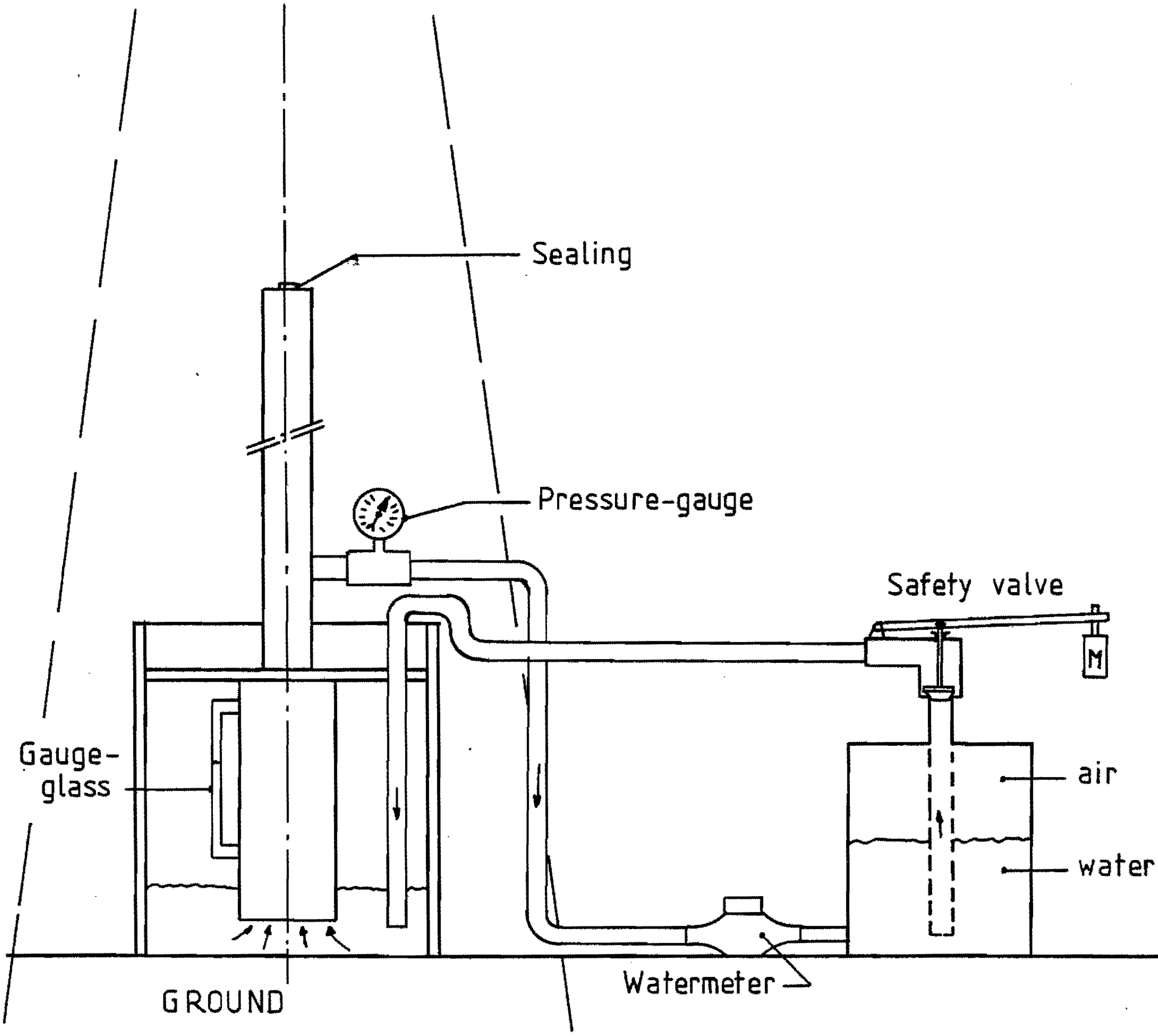


Figure 1: The pressure simulation for the WEU wind mill

2.2. Sensors and registration

As explained in the introduction an apparatus was developed in view of performing fieldmeasurements. The requirements for this instrument were:

1. to be used for different measuring times
   rotor diameters
   air densities
   water delivery heights
2. possibility to use several anemometers
3. clear output on paper, which contains:
   - sample time
   - the different input values
   - quantities as mean power, mean windspeed etc.
4. complete automatic system
5. simple operation
6. portable.

One can meet these requirements by using two separate parts, a measuring part and a data processing part. The measuring part measures the different values, while the processing part calculates values as mean power etc. (with aid of the input values of rotor diameters, air density etc.). This last unit was never used because it was not available in time. This turned out to be advantageous as the input data -which had to be typed for processing by the micro computer- were less in number.

It was decided that four input channels were necessary: three digital channels and one analogue channel.

The three digital channels receive pulses from read-switches or opto couplers (light emitting diode and light sensor) and these pulses must be summed during the measuring period.

The analogue channel averages a signal from a potentiometer; this is done by a so-called voltage regulated oscillator, in such a way, that one degree yawingangle gives one pulse per second (two degrees yawing angle gives 2 pulses per second etc.). It should be noted, that with the existing set-up no difference was made between positive and negative yawing angles.

The four signals measured are:

1. number of revolutions of the rotoraxis (by means of a opto-coupler)
   resolution: 1 pulse/revolution
2. number of litres water pumped by the wind mill (by means of a read-switch)
   resolution: 1 pulse/litre
3. windrun (by means of a read-switch)
   resolution: 1 pulse/100 m wind
4. yaw angle (by means of a potentiometer)
   resolution: 1 pulse/(per degree yawing angle * second)

A detailed description of the different sensors can be found in Appendix A. Because the process unit was not used, only the values of the four channels were printed. An example of four measurements is listed in Figure 2.

In this figure the word "TEL" is an abbreviation of the Dutch word "teller", which is equivalent to the English word "counter".

```
TEL 4 057831
TEL 3 001153
TEL 2 003088
TEL 1 000120

TEL 4 060949
TEL 3 000922
TEL 2 001832
TEL 1 000106

TEL 4 059104
TEL 3 000653
TEL 2 001289
TEL 1 000088

TEL 4 050716
TEL 3 001200
TEL 2 002406
TEL 1 000109
```

Figure 2: An example of the output of the registration unit

The four values display the following:

counter 1: windrun

counter 2: number of revolutions

counter 3: number of litres water

counter 4: yaw angle

All measurements are averages over ten minutes periods.

3 DATA PROCESSING AND RESULTS

3.1. Data processing

The four numbers per measurements as shown in Figure 2 are stored on a cassette tape with the aid of a PET micro processor. With this same processor alle measurements are processed into values which describe the performance of a wind mill.

In total 1449 ten minutes measurements are processed.

Per measurement the following sequence of processing was done:

1. See if one of the four counters shows a zero value.

   This will be the case, if for example the wind speed is zero or when the wind mill does not turn. Also a defect in one of the sensors can cause such a value.

   If one of the four numbers is zero, the measurement is ignored. This is necessary, because otherwise the processor has to divide by zero, which gives an "error" message and stops the processing.

2. If the measurement is accepted, the following quantities are calculated:

   $V = C_1 * 100/(T * 60)$

   $P_{wind} = 1/2 \rho V^3 \pi R^2$

   $P_{water} = H\ g\ C_3/(T * 60)$

   $\eta_{vol} = C_3/(C_2 * Vol)$

   $C_p \eta = P_{water}/P_{wind}$

   $\lambda = 2\pi R\ C_2/(C_1 * 100)$

   $\delta = C_4/(T * 60)$

   $n = C_2/(T * 60)$

   $Q = C_3$

The symbols are used for:

V	: wind speed (m/s)
P_{wind}	: power in the wind (W)
P_{water}	: theoretical power to lift an amount of water Q in a period T over a head H
η_{vol}	: volumetric efficiency
$C_p \eta$	: overall power coefficient
λ	: tipspeed ratio
δ	: angle of yaw
n	: number of revolutions per second (1/s)
Q	: quantity of pumped water (m^3)
ρ	: density of the air (kg/m^3)
H	: delivery height (m)
R	: rotor radius (m)
T	: measuring time (minutes)
Vol	: pump volume (litres)
C_1-C_4	: numerical values of counter 1-4

It will be clear, that the calculated values are averaged over the measuring period (here: ten minutes).

3. Now a check is made, if the measured values are reliable by checking the following conditions:

   1. $C_p \eta < 0.4$ (see explanation section 3.2.)
   2. $C_3 < 0.6\ C_2$

   If a measurement does not comply with one of the conditions then the measurement was ignored.

4. Now all data are stored in bins. Each bin is characterised by a wind speed interval. This way of data handling is described in [3].
5. Per bin the mean value and the standard deviation within the bin is calculated and printed.

An example of such a calculation is shown in Appendix B. The computer programme is given in Appendix C.
The result of all measurements are given in table 1 - 9 and figure 3 - 10. Each processed quantity is stored in its appropriate bin (bin i) characterised by the corresponding wind speed interval ($\frac{i-1}{2}$ m/s and i/2 m/s) in which it was measured. In this way distributions are obtained for the wind speed, power in the wind, power in the water, volumetric efficiency, overall power coefficient, tipspeed ratio, yaw angle, revolutions per second and the number of litres water pumped.

In the following tables the Dutch words "KLASSE, X-GEM., ST.DEV. and AANT." mean respectively bin number, mean value within the bin, standard deviation and the number of measurements belonging to the specific bin.

KLASSE	X-GEM.	ST.DEV.	AANT.
1	.0000	.0000	0
2	.0000	.0000	0
3	.0000	.0000	0
4	1.8055	.0621	6
5	2.2368	.1186	38
6	2.6962	.1328	90
7	3.1622	.1318	150
8	3.6632	.1356	193
9	4.1511	.1364	140
10	4.6557	.1383	137
11	5.1700	.1367	147
12	5.6666	.1284	101
13	6.1280	.1273	69
14	6.6488	.1286	28
15	7.0476	.0981	14
16	7.6875	.1301	8
17	8.0555	.0785	3
18	8.5000	.0000	1
19	.0000	.0000	0
20	.0000	.0000	0

Table 1: The distribution of the wind speed

KLASSE	X-GEM.	ST.DEV.	AANT.
1	.0000	.0000	0
2	.0000	.0000	0
3	.0000	.0000	0
4	26.9826	2.6088	6
5	51.5524	7.8113	38
6	90.1945	13.0446	90
7	145.2053	18.1322	150
8	225.4837	25.0141	193
9	327.8458	32.4251	140
10	462.2264	41.2753	137
11	632.6203	50.0637	147
12	832.5232	56.5569	101
13	1052.6130	66.1397	69
14	1344.2003	78.2363	28
15	1600.0243	68.6443	14
16	2077.1711	105.0031	8
17	2388.6638	70.3565	3
18	2805.4408	.0000	1
19	.0000	.0000	0
20	.0000	.0000	0

Table 2: The distribution of the power in the wind corresponding to the bins of Table 1

KLASSE	X-GEM.	ST.DEV.	AANT.
1	.0000	.0000	0
2	.0000	.0000	0
3	.0000	.0000	0
4	8.4611	1.7614	6
5	14.6827	5.8303	38
6	28.9722	6.3405	90
7	42.8762	8.7046	150
8	54.8089	8.1825	193
9	62.5177	8.6168	140
10	71.1207	8.4661	137
11	80.5654	9.1943	147
12	88.7222	6.6873	101
13	95.2494	8.2411	69
14	101.7612	7.9060	28
15	103.2677	6.4724	14
16	103.8020	5.2839	8
17	84.9382	29.2175	3
18	108.6457	.0000	1
19	.0000	.0000	0
20	.0000	.0000	0

Table 3: The distribution of the power needed to lift the water

KLASSE	X-GEM.	ST.DEV.	AANT.
1	.0000	.0000	0
2	.0000	.0000	0
3	.0000	.0000	0
4	.8742	.1279	6
5	.7460	.1529	38
6	.6789	.1255	90
7	.6354	.0977	150
8	.6109	.0704	193
9	.5876	.0486	140
10	.5703	.0393	137
11	.5586	.0295	147
12	.5609	.0231	101
13	.5630	.0284	69
14	.5694	.0251	28
15	.5697	.0199	14
16	.5607	.0146	8
17	.6149	.0837	3
18	.5632	.0000	1
19	.0000	.0000	0
20	.0000	.0000	0

Table 4: The distribution of the volumetric efficiency

KLASSE	X-GEM.	ST.DEV.	AANT.
1	.0000	.0000	0
2	.0000	.0000	0
3	.0000	.0000	0
4	.3159	.0665	6
5	.2820	.0982	38
6	.3219	.0573	90
7	.2962	.0534	150
8	.2454	.0420	193
9	.1916	.0266	140
10	.1547	.0203	137
11	.1277	.0150	147
12	.1069	.0100	101
13	.0906	.0075	69
14	.0758	.0066	28
15	.0646	.0050	14
16	.0501	.0046	8
17	.0353	.0117	3
18	.0387	.0000	1
19	.0000	.0000	0
20	.0000	.0000	0

Table 5: The distribution of the overall power coefficient

KLASSE	X-GEM.	ST.DEV.	AANT.
1	.0000	.0000	0
2	.0000	.0000	0
3	.0000	.0000	0
4	.5909	.0876	6
5	.9607	.3877	38
6	1.8148	.5566	90
7	2.4078	.6137	150
8	2.7317	.5109	193
9	2.8363	.4290	140
10	2.9494	.3085	137
11	3.0657	.2853	147
12	3.0713	.2035	101
13	3.0332	.1662	69
14	2.9537	.1365	28
15	2.8288	.1441	14
16	2.6498	.1375	8
17	1.9931	.8261	3
18	2.4960	.0000	1
19	.0000	.0000	0
20	.0000	.0000	0

Table 6: Distribution of the tipspeed ratio

KLASSE	X-GEM.	ST.DEV.	AANT.
1	.0000	.0000	0
2	.0000	.0000	0
3	.0000	.0000	0
4	21.6380	3.4887	6
5	18.2671	3.1047	38
6	15.7230	3.5165	90
7	14.3227	3.2540	150
8	15.0961	3.7967	193
9	15.4743	3.5316	140
10	16.0572	3.2986	137
11	16.9001	2.4647	147
12	17.5562	2.0806	101
13	18.4957	2.0049	69
14	20.6870	1.8347	28
15	19.8085	2.2304	14
16	20.8883	8.6074	8
17	36.1494	15.6464	3
18	26.9700	.0000	1
19	.0000	.0000	0
20	.0000	.0000	0

Table 7: The distribution of the yaw angle

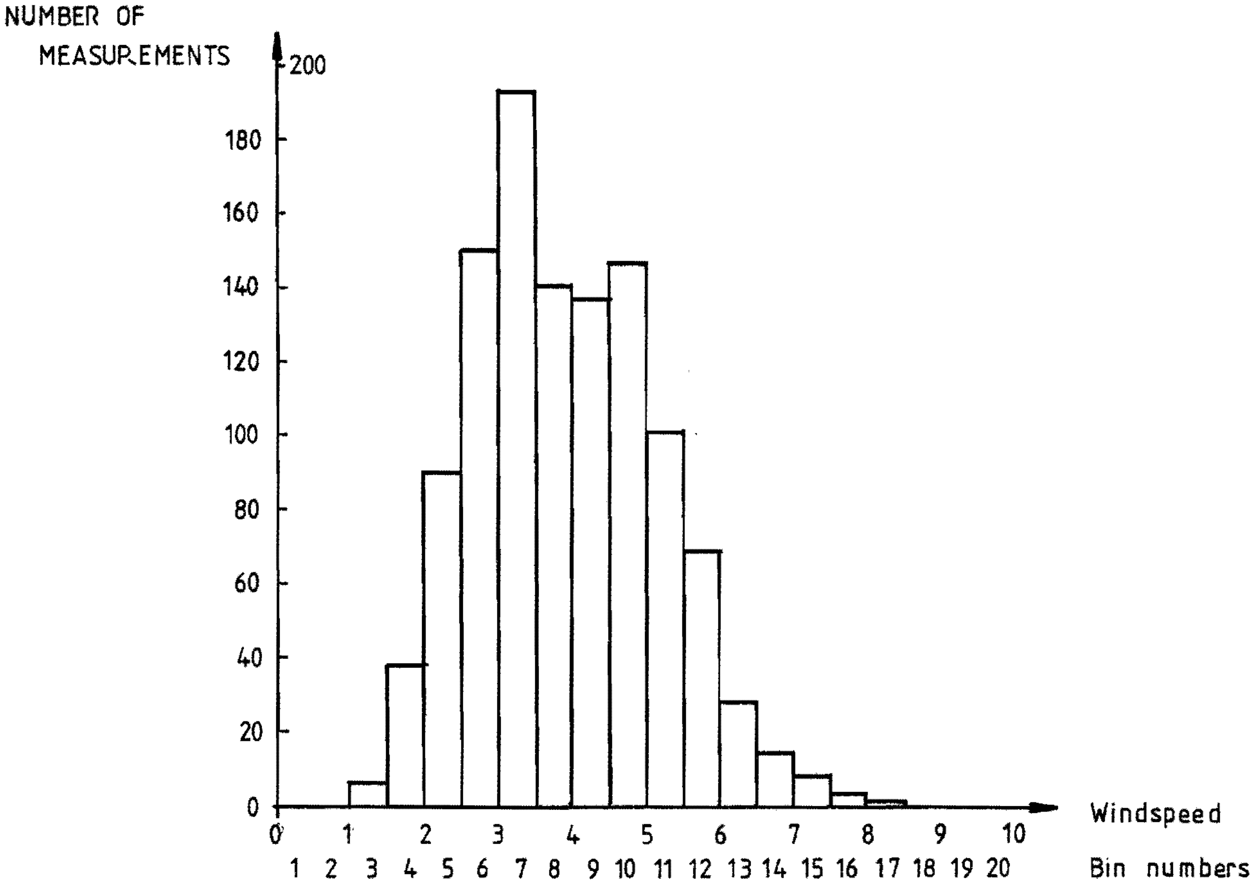
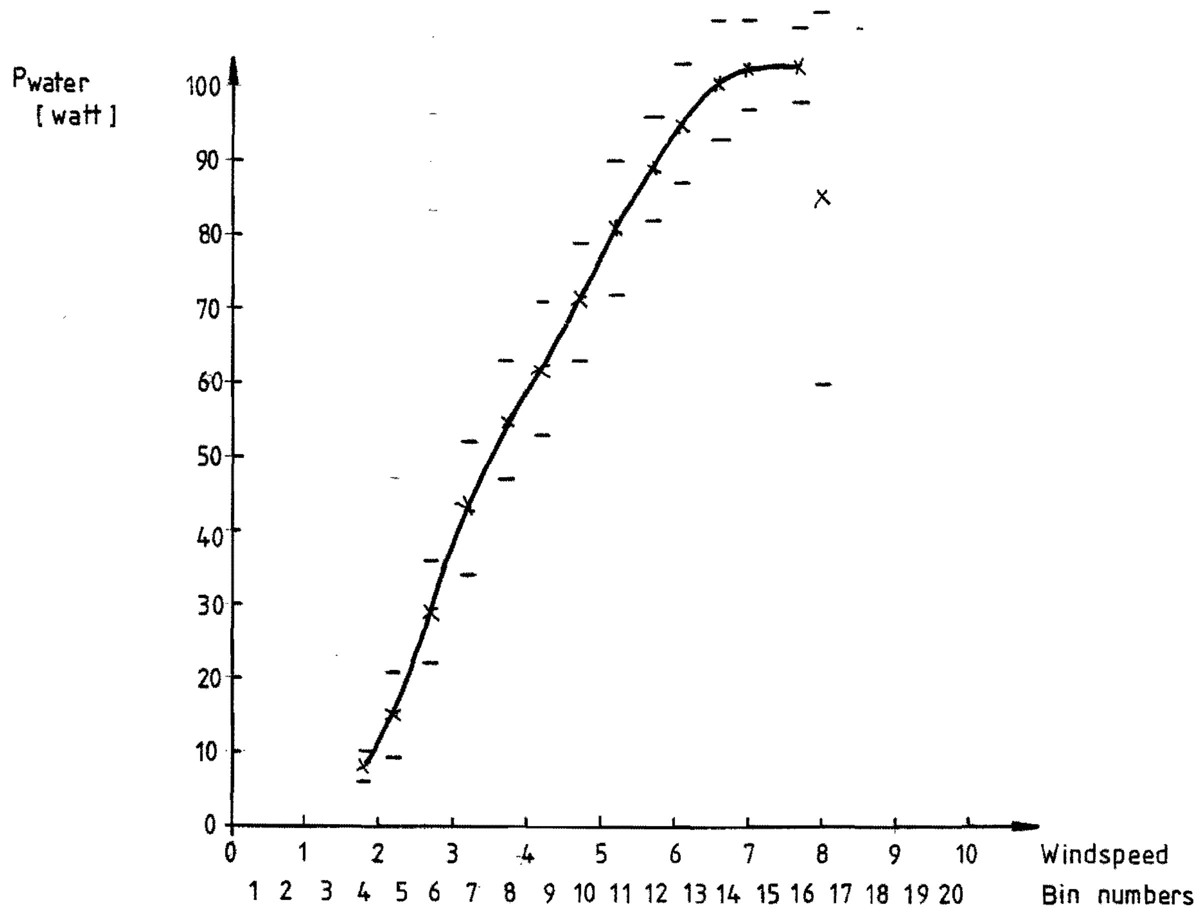


Figure 3: The number of measurements as a function of the wind speed.



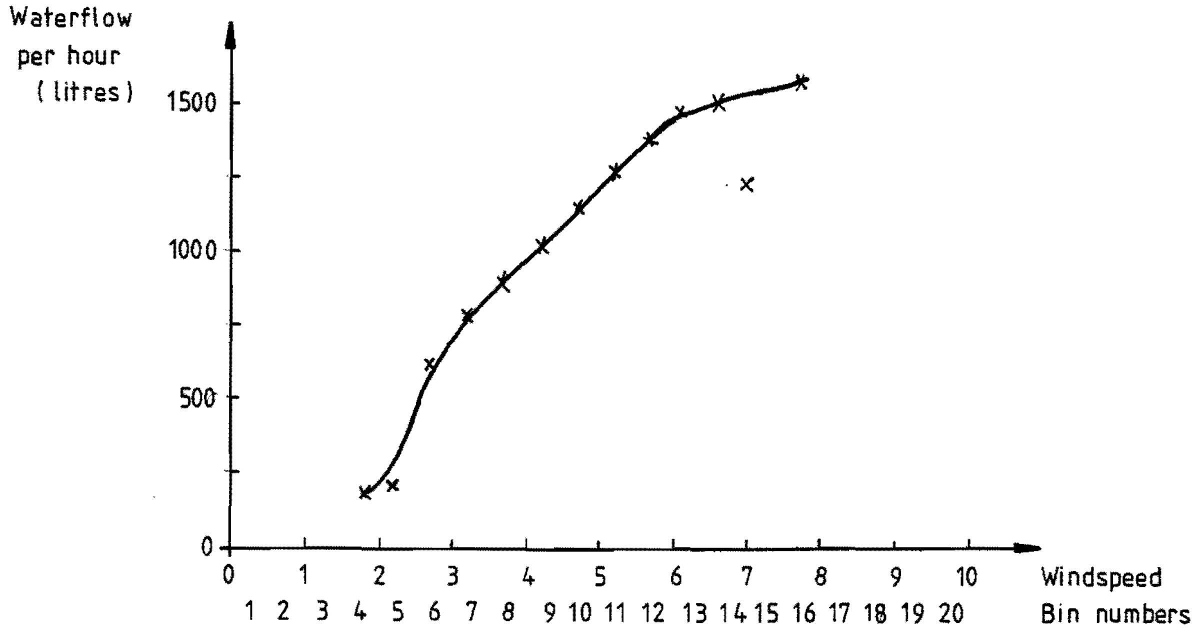


Figure 4: The output power P_{water} and water flow per hour at H = 15 m as a function of the wind speed

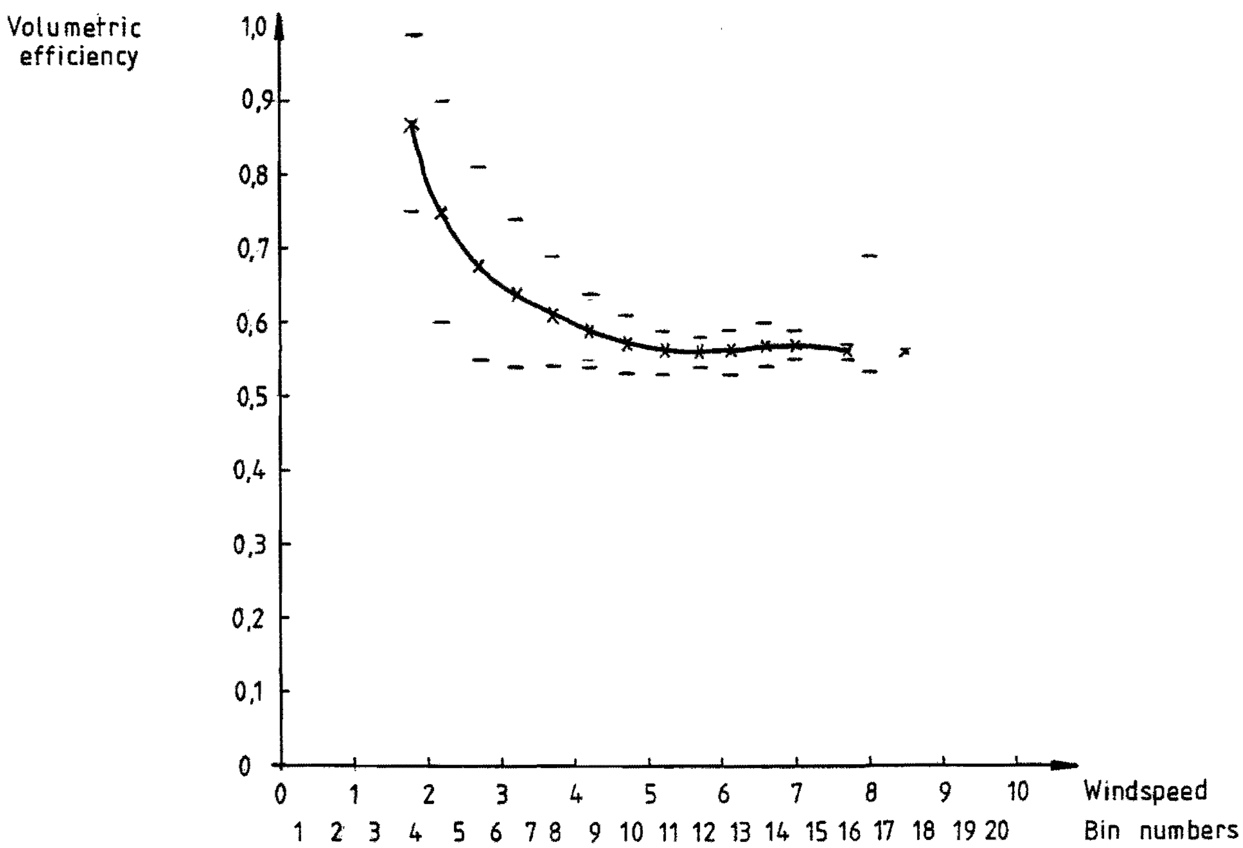


Figure 5: The volumetric efficiency as a function of the wind speed

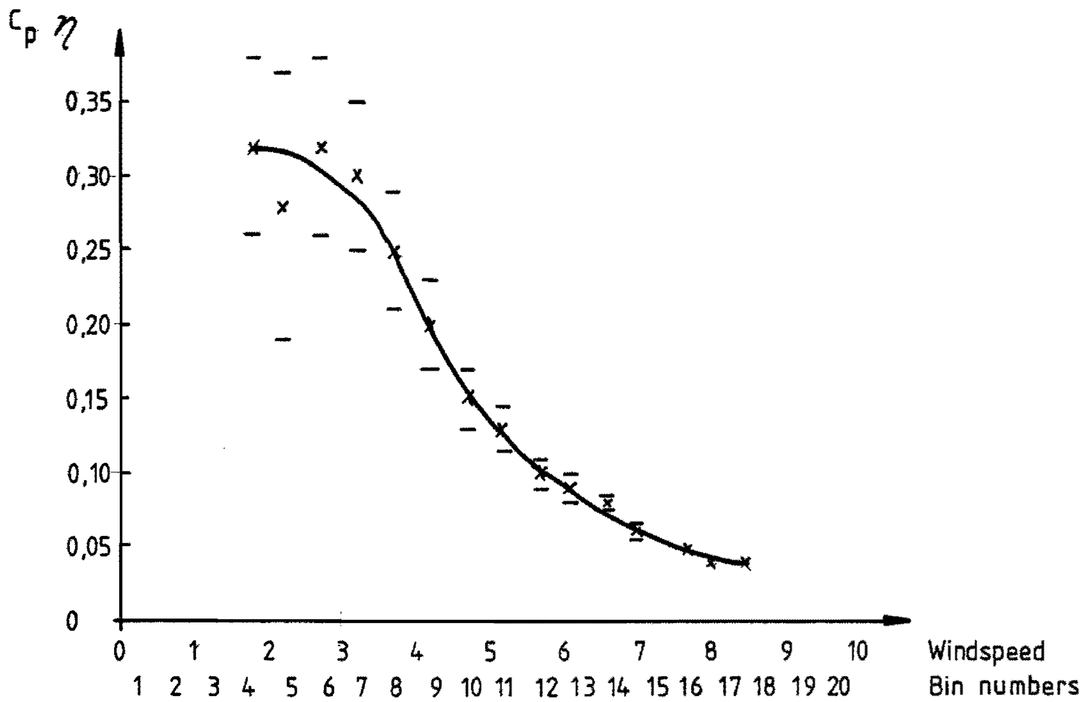


Figure 6: The overall power coefficient as a function of the wind speed

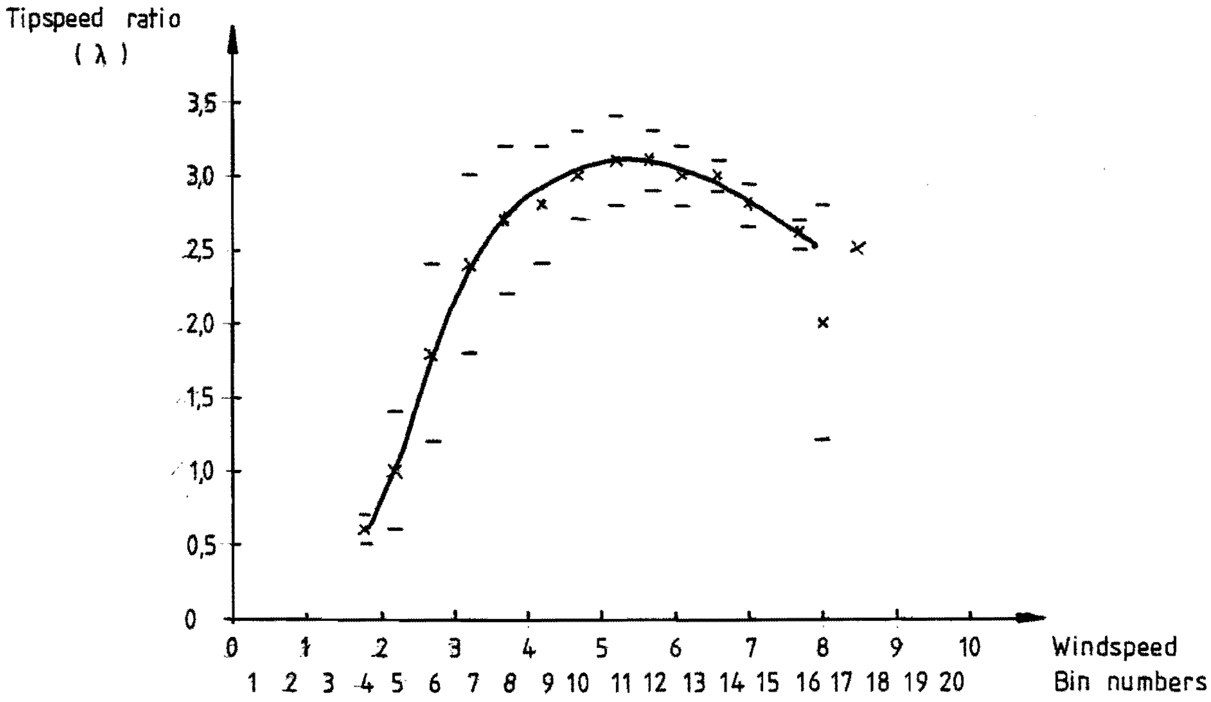


Figure 7: The tipspeed ratio as a function of the wind speed

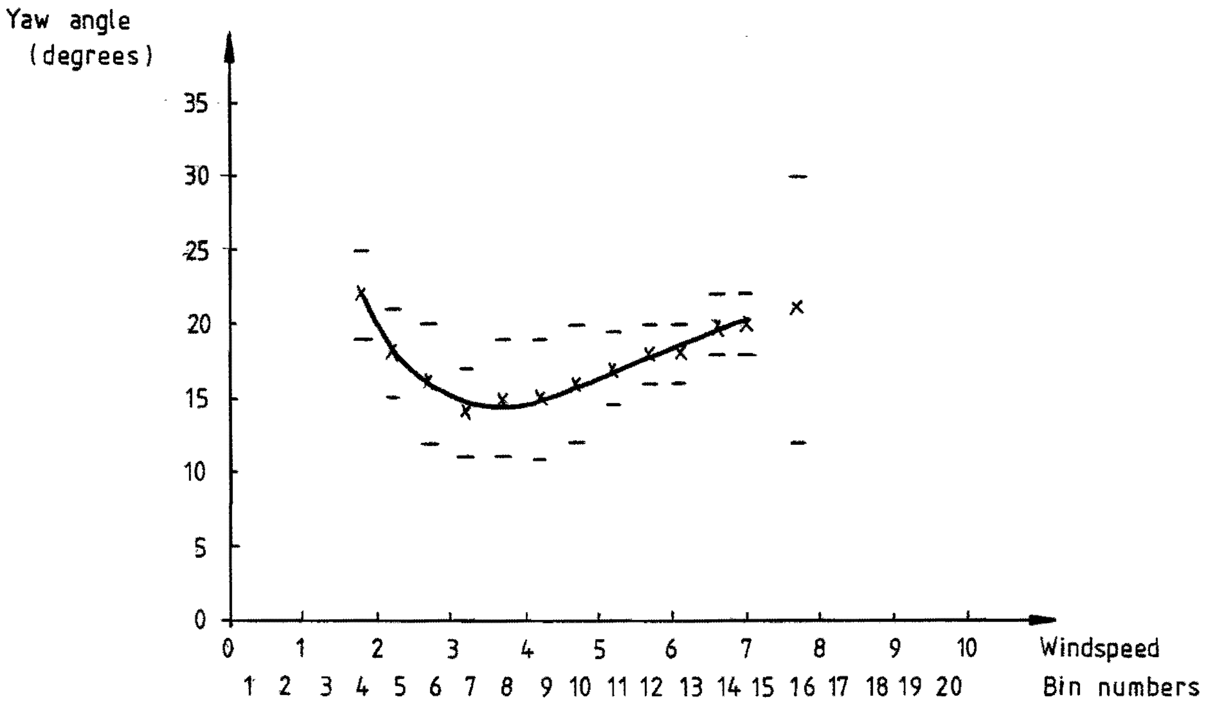


Figure 8: The absolute yaw angle as a function of the wind speed

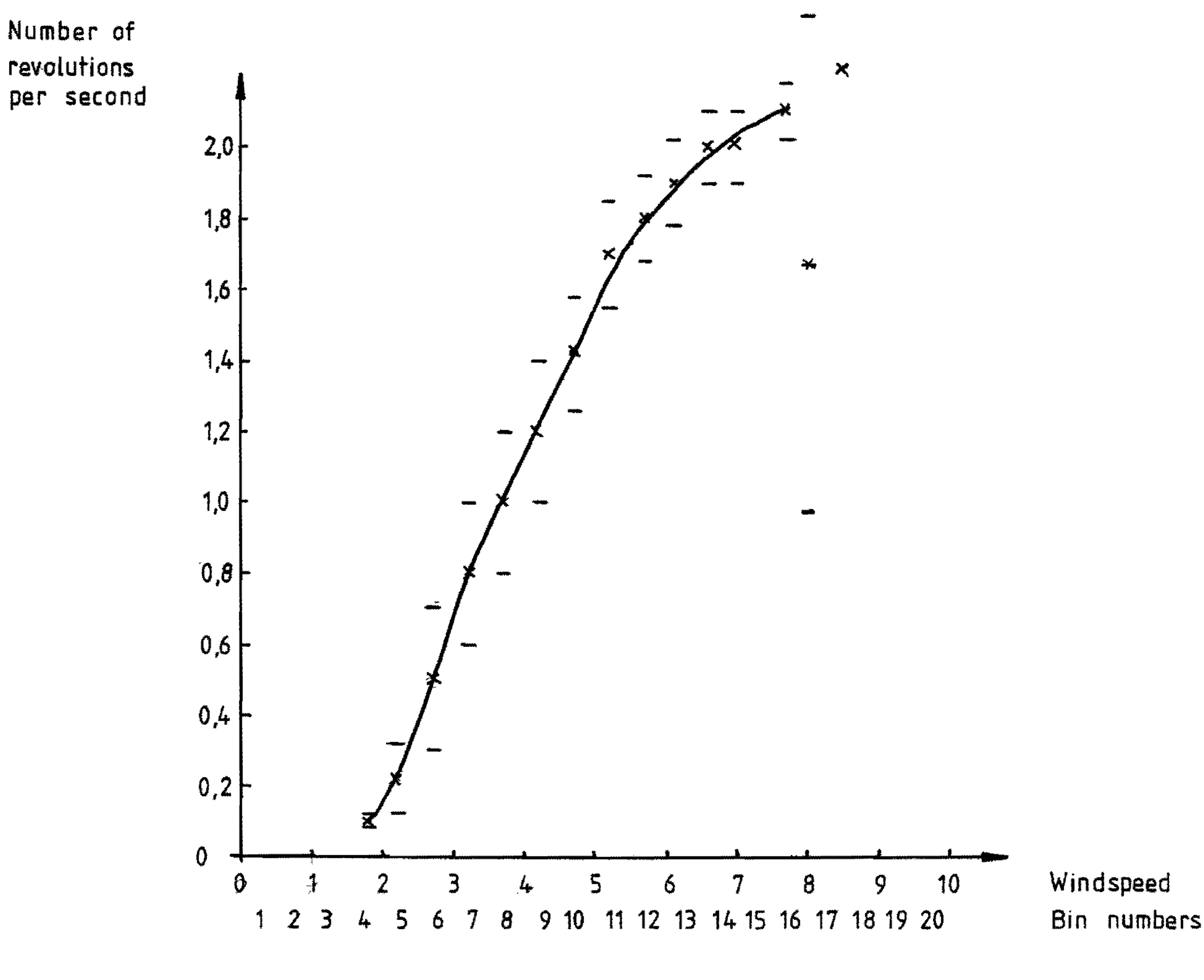


Figure 9: The number of revolutions per second as a function of the wind speed

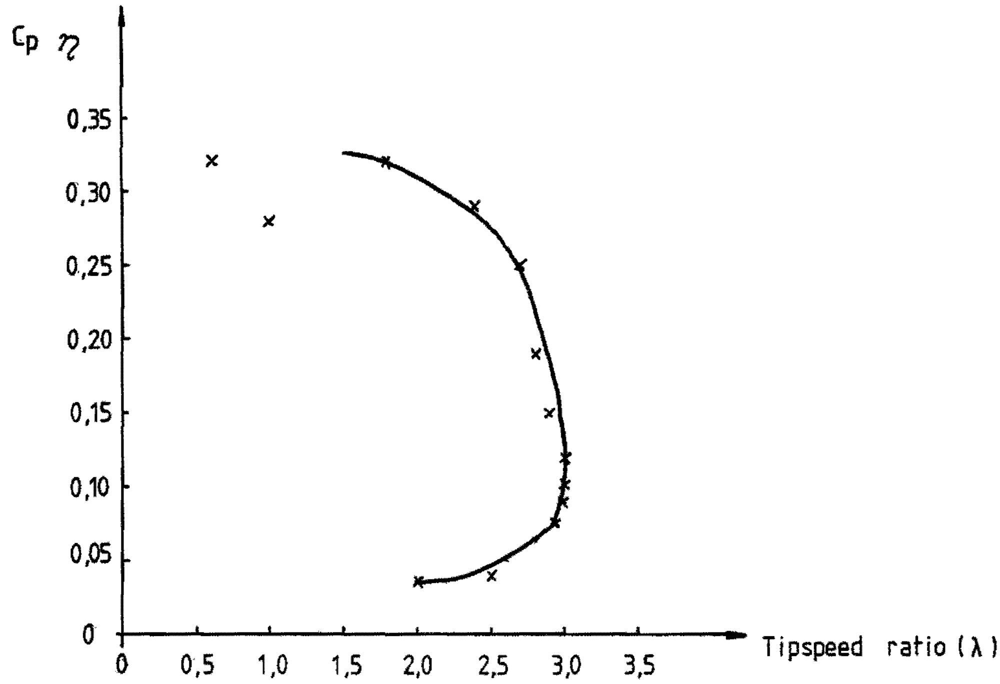


Figure 10: The overall power coefficient as a function of the tipspeed ratio. This curve is drawn from Figure 6 and Figure 7

3.2. First order trouble shooting

Before we will discuss the previously shown measurements we first will mention some items, which have influenced the reliability of the measurements.

1. In dismantling the pump for the winter it appeared, that the rubber disk of the foot valve was worn out. This explains why the pump was leaking when the mill was standing still. This was seen on the pressure indicator gradually dropping to zero.
2. Because the pump was leaking, the delivery height was less than the presetted delivery height of 15 m. In performing the calculations however a constant delivery height of 15 m was assumed. Especially when the wind speed is low, this effect is important and leads to an over estimate of the C_p η values. For this reason all measured $C_p \eta > 0.4$ (see 3.1.) were objected.
3. At high wind speeds, the pressure indicator was oscillating between 12 and 17 m of water. To avoid this in future, the pressure indicator should be placed on the pressure vessel instead of close to the pump. Also a gauge-glass on the vessel will be very useful (see Figure 1).
4. The meter was full of organic compounds (leaves etc.) which causes extra resistance of the pipe line. This can be avoided by putting a filter just before the watermeter. It must be possible to clean this filter easily.
5. The wind speed indicator gave few counts resulting in a high inaccuracy at low wind speeds. Another wind speed meter (for example a "Maximum" anemometer) will solve this.
6. At low rpm of the wind mill, the water was going to and fro in the pipes. This caused extra pulses recorded by the water meter each time the small magnet passes the read-switch. This can probably be avoided by putting the water meter down-stream of the pressure vessel.
7. Too few measurements were performed, especially at high wind speeds. This will cause high inaccuracy for these high wind classes.
8. By ignoring the high C_p values as well as the low values it is doubtful wether the resulting values are correct. To ignore the high C_p values can be correct but to ignore the low values (zero values) is not always correct. The difference in number of measurements between all measured periods and the "reliable" periods is shown in Figure 11.

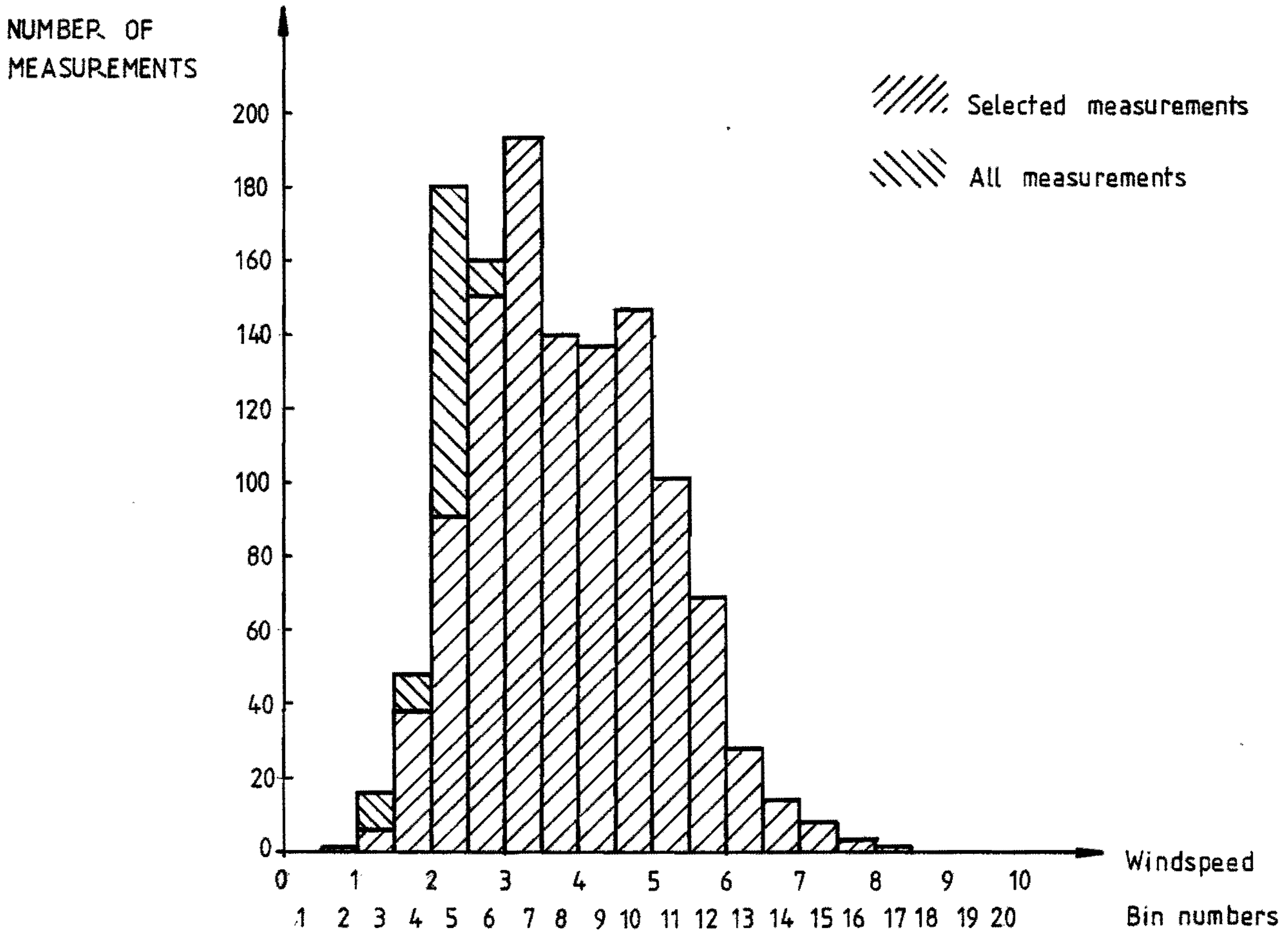


Figure 11: The difference between the number of all measurements and the selected measurements

4 DISCUSSION

4.1. Theoretical model and comparison with the measurements

Before we will discuss the results of the measurements we first will derive a theoretical curve, with which we can compare the measured values.

In fact there are two ways of predicting the power versus wind speed curve (which is the most important curve).

1. Based on the theory as described in [4] and [5]. In this model the C_p-λ curve is described by a quadratic curve and the pump as a constant torque load.
2. Combining a -in the wind tunnel- measured C_p-λ curve of a rotor with the rps-wind speed curve and assuming a constant η-value equal to 0.75 (generally accepted value for pump efficiency).

Starting with the first possibility we find in [5] that we need the following quantities: design wind speed (V_D), the ratio lambda maximal, lambda optimal (L), the maximal total energy efficiency ($C_p \eta_{max}$) and the sweptarea of the rotor (A). The value of the design wind speed V_D can be found as described in [6]. This gives for this design wind speed 4 m/s (for detailed values see Appendix D). The value of L is 1.8 and for $(C_p \eta)_{max}$ = 0.24 (see Figure 13). These two values can be found in [7]. Although [7] refers to the THE I/2 rotor, it is assumed that the WEU I/3 rotor has the same characteristics. For the pump efficiency a value of 0.75 is taken, which is a generally accepted value. The following formula, which describes the output curve, can be derived.

$$P = \left\{ L \frac{V_D}{V}^{2} - (L-1)(\frac{V_D}{V})^{4} \right\} 1/2 \rho V_D^3 A (C_p \eta)_{max}$$

Writing this as a dimensionless formula and complete it with the specific values give

$$C_p = 0.24 \left\{ 1.8 \left(\frac{4}{V} \right)^2 - 0.8 \left(\frac{4}{V}\right)^4 \right\}$$

This formula is drawn in Figure 12 (curve I). Also the curve is drawn with a design speed of 3 m/s and a $(C_p \eta)_{max}$ of 0.30, which corresponds more to the measured results (curve II).

Another possibility to derive a C_p-V curve is with aid of the C_p-λ curve (from [7]) and figure 9. We suppose here that the pump has a constant efficiency of 75%. In figure 13 the C_p-λ curve is shown as presented in [7].

Curve III plotted in Figure 12 is the result of the derivation. The deflection of the line for wind speeds higher than 5 m/s is the result of the safety system. When the wind speed is higher than 5 to 6 m/s the rotor is turned out of the wind.

For a rotor in yaw the C_p value will be less than the value for which the rotor is perpendicular to the wind. The theoretical curve III in Figure 12 is based on the C_p-λ curve without yaw, so the C_p values are too high. In Figure 12 we can also draw the measuremed C_p-V curve; this gives curve IV.

We see now that the measured curve fits fairly well with curve II and curve III, and curve III fits fairly well with curve II, at least at low wind speeds.

An important question is now, how it is possible, that curve 1, the curve based on a design speed of 4 m/s does not fit at all to the measured curve.

First of all we must have a look at Figure 5. There we see, that the volumetric efficiency is 60% - 55%. This is quite low, compared to values of 80% - 90% which are usually accepted. One of the explanations can be the leaking piston and foot valve. If we also accept then that the energetic efficiency will be 60% - 55%, then we find for the design wind speed 3 instead of 4 m/s. We can explain this as follows.

The low volumetric efficiency can be regarded as a 60% smaller stroke. The formula for the design speed contains the stroke to the power of one half

$$V_D \sim (s)^{1/2}$$

Because the root of 0.60 is about 0.8 this gives for V_D 3 instead of 4 m/s. It is very remarkable that from Figure 13 and Figure 9 also follows a design speed of about 3 m/s.

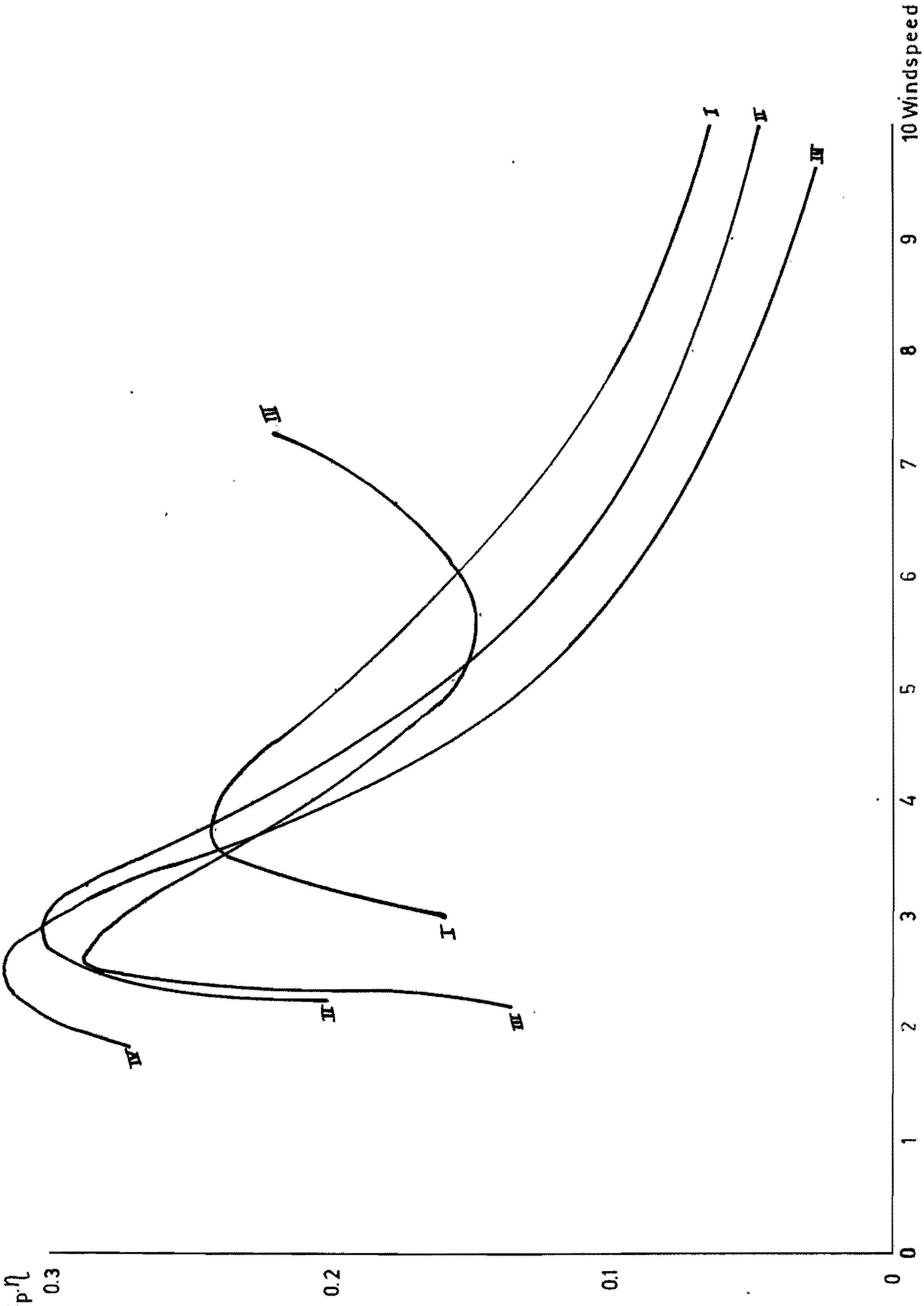


Figure 12: The theoretical and measured curves for the output of the wind mill

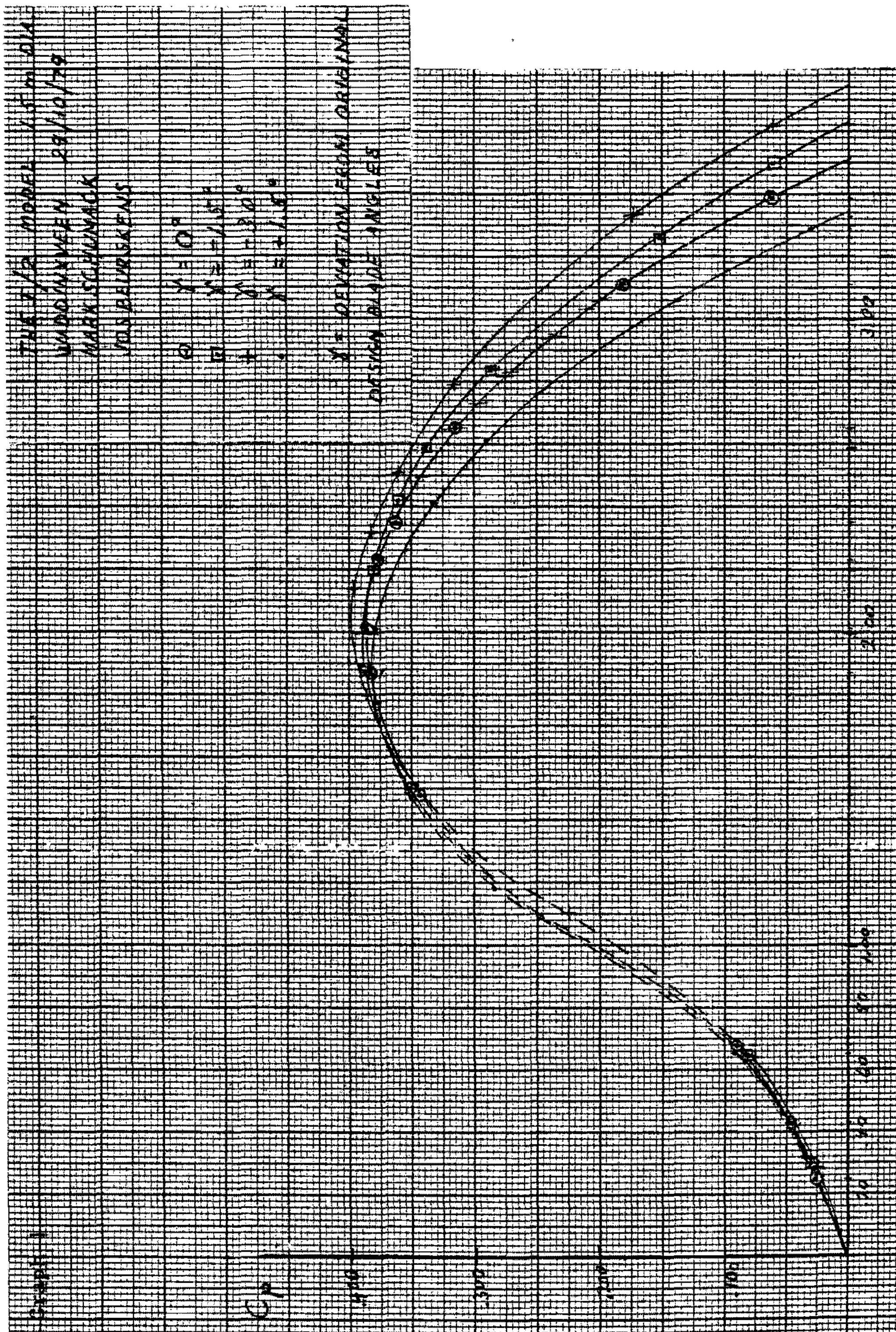


Figure 13: The cp-λ curve for the THE I/2 wind mill. It is supposed, that the WEU I/3 rotor has the same characteristics

4.2. Final remarks

As conclusion for the measurements as presented in this report we remark the following:

- The measuring method gives a good idea of the output of the wind mill. Typing the output (C_1 - C_4) for processing is however time consuming.
- In future one should consider the remarks of section 3.2. Especially the points 2, 3, 5 and 6 need attention.
- From Figure 12 it can be seen, that the measured curve can be predicted reasonably.
- One has to check in advance, whether the whole wind mill is in good condition (see point 1, section 3.2.).
- The whole wind mill system has a good efficiency when the wind speed is equal to the design wind speed ($C_p \eta$ = 0.32!).
- It is desirable that attention is paid to the fact, that measuring devices must be fastened to a prototype before the windmill is erected on the field.

REFERENCES

[1] **Digital data working up of wind mill measurements**
by P. Peters and P. van Heerenbeck (in Dutch)
Final study report Technical College Eindhoven April 1980

[2] **Experiences with the WEU-I prototype in Eindhoven**
by P. v.d. Does, A. Hageman, G. Hospers, N. Pieterse
Internal SWD report January 1980

[3] **International recommended practices for wind energy conversion systems testing** (concept 1981)
1. power performance testing
International Energy Agency Expert Group (concept 1981)

[4]* **The output of waterpumping wind mills in non-Weibull distributed wind regimes**
by E. Lysen (in Dutch)
Internal report R 396 D March 1980

[5]* **Output prediction for wind turbines in Weibull distributed wind regimes**
by E. Lysen
Internal report R 475 D April 1980

[6]* **Tentative calculations on the THE II design**
by A. Kragten (in Dutch)
Internal report R 410 D January 1980

[7]* **Results of Windtunnel Tests on the Scale Model of the THE I/2 Rotor**
by M. Schumack
Internal report R 408 S December 1979

* Internal report of the Wind Energy Group, laboratory of fluid dynamics and heat transfer, Department of Physics, University of Technology Eindhoven.

APPENDIX A

1. rpm measurements

On the axis of the WEU I/3 wind mill a disk was fastened with one slit on the circumference. This slit is situated in such a manner, that when the crank is in the highest position, the slit passes the opto-coupler*. Each time the slit passes this sensor the light falls on the cell and a pulse signal is generated. These pulses are counted in an electronic circuit which is situated in the central apparatus.

2. water quantity measurements

These measurements are done with a commercial waterflow meter. In this flow meter a read-switch is mounted on a dial, so with every litre of pumped water one contact is made. A bounce-free circuit was made and fed from the central apparatus.
The make of the water meter was: Pollux SPX.
The type number was M-N 20 (x) ZK-1.

3. wind run measurements

For these measurements a Casella cup anemometer is used. The internal gearing is such, that per 100 meter wind which passes the anemometer one pulse is given by a read-switch. The signals are counted in the central apparatus in the same way as the pulses of the water meter.
The make and type of the anemometer were: Casella; W 1254/2.

4. Measurement of the yaw angle

These measurements are done with a wind vane that was mounted on the head of the wind mill. A potentiometer which was fed from the central apparatus gave a signal varying from zero to twelve volts. When the rotor was perpendicular to the wind, the potentiometer gave six volts.

* This position is chosen to avoid double counting when the wind mill oscillates around the bottom dead point.

A voltage controlled oscillator changed this signal into a number of counts. This was done in the following way:
each second a sample was taken from the potentiometer. This sample was translated into a number of pulses and summed in the according memory. The number of pulses generated when the wind mill was yawed 10 degrees to the wind is 10 pulses each second. The conformity of yaw angle and number of pulses generated is shown in Figure 14.

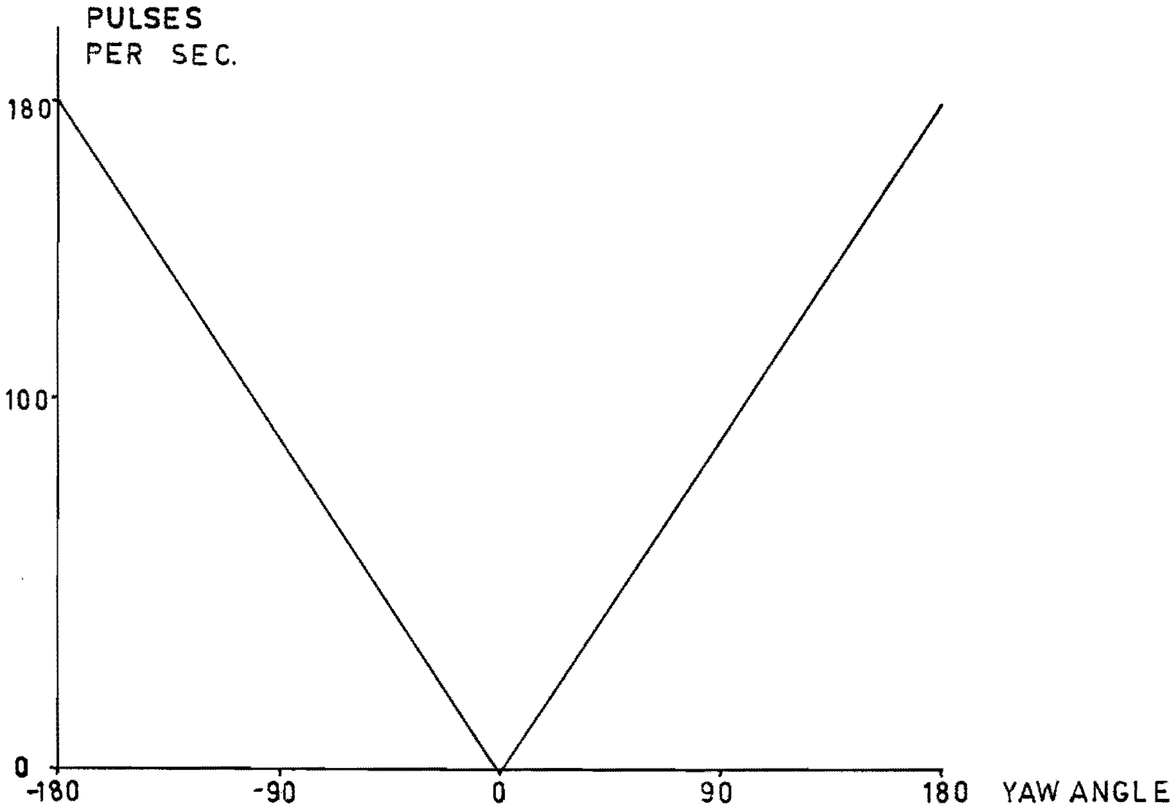


Figure 14: The conformity of voltage (as yaw angle) and the number of generated pulses

APPENDIX B

Example of calculations belonging to measurements of ten minutes.

$T_1 = 13$ $\rho = 1.25$ kg/m³ $g = 9.81$

$T_2 = 145$ Vol = 0.59229 l

$T_3 = 62$ H = 15 m

$T_4 = 8976$ R = 1.525 m

$V = 13 * 100/(10 * 60) = 2.17$ m/s

$P_{wind} = 1/2 * 1.25 * (2.17)^3 * \pi * (1.525)^2 = 46.45$ W

$P_{water} = 15 * 62 * 9.81/(10 * 60) = 15.21$ W

$\eta_{vol} = 62/(145 * .59229) = .72$

$C_p\eta = 15.21/46.45 = .33$

$\lambda = 2 * \pi * 145 * 1.525/(100 * 12) = 1.07$

$\delta = 8976/(10 * 60) = 14.96°$

$n = 145/(10 * 60) = 0.24\ s^{-1}$

Q = 62 l

Further for each value the squared value was calculated.
This was done to calculate the standard deviation with the formula

$$\sigma = \frac{\overline{X^2} - \sum_{i=1}^{N} X_i^2}{N}$$

Before summing a measurement into the corresponding bin, one can check if the values are acceptable. For our measurements all measurements with a overall power coefficient above 40% were omitted as well as measurements with a volumetric efficiency higher than 100%. Now the bin number was choosen according to the wind speed. In this case is the fifth bin C, 0-0.99 m/s-, 1st bin;0.5-0.999-, 2nd bin, etc.). Now each value was summed in its according bin and also the total numbers which are summed are put in a bin.

If all measurements are processed on this way the mean values of each bin, and the standard deviation, is calculated and printed.

The programme, used for analysing the data.

```
1000 OPEN5,4,2:OPEN6,4,1:OPEN7,4
1010 PRINT#5,"  999   9999.9999   999.9999    9999"
1020 PRINT"▒"
1030 POKE59468,14:DIMA(10,100)
1040 PRINT" PROGRAMMA TER VERWERKING "
1050 PRINT" VAN WINDMOLEN GEGEVENS.  "
1060 PRINT" GESCHREVEN DOOR :        "
1070 PRINT"          R.BISSCHOPS     "
1080 PRINT" T.B.V. WINDENERGIE GROEP "
1090 PRINT"         V.T.F.GEB.W&S    "
1100 PRINT"         ▒▒▒▒▒ ▒▒▒"
1110 PRINT"           ▒  ▒  "
1120 PRINT"           ▒▒▒▒▒▒"
1130 PRINT"           ▒  ▒  "
1140 PRINT"           ▒  ▒▒▒"
1150 PRINT"  TECHNISCHE HOGESCHOOL    "
1160 PRINT
1170 PRINT"  POSTBUS 513              "
1180 PRINT"  5600 MB EINDHOVEN        "
1190 PRINT"  #3 30 DECEMBER 1981      "
1200 FORR=1TO4000:NEXT
1210 DIMF$(62)
1220 REM***HOOFDPROGRAMMA***
1230 PRINT"▒WENST U INSTRUCTIES J/N?"
1240 GETA$:IFA$="J"THEN1270
1250 IFA$="N"THEN1420
1260 IFA$<>"N"ANDA$<>"J"THEN1240
1270 PRINT"▒DIT PROGRAMMA VERWERKT MEETGEGEVENS."
1280 PRINT"ER WORDEN STEEDS 4 TELLERSTANDEN GE-"
1290 PRINT"VRAAGT."
1300 PRINT"GETALLEN WORDEN GEVOLGD DOOR'RETURN'."
1310 PRINT"VRAGEN WORDEN BEANTWOORD DOOR J/N IN "
1320 PRINT"TE TYPEN."
1330 PRINT"U KUNT EEN TUSSEN OUTPUT VRAGEN."
1340 PRINT"DE MOGELIJKHEID GEGEVENS TE VERWIJDE-"
1350 PRINT"REN BESTAAT OOK."
1360 PRINT"▒▒BEGRIJPT U DIT ?"
1370 GETA$:IFA$="J"THEN1420
1380 IFA$="N"THEN1400
1390 IFA$<>"J"ANDA$<>"N"THEN1370
1400 PRINT"▒▒▒▒NOGMAALS DAN !":FOR W=1TO1000:NEXT
1410 GOTO1270
1420 PRINT"▒EERST WORDEN GEGEVENS OPGEVRAAGD."
1430 FORW=1TO1500:NEXT
1440 GOSUB1970
1450 PRINT"▒U KUNT NU :"
1460 PRINT"   A-NIEUWE TELLERWAARDEN GEVEN.
1470 PRINT"   B-GEGEVENS VERWIJDEREN.
1480 PRINT"   C-TUSSEN OUTPUT VRAGEN.
1490 PRINT"   D-HET PROGRAMMA BEEINDIGEN.
1500 PRINT"   E-GEGEVENS VAN BAND VERWERKEN.
1510 PRINT"▒▒UW KEUZE IS ?"
1520 GETA$:IFA$="A"THEN1580
1530 IFA$="B"THEN1670
1540 IFA$="C"THEN1720
1550 IFA$="D"THEN1740
1560 IFA$="E"THEN2930
1570 GOTO1520
```

```
1580 GOSUB2190
1590 GOSUB1810
1600 IFQTHEN1620:REM**ONGELDIGE WAARDE**
1610 GOTO1640
1620 PRINT"▮▮▮LAATSTE METING IS ONGELDIG.":FOR W=1TO1000:NEXT
1630 GOTO1660
1640 GOSUB2100
1650 GOSUB2130
1660 GOTO1450
1670 GOSUB2190
1680 GOSUB1810
1690 GOSUB2100
1700 GOSUB1750
1710 GOTO1450
1720 GOSUB2460
1730 GOTO1450
1740 PRINT"▮▮▮▮O.K. TOT ZIENS.":END
1750 REM***KLASSE VAKKEN HERSTELLEN***
1760 FORU=1TO7
1770 A(U,I)=A(U,I)-B(U)
1780 A(U,I+1)=A(U,I+1)-(B(U)↑2)
1790 NEXT:A(10,I)=A(10,I)-1:AM=AM-1
1800 RETURN
1810 REM***BEREKENINGEN 7 GROOTHEDEN***
1820 AM=AM+1
1830 IFT1<1ORT2<1ORT3<1ORT4<1THEN1940
1840 B(1)=T1*100/(T*60)
1850 B(2)=.5*M*(B(1)↑3)*(22/7)*(R↑2)
1860 B(3)=T3*H*9.81/(T*60)
1870 B(4)=T3/(T2*V)
1880 B(5)=B(3)/B(2)
1890 B(6)=44*T2*R/(T*60*7*B(1))
1900 B(7)=T4/(T*60)
1910 B(8)=T2/(T*60)
1920 B(9)=T3*V
1930 GOTO1960
1940 OM=OM+1
1950 Q=1
1960 RETURN
1970 REM***OPVRAGEN GEGEVENS***
1980 PRINT"▮"
1990 INPUT"MEETTIJD                 ";T
2000 INPUT"OPVOERHOOGTE BEDRAAGT    ";H
2010 INPUT"LUCHTDICHTHEID           ";M
2020 INPUT"ROTOR DIAMETER           ";R
2030 INPUT"POMPVOLUME               ";V
2040 PRINT"▮▮CONTROLEER DEZE GEGEVENS!!"
2050 PRINT"▮O.K.?";
2060 GETA$
2070 IFA$="J"THENRETURN
2080 IFA$="N"THEN1970
2090 GOTO2060
2100 REM***INDELEN IN KLASSEN***
2110 I=INT((B(1)/.25))*2+1
2120 RETURN
2130 REM***KLASSE VAKKEN AANVULLLEN***
2140 FORU=1TO9
2150 A(U,I)=A(U,I)+B(U):REM***SOM X***
2160 A(U,I+1)=A(U,I+1)+(B(U)↑2):REM***SOM X↑2***
2170 NEXT:A(10,I)=A(10,I)+1:REM***COUNTER***
2180 RETURN
```

```
2190 REM***LOFENDE PRINT OUT, OPVRAGEN NIEUWE WAARDEN***
2200 PRINT"■"
2210 IFQ=1THENPRINT"■LAATSTE METING ONGELDIG"
2220 PRINT"LAATSTE TELLERWAARDEN :"
2230 PRINT"TELLER 1:";T1:PRINT"TELLER 2:";T2
2240 PRINT"TELLER 3:";T3:PRINT"TELLER 4:";T4
2250 PRINT"■INGEDEELD IN KLASSE:"(I+1)/2
2260 PRINT"AANTAL WAARNEMINGEN TOT NU";AM
2270 PRINT"WAARVAN ONGELDIG            ";OM
2280 PRINT"LAATST BEREKENDE WAARDEN:"
2290 PRINT"V-WIND IN M/S        :";B(1)
2300 PRINT"P-LUCHT IN WATT      :";B(2)
2310 PRINT"P-WATER IN WATT      :";B(3)
2320 PRINT"ETA-VOLUMETRISCH     :";B(4)
2330 PRINT"CP-ETA               :";B(5)
2340 PRINT"LAMBDA               :";B(6)
2350 PRINT"SCHEEFHOEK IN GR.    :";B(7)
2360 PRINT"■NIEUWE STAND TELLER 1";:INPUTT1
2370 PRINT"              TELLER 2";:INPUTT2
2380 PRINT"              TELLER 3";:INPUTT3
2390 PRINT"              TELLER 4";:INPUTT4
2400 Q=0
2410 PRINT"ZIJN DEZE WAARDEN CORRECT ?";
2420 GETA$
2430 IFA$="J"THENRETURN
2440 IFA$="N"THEN2190
2450 GOTO2420
2460 REM***PRINT OUT***
2470 PRINT"■U WENST ?"
2480 PRINT"   1-KLASSE <> V-WIND"
2490 PRINT"   2-KLASSE <> P-LUCHT"
2500 PRINT"   3-KLASSE <> P-WATER"
2510 PRINT"   4-KLASSE <> ETA-VOL."
2520 PRINT"   5-KLASSE <> CP-ETA"
2530 PRINT"   6-KLASSE <> LAMBDA"
2540 PRINT"   7-KLASSE <> FOUTHOEK"
2550 PRINT"   8-KLASSE <> TOERENTAL"
2560 PRINT"   9-KLASSE <> VERPOMPTE HOEV. WATER"
2570 PRINT"■■UW KEUZE ?";
2580 GETK:IFK<1ORK>9THEN2580
2590 K=INT(K)
2600 IFK=1THENA$="KLASSE <> V-WIND"
2610 IFK=2THENA$="KLASSE <> P-LUCHT"
2620 IFK=3THENA$="KLASSE <> P-WATER"
2630 IFK=4THENA$="KLASSE <> ETA-VOL."
2640 IFK=5THENA$="KLASSE <> CP-ETA"
2650 IFK=6THENA$="KLASSE <> LAMBDA"
2660 IFK=7THENA$="KLASSE <> FOUTHOEK"
2670 IFK=8THENA$="KLASSE <> TOERENTAL"
2680 IFK=9THENA$="KLASSE <> VERPOMPTE HOEV. WATER"
2690 PRINT"■■■■■UW KEUZE "A$
2700 PRINT#7,"■■■"
2710 PRINT#7,SPC(40)A$
2720 PRINT#7,"KLASSE      X-GEM.     ST.DEV.     AANT."
2730 Y=1:Z=79:GOSUB2780
2740 PRINT"■NOGMAALS VIDEO PRINT OUT ?";
2750 GETA$:IFA$="J"THEN2460
2760 IFA$="N"THENRETURN
2770 GOTO2750
2780 REM***HULPROUTINE VIDEO PRINT OUT***
2790 PRINT"■KEUZE :";A$
2800 PRINT#7,CHR$(17)CHR$(17)
```

```
2810 FORX=YTOZSTEP2
2820 IFA(10,X)<1THENA(10,X)=1E+20
2830 P1=(X+1)/2
2840 P=A(K,X)/A(10,X)
2850 S=(A(K,X+1)/A(10,X)-(P↑2)):S=S↑2:S=SQR(SQR(S))
2860 IFA(10,X)=1E+20THENA(10,X)=0
2870 P2=A(10,X)
2880 PRINT#6,P1,P,S,P2
2890 NEXT
2900 PRINT"RETURN ?"
2910 GETB$:IFB$="J"THENRETURN
2920 IFB$<>"J"THEN2910
2930 REM***VERWERKING BAND***
2940 PRINT"VERWERKING BAND GEGEVENS."
2950 PRINT"HET AANTAL GEGEVENS IN DE FILE IS";:INPUTAF
2960 PRINT"CONTROLEER OF DE JUISTE BAND;                "
2970 PRINT"        -AANWEZIG IS.                        "
2980 PRINT"        -EXACT KLAAR STAAT.                  "
2990 PRINT"  TYPE 'B' ALS O.K.!                         "
3000 GETA$:IFA$="B"THEN3020
3010 GOTO3000
3020 PRINT"DE GEGEVENS VERSCHIJNEN OP HET SCHERM.
3030 OPEN2,1,0,"NEU-GEGEVENS"
3040 INPUT#2,F$:PRINTF$
3050 N=0
3060 INPUT#2,A$:N=N+1
3070 B$=LEFT$(A$,6):C$=MID$(A$,7,6)
3080 D$=MID$(A$,13,6):E$=RIGHT$(A$,6)
3090 PRINTB$;SPC(2)C$;SPC(2)D$;SPC(2)E$;SPC(2)N
3100 T1=VAL(B$):T2=VAL(C$):T3=VAL(D$):T4=VAL(E$)
3110 Q=0
3120 GOSUB1810
3130 GOSUB3220
3140 IFQTHEN3170
3150 GOSUB2100
3160 GOSUB2130
3170 IFN=AFTHEN3190
3180 GOTO3060
3190 CLOSE2
3200 GOTO1450
3210 END
3220 REM***SUBROUTINE VOORWAARDEN***
3230 IFT3>.6*T2THENQ=1
3240 IFB(5)>.4THENQ=1
3250 IFB(1)=>3ANDB(1)<3.5ANDB(7)>20THENQ=1
3260 REM
3270 REM
3280 REM
3290 REM
3300 REM
3310 REM
3320 RETURN
READY.
```

APPENDIX D

The design wind speed.

From [5] we know that the design wind speed can be determined with the following formula:

$$V_D = \frac{sD^2 \rho_w \, g \, H \, \lambda_o}{4 \, (C_p \eta)_{max} \, \rho \, \pi R^3}$$

The symbols and their value are:

s	= stroke of the pump	0.57 m
D	= diameter of the pump	0.115 m
ρ_w	= water density	1000 kg/m^3
g	= gravitational acceleration	9.81 m/s^2
H	= delivery height	15 m
λ_o	= optimal lambda value	2
$(C_p \eta)_{max}$	= maximal energy efficiency	0.24
ρ	= density of the air	1.25 kg/m^3
R	= radius of the rotor	1.525 m

This gives for V_D the value 4 m/s.