WIND TURBINE DESIGN, MANUFACTURING AND TESTING

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I. INTRODUCTION

The principles governing the operation of the horizontal axis wind machine are well known, and for many years it has been possible to design specific machines for specific purposes, and they perform their duties very well. The wind turbine designer has the option to design the machine for the desired peak power levels, and also for the wind speed at which these power levels can be achieved. He can either design with large blade area and large pitch angles to give high starting torque and peak powers at relatively low rpm, or with two or three long slender blades and small angles to provide low torque in low speed winds but high efficiency and peak outputs when operating at high velocity ratios. In each case it is necessary to design the blades with the required shape, including a continuous twist about the longitudinal axis from the blade root to the blade tip. This means that while a particular blade is very well suited for one job it is neither suited for nor adaptable to the other job. Thus, each machine requires its own specific blade design, and generally each blade is designed and fabricated with a fixed length, twist rate, and pitch angle.

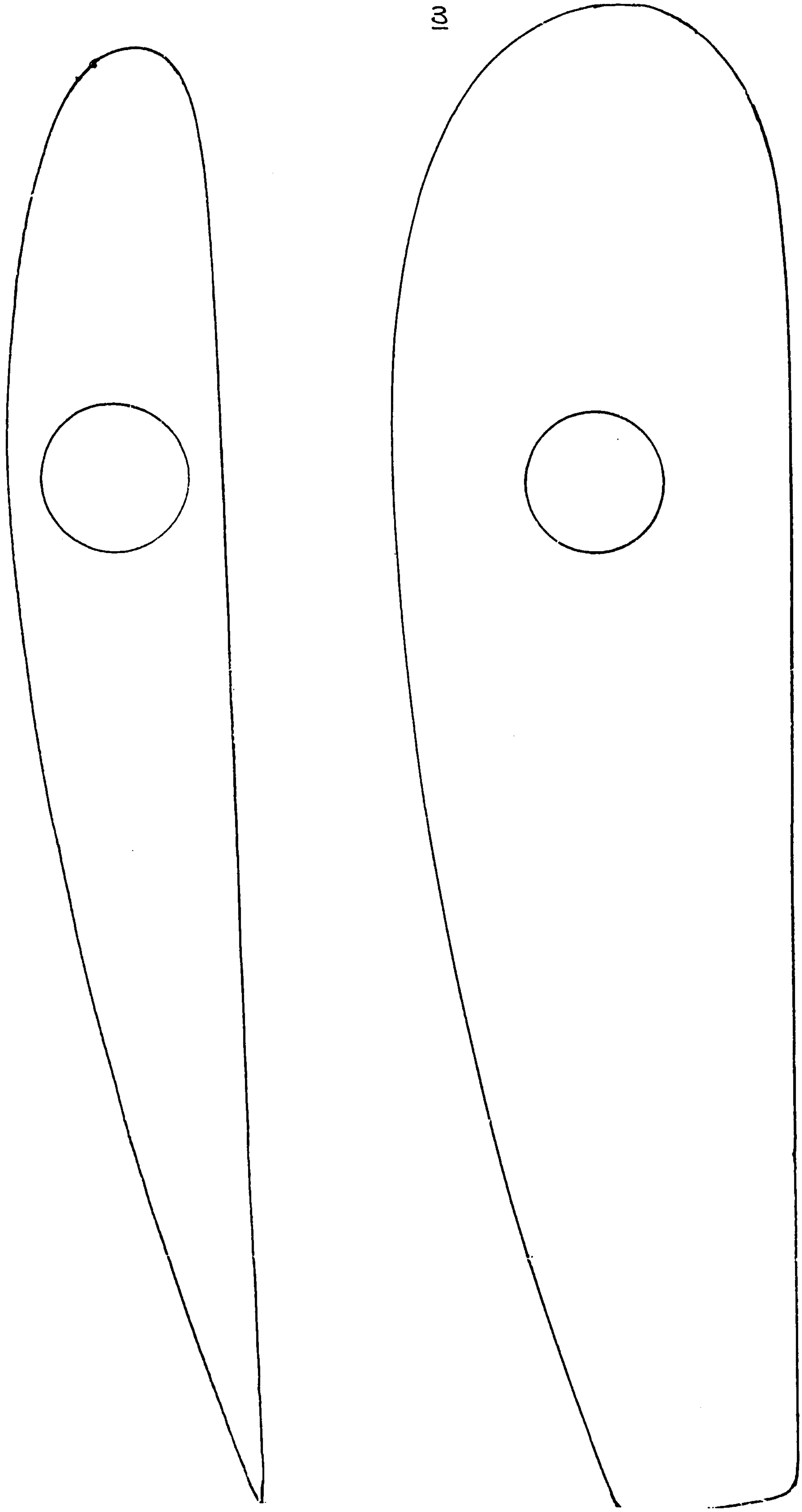
The construction presented in this report, the segmented blade turbine is aimed primarily at economics rather than aerodynamics It is not proposed that the segmented blade will give better performance than a continuously contoured blade for a particular application, but rather that the segmented blade will give the flexibility to allow the same inexpensive building blocks to be used for blades of a variety of applications.

2. Wind turbine design

The wind turbine was designed to be manufactured with simple technology, taking into consideration that the prevailing wind velocity in the middle east, especially in Egypt, Jordan and Turkey varied from 3-6 m/sec.

2.1 Design procedures

The turbine blade was designed from similar air foil segments, so that it is easy to manufacture them by mass production methods. This makes it possible to change easily the twist angle without changing the airfoil shape. Figure shows a cross section of the chosen airfoil (a) and its end plates (b)



This air foil is the NACA 4312 air foil with an angle of attack of 12 degrees and width of 11.65 inch. The end blades act has aerodynamic fences and rotate the individual segments into a series of effectively infinite aspect ratio wings. The following drawing Figure 2 represents the hub details on which the three blades of the turbine are fixed.

The wind speed will be simulated by a truck which also carries the measuring equipment. This truck limits, of course, the turbine diameter (the chosen turbine diameter was 13 ft.).

The maximum power P_{max} utilized from the wind power is not more than 0.59.

$$P_{max} = 0.59\ (1/2S\ A\ V^3)$$

S = Air density

A = captured area

V = Wind velocity

for medium speed machines the power coefficient cp (power produced by machine/wind power) ranges from 0.2 to 0.4.

The tip speed ratio T_R (tip velocity/wind velocity = RW/V) ranges from 2 to 5.

Assume tip speed ratio 3; for this tip speed ratio the number of blades is 2 or 3. Assume 3 blades, fig. 3 shows the design details of blade of the turbine.

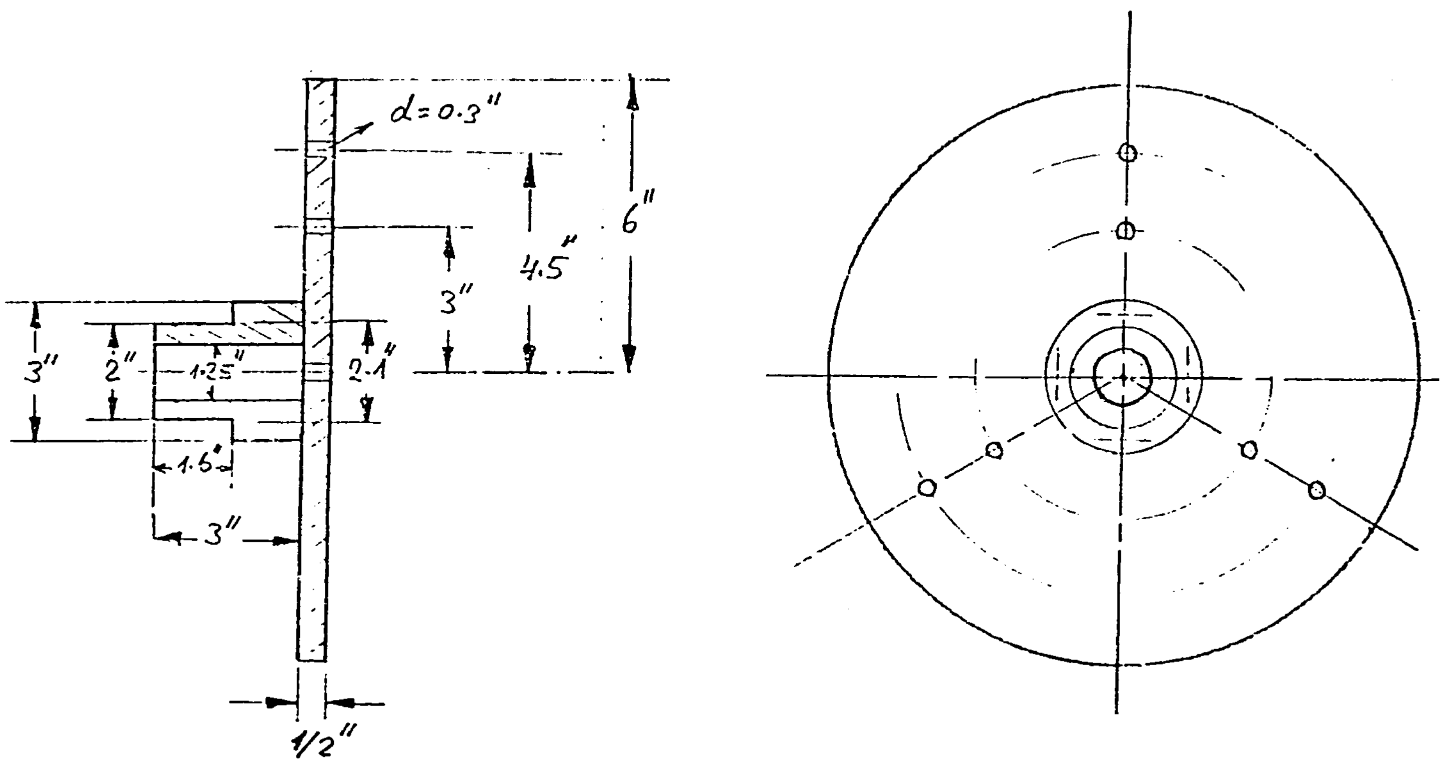
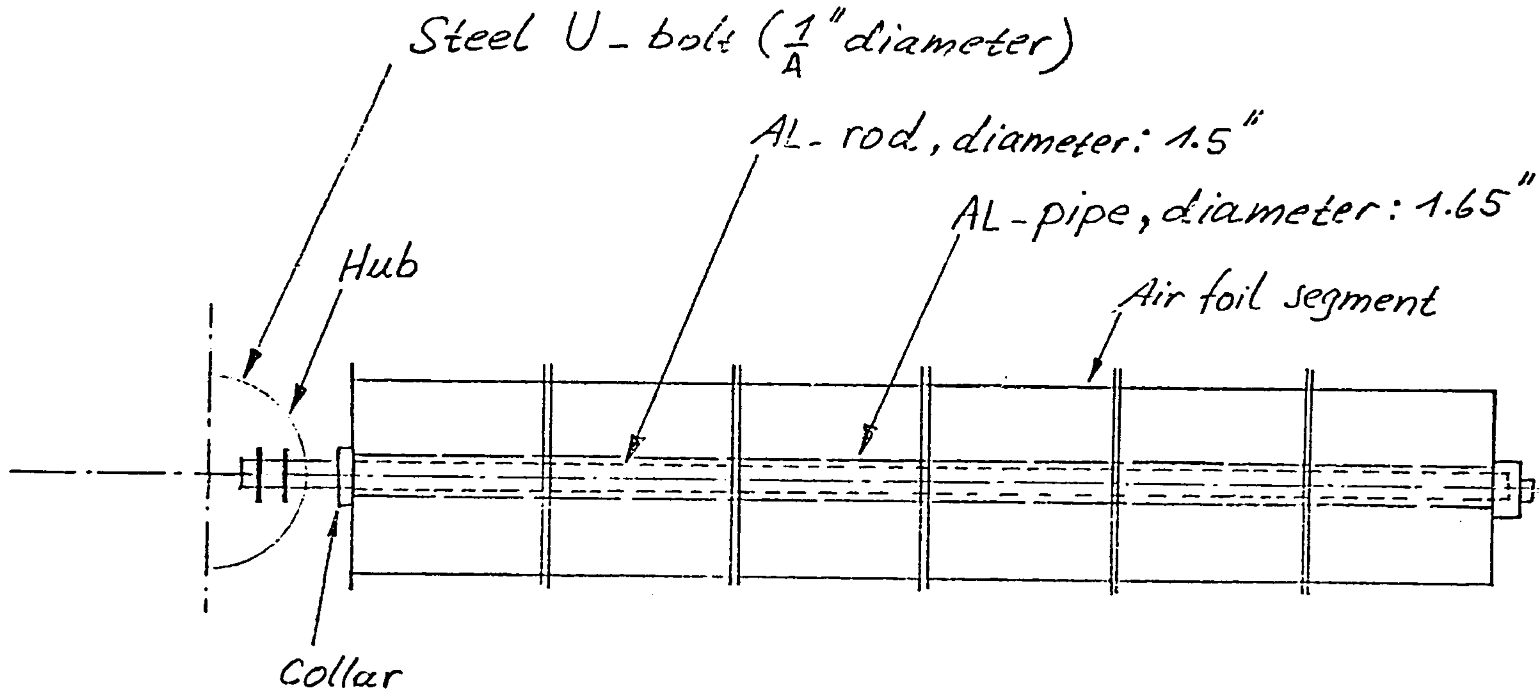


Fig. 2



Steel U-bolt (1/A" diameter)
AL-rod, diameter: 1.5"
AL-pipe, diameter: 1.65"
Hub
Air foil segment
Collar

Fig(3)

Assume also wind speed of 4.5 m/sec is equal to 14.8 ft/sec.

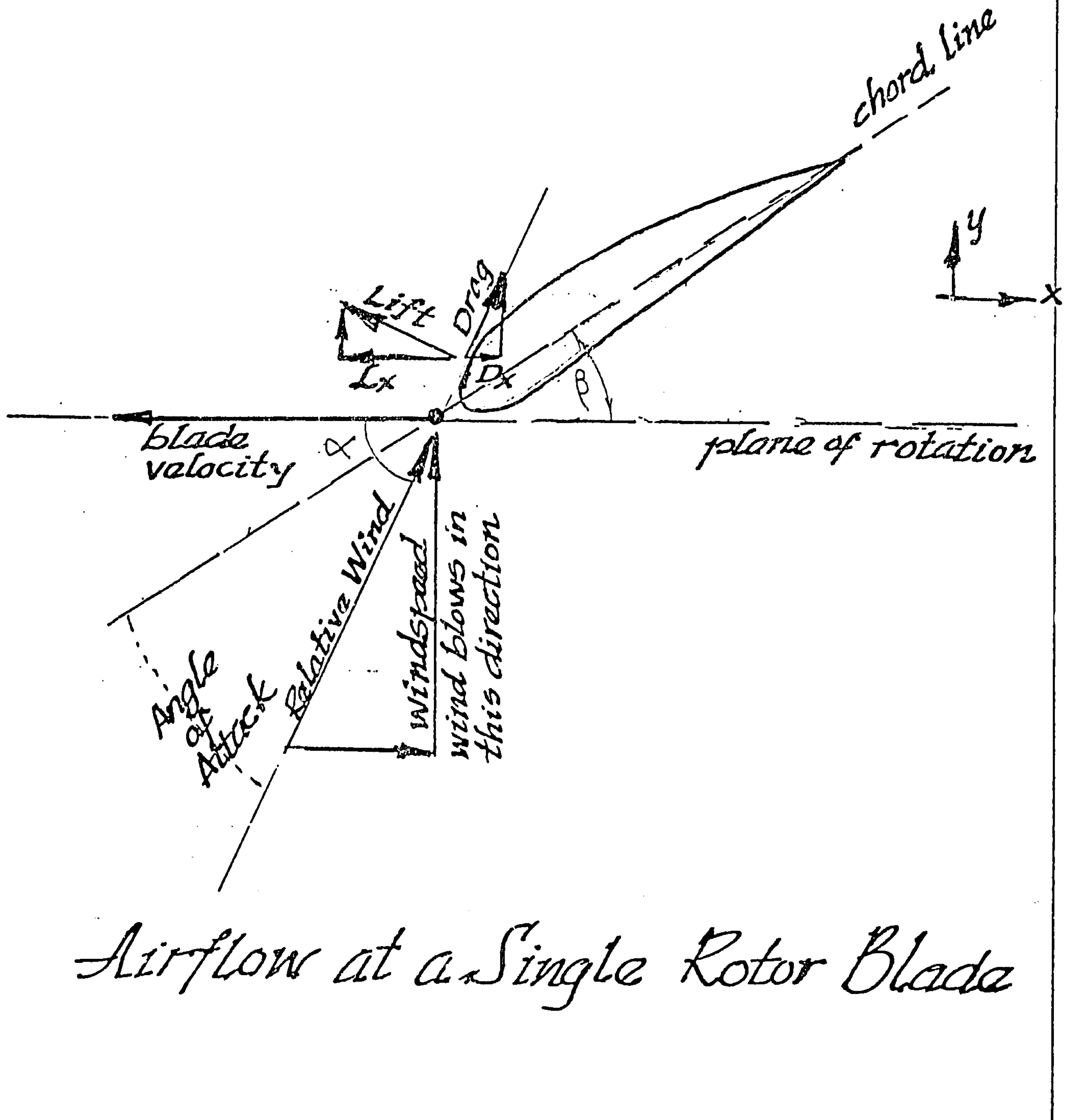
$$T_R = 3 = \frac{WR}{V}$$

W_S rotation speed of the wind turbine (rad/sec)
R_S turbine tip radius (ft)

$$W = \frac{3V}{R} = 3 \times \frac{14.8}{6.5} = 6.8 \text{ rad/sec.}$$

$$N = 6.8 \times \frac{60}{2\pi} = 65 \text{ rpm}$$

Figure 4 shows the attack angle and the twist angle of the air foil segment.



Airflow at a Single Rotor Blade

Fig.4

$$\tan\alpha = \frac{V}{RW}$$

= angle of apparent relative wind

Example: $R_1 \; XW = \frac{13.85}{12} \times 6.8 = 7.88$ ft/sec.

$$\alpha = 62°$$

$$\text{twist angle } \beta = \alpha - 12° = 62° - 12° = 50°$$

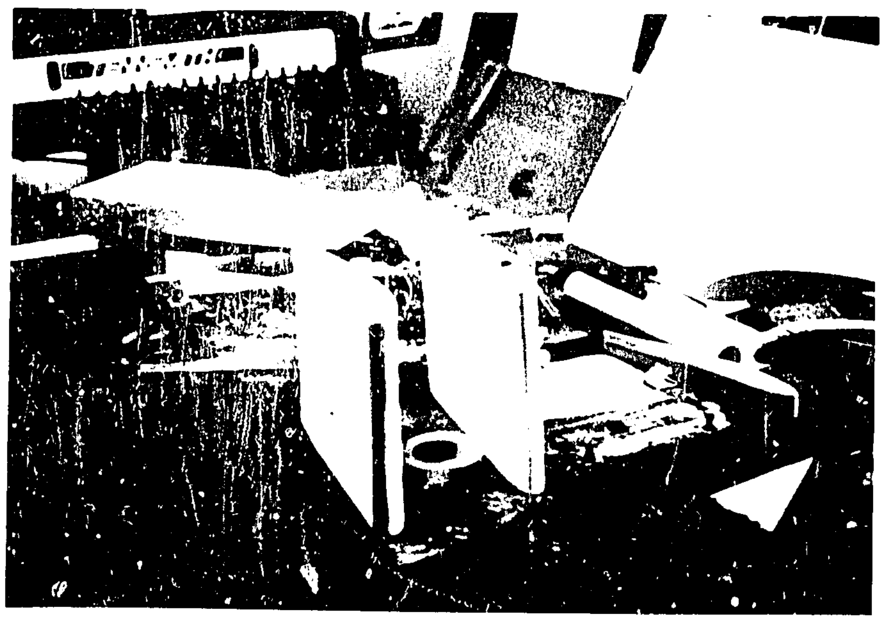
R_1 is the radius of rotation measured from the centre of the airfoil section. (Note that each turbine blade has six airfoil segments). The following table (1) represents the results of the twist angle's calculation.

radius/inch	RW (ft/sec)	α	β
R_1 = 13.85	7.88	62°	50°
R_2 = 25.55	14.54	45.6	33.6
R_3 = 37.25	21.2	35.0	23.0
R_4 = 48.95	27.86	28.0	16.0
R_5 = 60.65	34.52	23.27	11.27
R_6 = 72.35	41.18	19.83	7.83

TABLE (1)

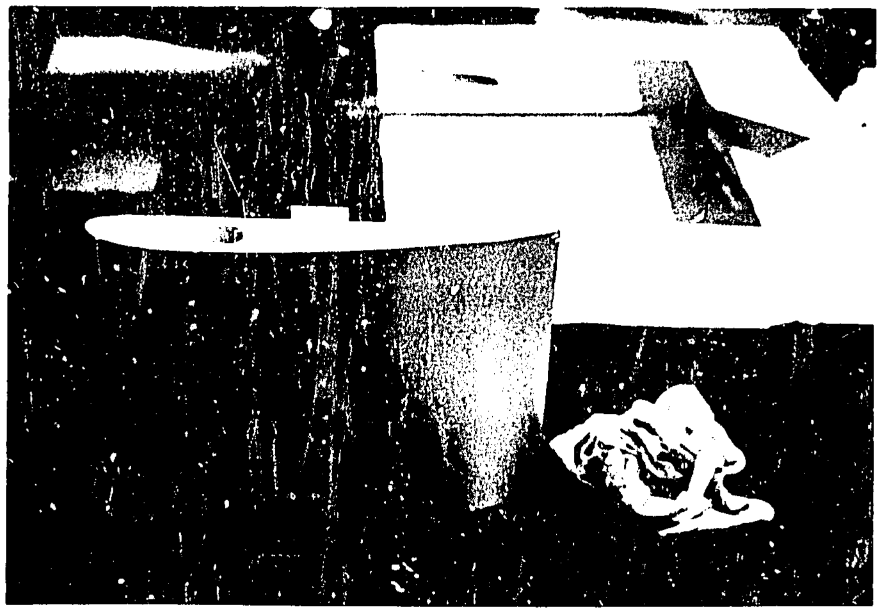
3. Manufacturing process:

- The air foil material is urethane foam, which was chosen because of availability, cheap, light and easy to manufacture.
- The cutting process was carried out with a thin blade saw using a wooden airfoil model.



- A hole was then cut through the approximate aerodynamic centre of the air foil section by using a pipe with a serrated end.
- The air foil sections were painted with a plastic paint (weather-shedder, gloss latex).
- The air foil sections were wrapped with aluminum sheet (0.008 inch thickness) which is available as a waste of the newspaper press (area: 31 x 22.6 inch). This was done by blind rivets and then applied a self-adhesive aluminum tape on the connections to provide protection from weather and ultraviolet rays.

- The end plates were made from aluminum-sheets (thickness 0.21 inch) and cemented to both sides of the air foil.



- The hub was made from aluminum (details are given in Fig. 2).
- Each six airfoil segments were mounted on an aluminum-pipe (diameter 1.625 inch) which is fixed on an aluminum-rod (diameter 1.5 inch). This rod is fixed to the hub with two U-bolts (bolts diameter 1/4 inch).
- The twist angle of each airfoil segment was adjusted according to Table 1. Now the wind turbine is ready to be mounted on the truck for testing.

4. Testing of the Wind turbine:

- The wind turbine was mounted on the truck and connected to a transmission system which connects the wind turbine to the electric generator. The testing equipments were mounted also on the truck.

- The electric circuit for the testing apparatus is shown in fig. 5.

The following variables were measured:

a. Wind velocity (truck speed in mph)

b. Output voltage of the generator,

c. Output Current of the generator, I

d. Turbine speed of rotation in rpm, N

The turbine was loaded by a set of parallel connected lamps of 250 watts each

TEST DATA

V mph	Load W	volt	I Amp.	N rpm	P_{Gen} W	P_{Wind} W	Cp %	T_R
20	250	13	16.8	17.4	218.2	5120	8.85	0.4
	500	12.5	9.3	16.66	116.34	5120	4.7	0.38
	1000	12.3	18.5	17.5	227.8	5120	9.26	0.4
25	250	13	33	19.2	429	10000	8.9	0.36
	500	13	47.8	20.8	622.5	10000	13	0.39
	1000	12.5	61.8	18.9	772.7	10000	16	0.35
30	250	13	110.5	23	1437.7	17280	17.3	0.36
	500	13	113.3	24.3	1473.3	17280	17.8	0.45
	1000	12.8	118.9	22.5	1521.4	17280	18.3	0.35
35	250	13.8	132.5	25	1828.7	27440	13.8	0.33
	500	13.2	155.6	24	2053.3	27440	15.6	0.32
	1000	13	179.7	25	2335.9	27440	17.7	0.33

WIND DATA INSTRUMENTATION

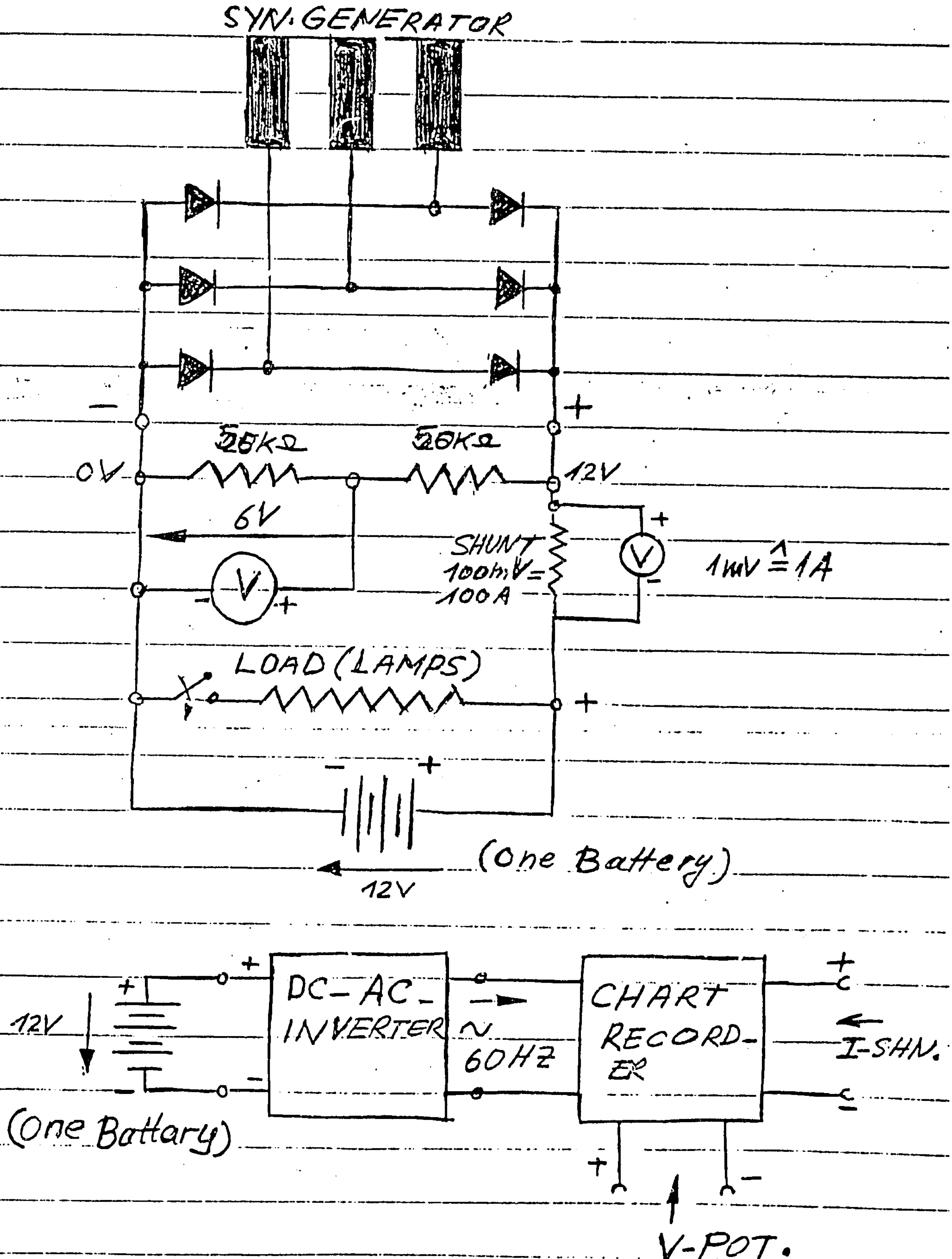
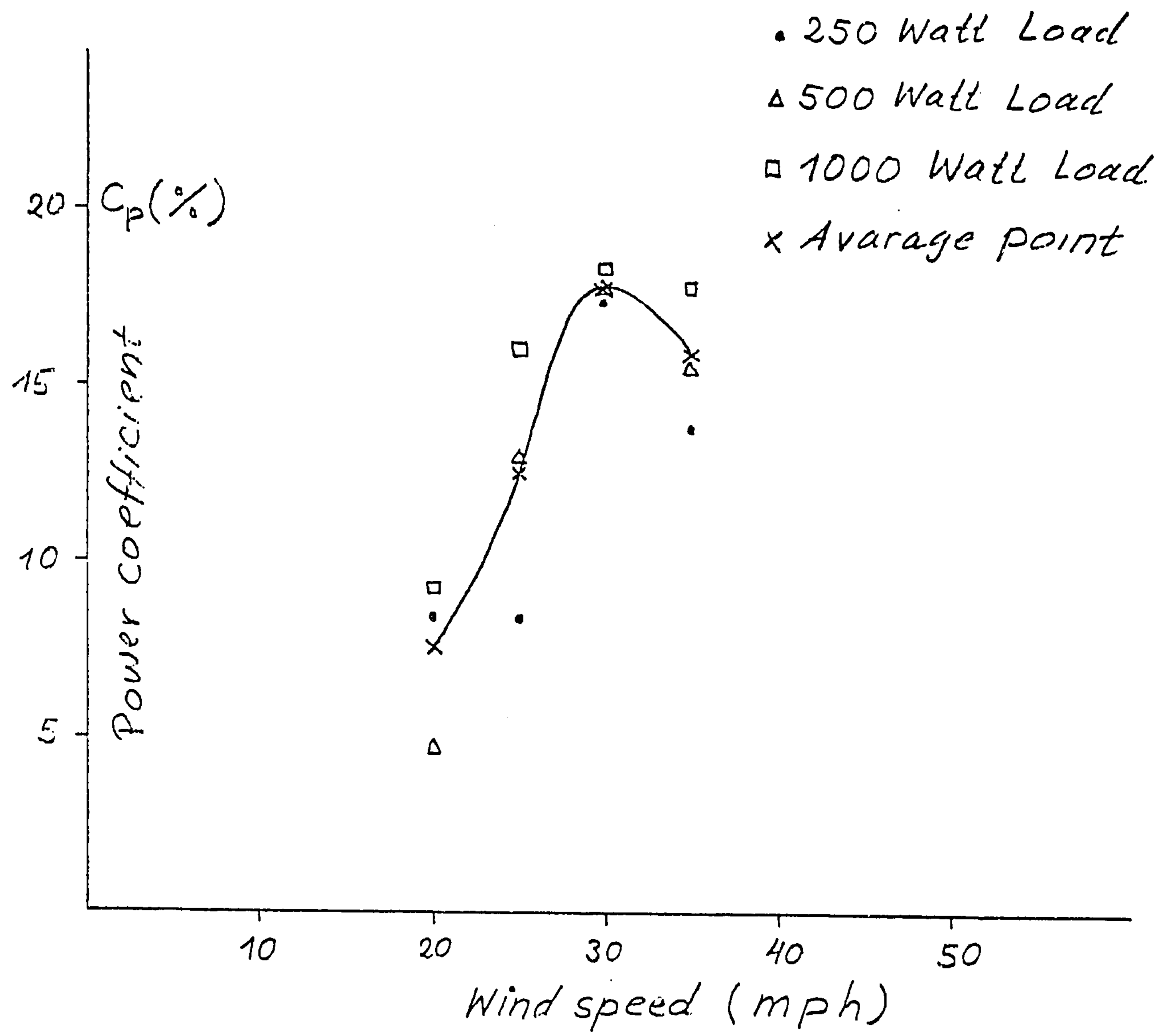


Fig. 5

Figure 6 shows the relation between wind speed and the power coefficient at different load conditions. It is clear that increasing wind speed will increase the power coefficient until a certain speed which in this case is 30 mph. At this optimal speed the variation of the load has little effect on the power coefficient. At a higher wind speed than 30 mph the power coefficient decreases.

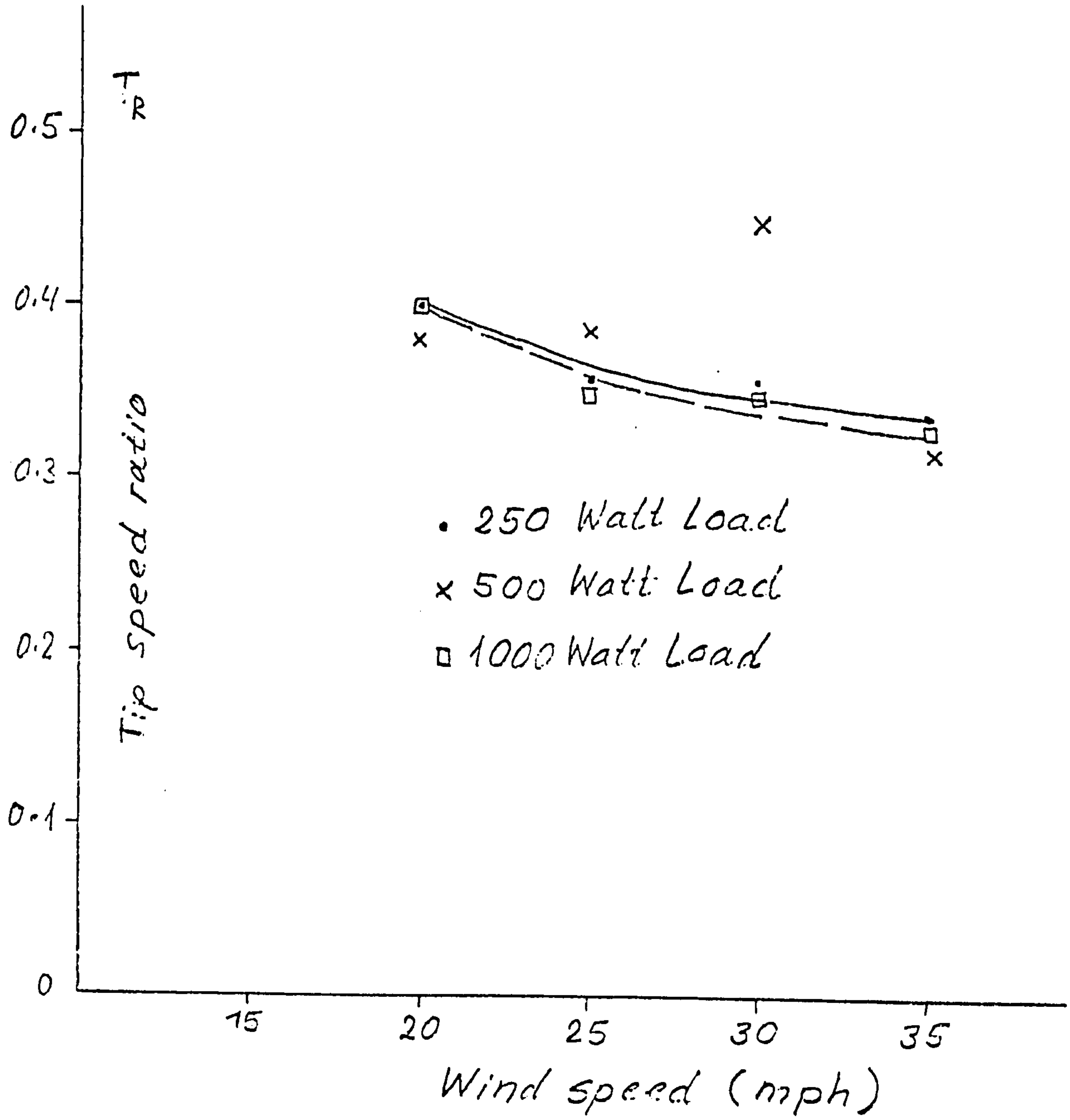
Figure 7 shows the relation between wind speed and tip speed ratio at different load conditions. It shows that increasing the wind speed has little influence on the tip speed ratio. Also, the change of the load has slight effect on the tip speed ratio. This means that this wind turbine is not sensitive for changing the load at a certain wind speed.

Figure 8 shows the output current of the generator as a function of wind speed where the load as a parameter. As expected the current increases with increase of the wind speed.



• 250 Watt Load
△ 500 Watt Load
□ 1000 Watt Load
× Avarage point
20
15
10
5
Cp(%)
Power coefficient
10
20
30
40
50
Wind speed (mph)

Fig.(6)



T_R
0.5
0.4
0.3
0.2
0.1
0
Tip speed ratio
• 250 Watt Load
x 500 Watt Load
□ 1000 Watt Load
15
20
25
30
35
Wind speed (mph)

Fig 7

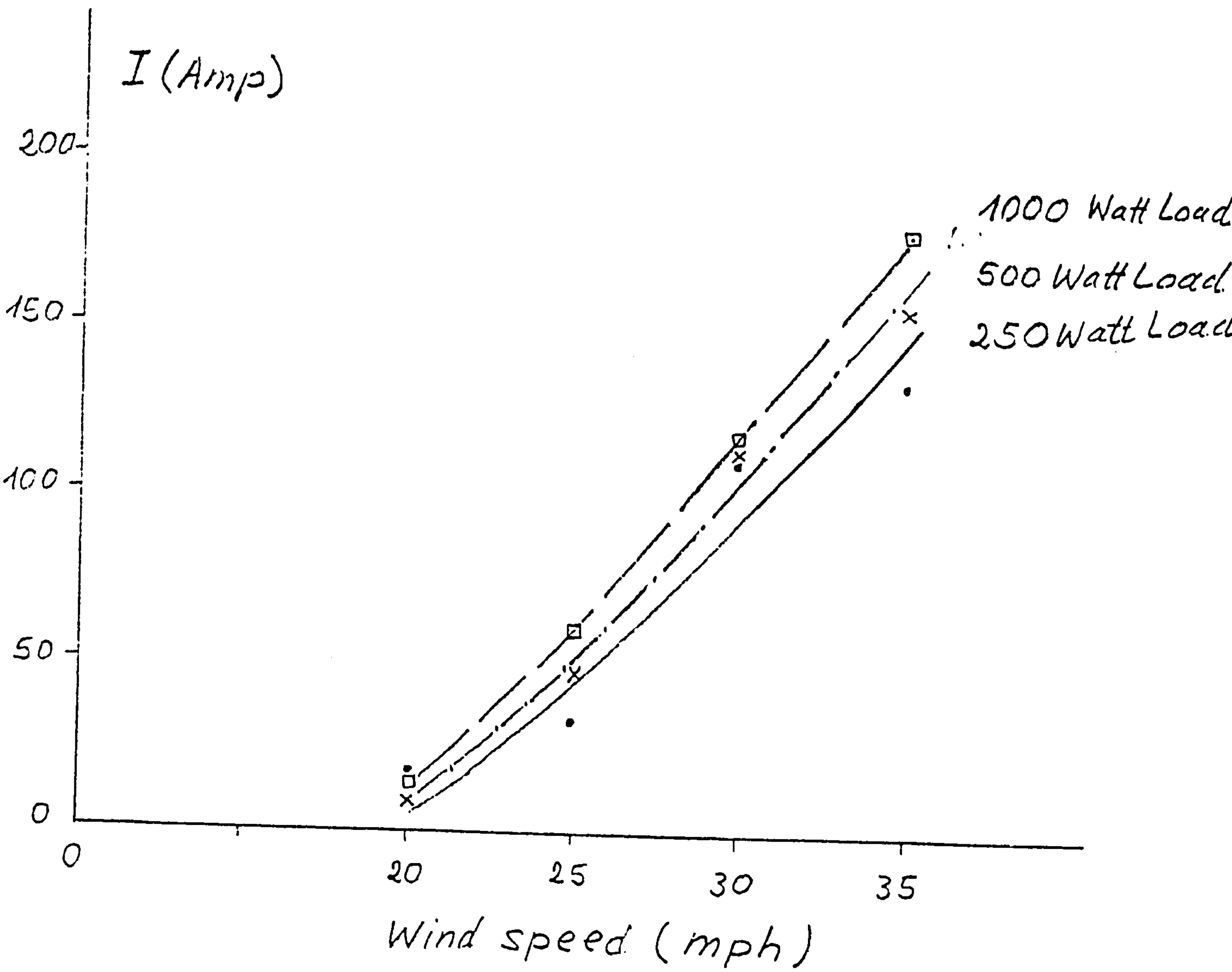

I (Amp)
200
150
100
50
0
0
20
25
30
35
Wind speed (mph)
1000 Watt Load
500 Watt Load
250 Watt Load

Fig. 8

5. Conclusion

This work has proved that it is possible to build a stable and power full wind turbine with simple technology.

During testing phases the wind turbine was run without load at more than 100 rpm.

It was found that this turbine, with the calculated angle of twist, does not produce electrical power at a wind speed lower than 20 mph.

In respect to the test conditions and the shortage of time, it was found that this wind turbine has an optimum power coefficient at 30 mph.

Placing in mind the previous conclusions, we suggest that the wind turbine should be tested at different angles of twist. Also the generator should be so chosen that its rated rpm fits the rated speed of the wind turbine. Also, the testing runs should be longer to have a stable wind turbine speed before loading.

The measuring equipment especially the battery which was inserted to give the generator its existing field should be carefully examined (the battery should be fully charged.)