DESIGN, FABRICATION AND TESTING OF A SAVONIUS TYPE WINDMILL WITH A DEFLECTOR AUGMENTOR

By

SATYAJITH MATHEW

THESIS

Submitted in partial fulfilment of the requirement for the degree
MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING
Faculty of Agricultural Engineering
Kerala Agricultural University

Department of Farm power Machinery and Energy
Kelappaji College of Agricultural Engineering and Technology
Tavanur - Malappuram
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DECLARATION

I hereby declare that this thesis entitled "Design, fabrication and testing of a Savonius type windmill with a deflector augmentor" is a bona fide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Tavanur,
1st June 1989

SATYAJITH MATHEW

CERTIFICATE

Certified that this thesis, entitled "Design, fabrication and testing of a Savonius type windmill with a deflector augmentor" is a record of research work done independently by Shri SATYAJITH MATHEW under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to him.

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CERTIFICATE

We, the undersigned members of the Advisory Committee of Shri SATYAJITH MATHEW, a candidate for the degree of Master of Science in Agricultural Engineering agree that the thesis entitled "Design, fabrication and testing of a Savonius type windmill with a deflector augmentor" may be submitted by Shri SATYAJITH MATHEW in partial fulfilment of the requirement for the degree.

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At this moment, I also do remember my parents whose help on this work I thankfully acknowledge.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SYMBOLS AND ABBREVIATIONS USED

A	-	Total area of the deflector
A^1	-	Effective wind facing area of deflector
bhp hr	-	Brake horse power hour
C_d	-	Coefficient of drag
CIAE	-	Central Institute of Agricultural Engineering
cm	-	Centimeter
C_p	-	Coefficient of power
C_q	-	Coefficient of torque
d_1	-	Inner diameter of the shaft
d_2	-	Outer diameter of the shaft
D	-	Diameter of the rotor
f	-	Safe stress
F	-	Net driving force
F_A	-	Force acting on the tight side of the belt
F_B	-	Force acting on the slack side of the belt
F_D	-	Drag force
Fig	-	Figure
G.I.	-	Galvanised iron

hp - Horse power

KAU - Kerala Agricultural University

kg/m^3 - Kilogramme per meter cubed

kg m/s - Kilogramme meter per second

km/hr - Kilometer per hour

KW - Kilowatt

kWh - Kilowatt hour

l/day - Litre(s) per day

l/hr - Litre(s) per hour

l/min - Litre(s) per minute

m - Meter

mm - Millimeter

m/s - Meter per second

M_{max} - Maximum bending moment

M_x - Bending moment at section 'XX'

N - Number of revolutions

Nos - Numbers

P_1 - Self weight of the foundation

P_2 - Downward load on the stay wires

P_3 Weight of the structure

P^1 - Power developed by the wind mill

P_T	-	Total power available at the rotor crosssection
PAU	-	Punjab Agricultural University
R	-	Radius of the rotor
R_1	-	Reaction at Point 1
R_2	-	Reaction at Point 2
r	-	Radius of brake drum
rpm	-	Revolution(s) per minute
Rs	-	Rupees
S	-	Second
T	-	Torque
t_{max}	-	Maximum torque
TNAU	-	Tamil Nadu Agricultural University
U	-	Wind velocity at the rotor
V	-	Volt
V_i	-	Initial wind velocity
V_o	-	Final wind velocity
ω	-	Angular velocity
Z	-	Section modulus
π	-	Pie $(\frac{22}{7})$
λ	-	Tip speed ratio
o	-	Degree
ρ	-	Mass density of air
ρ'	-	Weight density of air

INTRODUCTION

INTRODUCTION

1.1 Present energy situation

India consumes energy from various sources ranging from nuclear fuel to animal waste and from manual energy to animal energy. Major portion of the energy need is met by non-renewable energy sources. The non-renewable energy sources are running out. Moreover even at today's prices, it puts a considerable burden on the economy. This indicates the need of increasing the share of renewable energy sources.

A recent study has estimated that it should be possible to replace the diesel oil required for water pumping and rural industry by renewable energy sources by the year 2000. It may also be possible to replace fifty percent petroleum products required in the household and transport sectors. Some twenty-five percent of fuel oil and twenty percent of coal normally used for low and medium temperature heat can also be replaced by renewable sources. If appropriate policy measures are taken to bring about the replacement of the commercial energy sources by new and renewable energy sources, it may be possible to meet eighty-five percent of total energy demand in the year 2000 through non-commercial and renewable sources including hydro-power.

A wide variety of renewable energy sources are available for exploitation. These include hydropower, solar energy, bio-energy, wind energy, ocean energy and animal energy. The technologies to tap these renewable energy sources in relation with end uses are at different stages of commercialisation.

The energy associated with wind is enormous. Large quantities of energy are constantly transferred to the wind from the sun. It has been estimated that the total power capacity of the winds surrounding the earth is of the order of 10^{11} giga watts. This indicates the great potential of wind energy.

1.2 The Global attempt

Wind mills have a distinguished history that dates back many centuries. In olden days, wind mills were used for draining marshes, processing timbers, turning mill stones, pumping water and works of that sort.

Near the beginning of fourteenth Century, the Dutch had become the leading craftsmen in designing wind mills. By 1600 A.D., Holland introduced the wind power in paper and wood industry. In Denmark, towards the end of nineteenth Century, there were around 3,000 industrial wind mills and 30,000 other types in use for homes and farms. These had a total output power of about 200 mega watts.

More than six million wind mills have been used in United States since 1850 to pump water and to generate electricity. It is estimated that 1,50,000 are still in operation.

Large wind machines were used in other countries around 1955. Nearly 30,000 wind power plants were in operation in the U.S.S.R. The Gedser wind turbine was operated in Denmark untill the 1960's. It was giving 200 KW of electrical power, had a rotor of 27 m diameter and produced 4,00,000 KWH of electricity annually.

The world's interest in wind energy gradually declined in next 25 years following 1950 when the fossil fuels at a lower rate were available in abundance. However, recently it is attracting attention again for large scale energy production as the conventional fuels are becoming scarce. Feasibility studies have been initiated in a number of countries to assess the technical and economic problems of wind energy for different applications. The United States has undertaken an extensive wind energy conversion system programme with the primary objectives of developing a system capable of providing significant contribution to energy requirements by the year 2000. United Kingdom is currently conducting wind power studies that will affect the ultimate design of large scale operations. Commercial plans are in the making for a 60 KW wind power plant capable of directly converting mechanical energy to heat energy and coupled with latent heat storage devices. Other countries like Sweden, France, Canada, Netherlands etc. are also actively involved in feasibility studies aimed at evaluating wind energy conversion systems.

1.3 Status of wind energy in India

In India, systematic efforts for wind energy utilization began as far back as 1952 with the formation of a Wind Power Sub Committee under the Council of Scientific and Industrial Research. A conference on large scale utilization of wind power held in September, 1955 recommended installation of 500 wind mills for practical demonstration and testing. In 1959, National Aeronautical Laboratory, Bangalore, designed the wind mill model WP-2 which became available to interested users. Wind Power Sub Committee endorsed the manufacture of 200 wind mills and their installation by the end of Second Five Year Plan. A number of experiments were carried out on WP-2 wind mill and several modifications were made.

After many years, the work on wind mills were revived when a panel constituted by NCST in 1973 recommended setting up of 30 WP-2 wind mills in two clusters of 10 numbers each in Gujarat, Rajasthan and Pondicherry. During the last few years several experimental prototypes have been developed at different parts of the country.

It was noticed that there was significant variation in monthly average wind speeds, at most of the locations except those situated at the eastern part of the country and near the tip of Penisula. In general wind speeds are found higher in the months of April, May, June and July.

It is seen that peak irrigation requirement coincides with this period. This underlines the adaptability of wind energy in irrigation. In addition, availability of electricity and fuel is not adequate in rural areas. However, the technology has to be such that the surcharge output can be matched with the requirements of water pumping for various crop combinations.

There is a very good potential for using wind mills for water pumping in Kerala. A very exhaustive wind data collection from every nook and corner of the State is practically not possible. However Department of Farm Power Machinery and Energy, Faculty of Agricultural Engineering, Tavanur, has collected and analysed available data to study the feasibility of wind turbines in Kerala. Table 1 shows the potential places.

Table 1. Duration of useful wind in Kerala

Place	Duration of useful wind
Alleppey	12 months
Calicut	10-12 months
Cannanore	5-8 months
Vellanikkara	6 months

In addition to these, the Department of Science and Technology of State Government has indicated the following places having potential for wind energy utilisation.

1. Kottamala
2. Kuttipuram
3. Keeloor
4. Ambalapuzha
5. Moolathara
6. Pallissery
7. Dhanuvachapuram

1.4 Agricultural uses

Agriculture is a very appropriate field for wind power application, as it needs less amount of energy than other industries. Today there are 7,50,000 wind mills in United States operating in remote western range lands for agricultural uses. The use of wind energy for farm operations has a series of distinctive features:

a) It requires individual units or systems much smaller than that is needed for industrial uses.

b) Power requirement is less.

c) Continuous supply of power is not required.

1.5 Classification of wind mills

Wind mills are broadly classified as horizontal axis machines and vertical axis machines, according to their axis of rotation. Horizontal axis machines are further classified according to their number of blades. The major types of vertical axis rotors are savonius rotors and darrieus rotors.

1.6 Savonius wind mill

Savonius wind mill is a vertical axis system having 'S' shaped blades. It is basically a drag device. The Savonius rotor has received attention as a simple wind mill with a large potential for application in developing countries. Although the efficiency of this design is low, its ability to accept wind from any direction and the simplicity of construction are the major advantages that make Savonius rotators suitable for developing countries. Moreover, the power transmission is easier reducing the losses. The major disadvantage of Savonius rotor is its low power coefficient. At the optimum tip speed ratio, coefficient of power, 'Cp' may go up to 0.20. It is found advantageous to funnel or concentrate wind into the turbine from outside the rotor section. Concentrating structures fixed statically around the turbine draw the wind into the rotor. This type of concentrators are found to increase the coefficient of power, 'Cp' up to 0.50, at a tip speed ratio of 1.5. As the construction of concentrating structures are very costly, these are seldom used with Savonius rotors. The concept of a self orienting deflector augmentor has been introduced in this context. It has therefore been decided to undertake the design, development and testing of a Savonius wind mill with the following objectives:

a) Design Savonius wind mill to produce 0.2 hp at a wind velocity of 14 Kmph.

b) To fabricate the wind mill.

c) To determine power coefficient 'Cp' of the wind mill at various tip speed ratio.

d) To find out the torque coefficient C_q at various tip speed ratio.

e) To find out the optimum tip speed ratio.

The wind mill is tested with and without deflector augmentor.

REVIEW OF LITERATURE

REVIEW OF LITERATURE

A brief review of history, classification and work done on design, development and testing of wind mills is presented in this chapter.

2.1 History and classification of wind mills

2.1.1 History

The earliest known wind machines date back to the ancient Persian wind mills in 200 B.C. which were used for grinding grain. Wind mills were introduced to the western world in the 1100 A.D. The earliest references that appear in the literature are 1105 A.D. in Arles, 1180 A.D. in Nassandy and 1191 A.D. in England. By the thirteenth Century wind mills were used extensively in many parts of Europe. Hereafter a number of wind mills were designed, fabricated and tested at different parts of the world.

By the mid - 1940s the use of large scale wind-operated electric generators was deemed uneconomical and all major installations were replaced by electric power-generating plants.

But recently, a resurrection of wind energy application had occurred, due to the energy crisis facing the world.

2.1.2 Classification

Many different types of wind machines were designed and constructed during the course of wind mill history. Wind mills are classified according to their axis of rotation, relative to the direction of wind. The major categories are:

a) Horizontal axis rotors

b) Vertical-axis rotors

c) Cross-wind horizontal-axis rotors

Horizontal axis rotors

Horizontal axis machines are those devices in which the axis of rotation is parallel to the direction of wind. These devices can either be lift or drag systems. Designs have been varied with number of blades. Systems can range from one bladed units to multi bladed systems having fifty or more blades. Horizontal axis rotors can be upward rotors or downward rotors. In upward rotor, blades rotates in front of the tower with respect to wind direction, and in downward rotor, blades rotates at the back of the tower. The various types are shown in Fig.1.

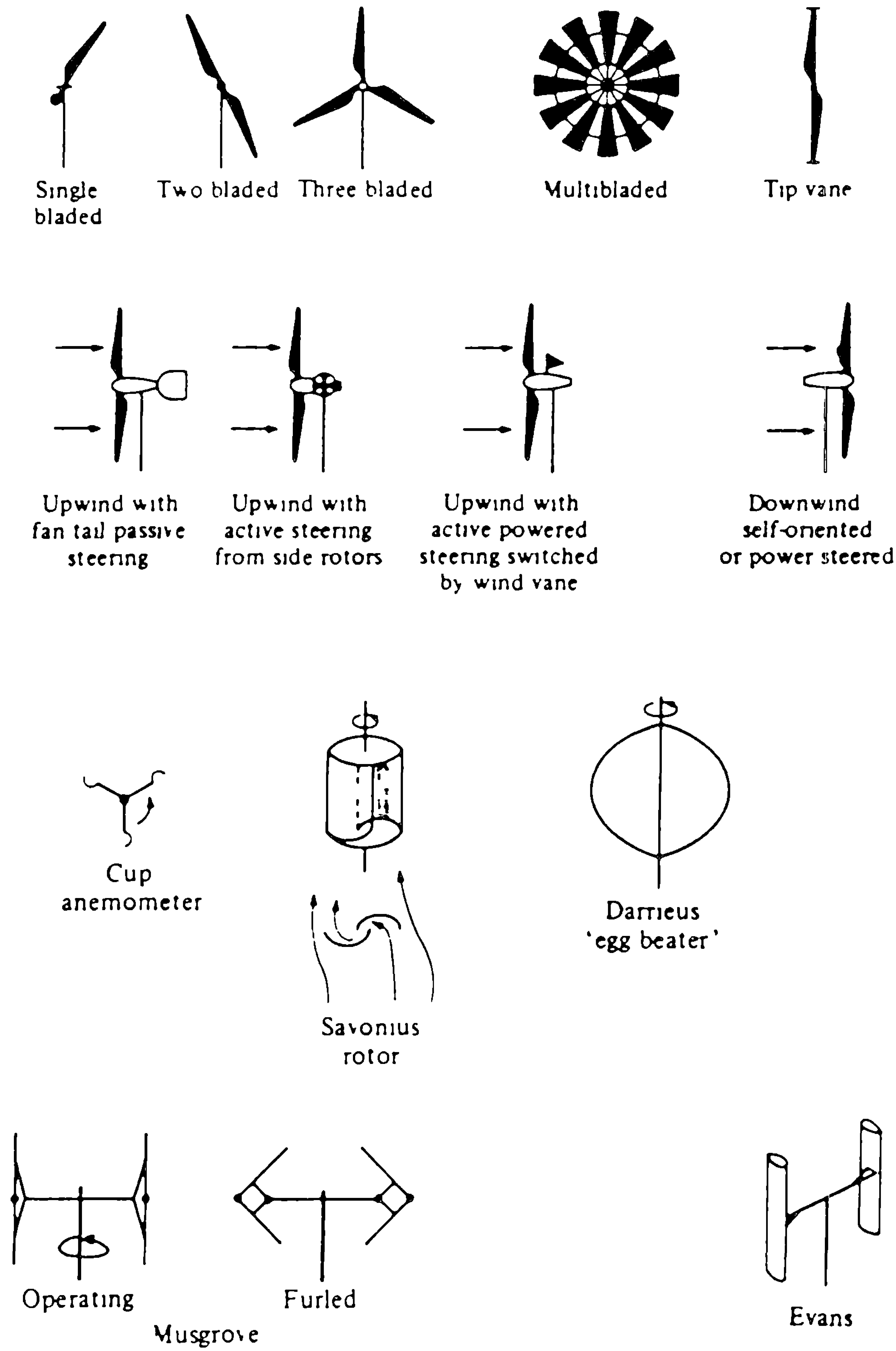


Fig.1 Classification of wind turbines

Vertical axis rotors

Vertical axis rotors are those which have their axis of rotation at right angles to both the earth's surface and the direction of wind. Their major advantage is that they do not have to be repositioned to the direction of on-coming wind as the wind stream direction changes.

Vertical axis rotors can be classified as:

a) Savonius rotor

b) Darrieus rotor

c) Cup anemometer

d) Musgrove rotor

e) Evans rotor

Cross-wind horizontal axis rotors

They are machines whose axis of rotation is horizontal with respect to the ground and at right angles to the direction of the wind (Fig.3). The most common type of designs are cross-wind paddle rotor and cross-wind Savonius design. They are primarily complicated systems having no marked advantages over the other designs.

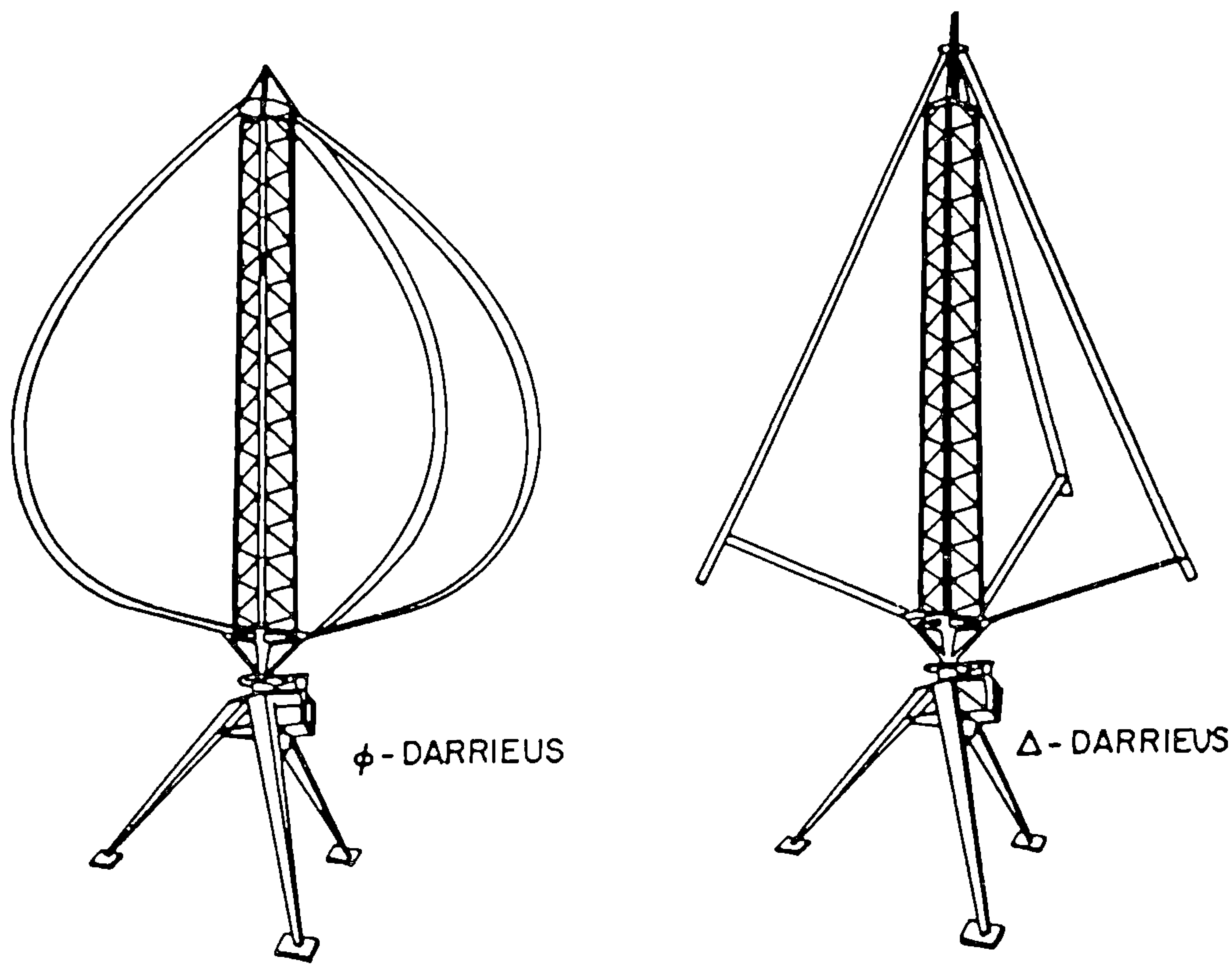
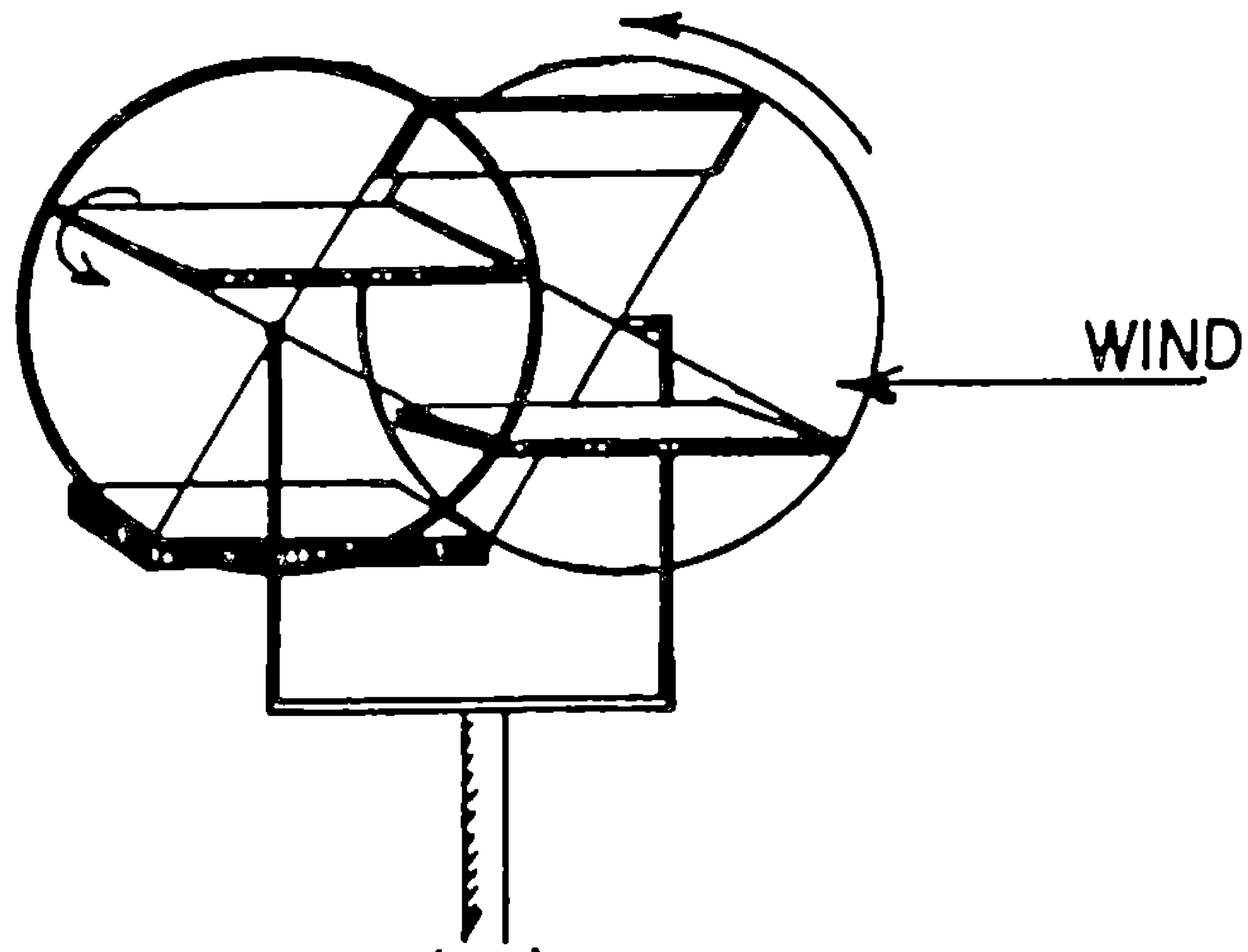
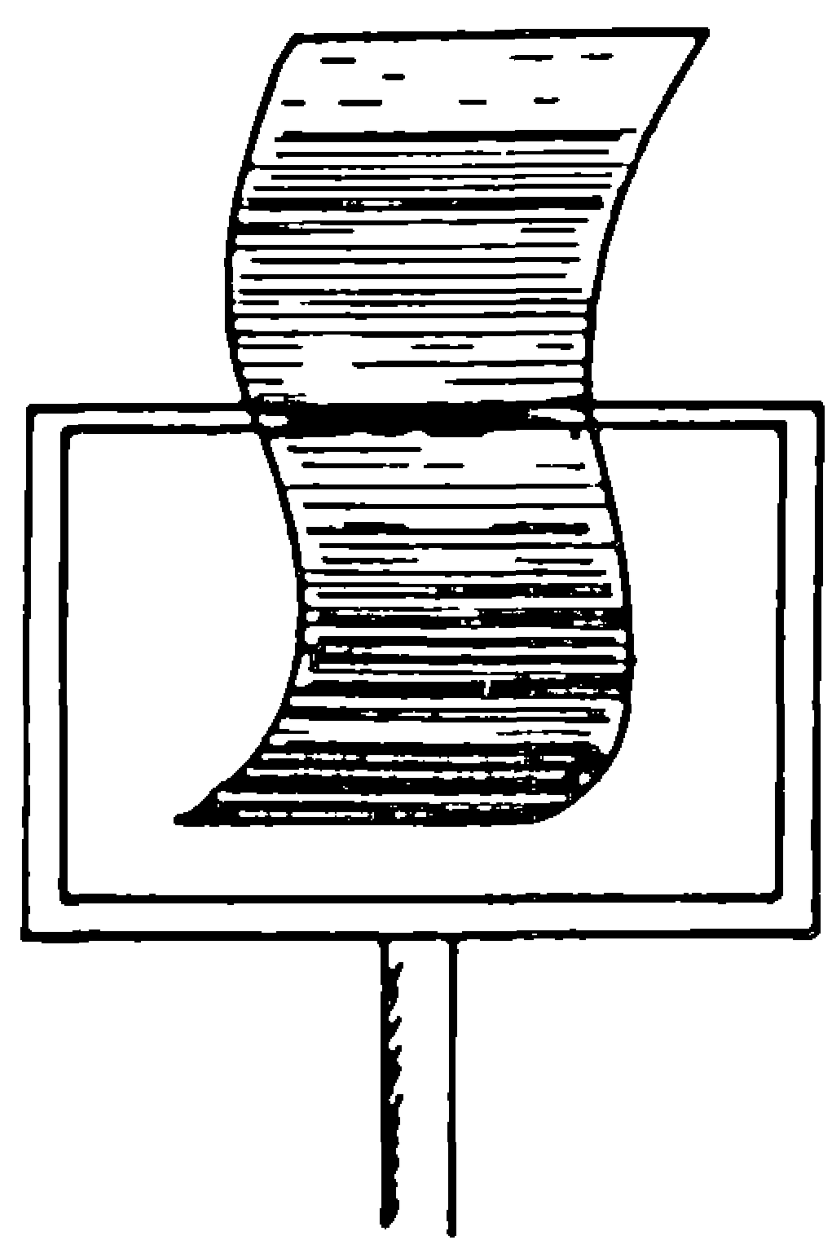


Fig.2 Different designs of Darrieus rotor



(A)



(B)

Fig.3 (A) Cross wind paddle design 1 and

3 (B) Cross wind Savonius design

2.2 Aerodynamic characteristics of rotor profile

Rankine, W. and Froude originated axial momentum theory, considering the flow past a wind turbine they found that the wind velocity at the disc of the wind mill is the average of initial and final velocities.

$$U = \frac{V_i + V_o}{2}$$

where

U - Wind velocity at the disc

V_i - Initial wind velocity

V_o - Final wind velocity

Power developed, P is given by

$$P = \rho AU \left(\frac{V_i^2}{2} - \frac{V_o^2}{2} \right)$$

OR

$$\frac{P}{1/2\ \rho AV_o^3} = 4a(1-a)^2$$

where

P - Power developed

ρ - Mass density of air

A - Area of the rotor

a - $\dfrac{V_i - U}{V_i}$

The above expression will have a maximum value when $a = 1/3$

$$\frac{P\ max}{1/2 \rho A V_1^3} = 0.593$$

Thus, the maximum power coefficient that can be attained by a rotor is 0.593.

For a drag machine, the maximum driving drag force is given by

$$F_D = C_D \rho A (V_1 - U)^2/2$$

where

F_D = Maximum drag force

C_d = Coefficient of drag

The power transmitted is

$$P_D = C_d \rho A(V_1 - U)^2 U/2$$

where

P_D = Power transmitted due to drag force. This is maximum with respect to V when $u = V_1/3$

So $$P_D\ max = \frac{1}{27} C_D \frac{\rho AV^3}{2}$$

$$P_D = C_p \rho A V_1^3/2$$

So $$C_p\ max = \frac{4}{27} C_D$$

Power coefficient of different rotors are compared in Fig.4.

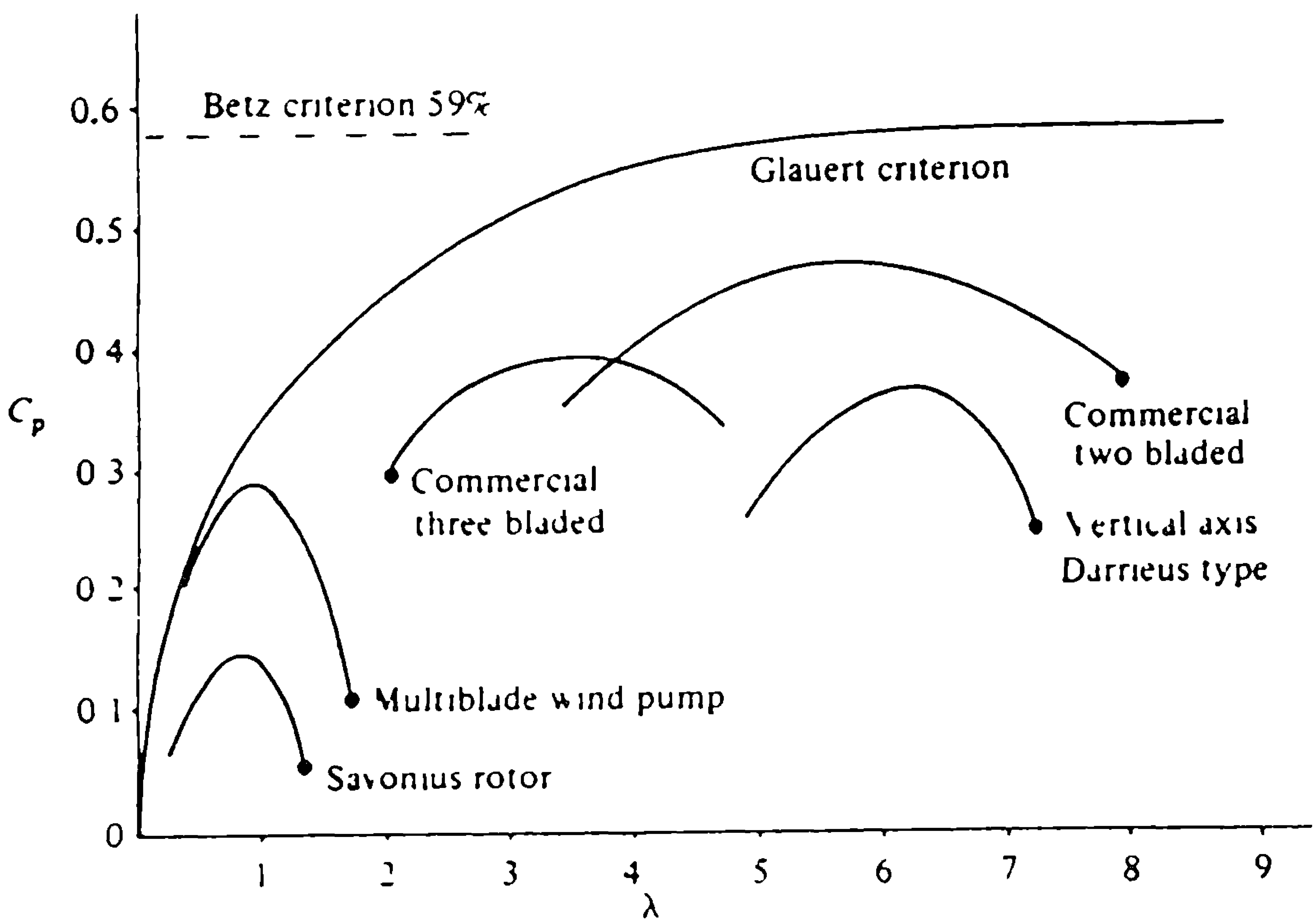


Fig.4 Power coefficient C_p as a function of tip speed ratio

Islam et. al. (1988) studied the application of cascade theory on the aerodynamic performance of horizontal axis wind turbine. In this study, the flow field was considered as rationally systematic and the wind turbine would be treated as an open rectilinear cascade. Forces acting on a differential element of blade were calculated and integration was carried out along the length of the blade to compute the performance of rotor. He came to a conclusion that performance of a horizontal axis wind machine at low tip speed ratio cannot be determined accurately by classical theory. For the high solidity multi-blade turbines, design tip speed ratio is generally low for getting high starting torque for the type of wind turbines cascade theory predicts better results than the momentum theory although the computational time is much higher in case of cascade theory.

2.3 Wind Profile characteristics

Exbote et. al. (1962) studied the wind profile characteristics of India and concluded that for large parts of the country, the optimum working speed of the wind mill must be at 7 km/hr.

Beurskens (1974) had traced the history of wind mills in North-west of Tanzania as well as in India and wind energy potential of Gaya region. Assuming 50 percent efficiency of wind mill-run pump, he had developed the following relationships for the power of the wind mill.

$$P = \frac{16}{27} \; 1/2 \; \rho A V^3$$

where

P - Power, watts

ρ - Density of the air, kg/m^3

A - Total swept area of rotor blades, m^2

V - Wind speed, m/s

Assuming an efficiency of 50 percent, he had derived the formula as given below:

$$P = \frac{1}{10} A V^3$$

He had developed velocity frequency distribution curve correlating fraction of total time that the wind speed work between different intervals of time. The utilization of wind energy has been brought out by considering the following water needs:

Cows	68 l/day
Sheep and goats	7 l/day
Pigs	18 l/day
Chickens and rabbits	18 l/day/100 Nos.

For low, medium and high irrigation heads, rotor diameter of 4.5 m has been considered and economics of wind mill project was analysed.

According to Beurskens (1974) for Gaya region where wind velocity is in the range of 7.2 - 9 km/hr, a wind mill of 6 m dia can lift water to meet the demand of the following:

a) 200 families of 4 to 5 persons

b) 400 head of cattle; and

c) Irrigating 0.5 hectares of land.

Srinivasa (1978) had brought out the wind energy resource potential for Karnataka region by delineating the zone of poor, moderate and good wind.

Krishnan (1978) had reviewed the utilization of wind resource for pumping water and power generation in India. Based on studies made, at the National Aeronautical Laboratory, Bangalore, he indicated that the regions with daily wind speed exceeding 8 km/hr are extremely important from the point of view of utilization.

Rastogi (1982) categorized the resource availability based on the review of literature and pointed out the need to undertake the inventory of wind resource in the country based on time, location, wind availability and topography.

Gurbachan Singh et. al. (1988) studied the wind profile for exploration of energy in Punjab. From the analysis of wind data, he came to the conclusion that the duration of wind above 5 km/hr varied from 40 to 50 percent of time during the months of March to August. However, during the other months it remained within 10 - 30 percent of time. A wind velocity of 8 km/hr is obtained during March to June at a rate of 20 to 30 percent.

Muhammad (1988) made feasibility studies of wind turbines in Kerala. Based on the data collected, they identified many potential parts in the State for economical exploitation of wind energy.

2.4 Design and constructional characteristics

John Smeaton (1700) introduced cast iron in the mill work. This simplified attaching long sails in a rotor. Smeaton did a considerable amount of work in establishing guidelines for designing wind mill sails, much of which are still followed. Some of his experimental work revealed that the velocity of sail's tip is almost proportional to the wind's speed. He also observed that the maximum load on the sail is almost directly proportional to the square of wind's velocity. Power generated is proportional to wind velocity cubed.

According to the energy resources development publication, Sherman (1976) reported that a survey of local wind characteristics summarising the following are required for the wind mill design.

i) Velocity and power frequency curves;

ii) Power duration curves; and

iii) Wind direction and distribution curves.

He had discussed the following horizontal axis rotors:

i) The classic Greek type sail rotor is suitable for high starting torque, low starting speed, low weight and low cost. The unit has been found in Thailand, China and Sri Lanka.

ii) Steel multi-vane fan rotor having rotor solidity of 90 - 100 percent as against 45 - 50 percent of Greek type are found in India, Syria and Thailand.

iii) Rectangular cambered steel plate blades twisted to give low pitch angle at the tip and high pitch angle at the root having rotor solidity 35 percent are found in Netherlands, Denmark and Tanzania.

iv) Princeton sail wing rotor of two blades having a double thickness of sail cloth supported by a rigid straight leading edge, rigid tip and root chord sections and a trailing edge cable tensioner between the tip and root section has been found in U.S.A.

v) High speed propeller type rotors are not usually considered for water pumping but they can be adapted to high speed centrifugal pumps.

According to the author the materials used for the construction of wings are flat thin material including metal, wood, plastic, bamboo and fibre mats with appropriate support.

The harnessing of wind has been attempted by flapping vane wind pump, tree pump and parachute pump. The pumps used in harnessing practice include:

a) Reciprocating pumps of single acting and double acting, diaphragm and inertia pump;

b) Rotory-motion pumps including square-wooden-pallet chain pump, round-steel-washer chain pump, large diameter slow speed centrifugal pump, axial flow pump, archemedian screw pump, peristaltic pump and water pump operated by compressed air.

The author has given details of the component design and matching under the following heads:

a) Control mechanism;

b) Rotor radius;

c) Pump size;

d) Power transmission mechanism;

e) Orientation mechanism;

f) Hub, main shaft, and bearing selection based on load analysis;

g) Tower design; and

h) Carriage assembly.

Rama Nathan (1986) made studies on design features of a low cost wind mill. He found that the drag force increased with the increase in wind velocity and the maximum value being 633.2×10^{-3} newton for the design under study. As the wind velocity is doubled, the drag force was found to increase by a factor of four irrespective of the level of wind velocity. The drag force increased at an average rate of 22×10^{-3} newton with increase in unit wind velocity. Yaw force and yaw moment were increased linearly with wind velocity and reached a value of 274.18×10^{-3} newton and

143.12×10^{-3} newton meter respectively. Owing to doubling of wind velocity, the vertical forces increased by four times.

2.5 Works done on wind energy conversion system

For the last few Centuries, research works were conducted all over the world to develop efficient wind energy conversion systems. In India, a number of research organisations like National Aeronautical Laboratory, Bangalore; Institute of Engineering and Rural Technology; Central Institute of Agricultural Engineering, Bhopal; Tamil Nadu Agricultural University, Coimbatore; Punjab Agricultural University, Ludhiana; Kerala Agricultural University, Tavanur, are actively involved in developing wind mills suitable for our rural areas. In the following pages, some of the important works conducted all over the world are discussed.

2.5.1 Work done abroad

2.5.1.1 Horizontal axis rotors

Andrew Meikkle (1772) developed a horizontal axis wind mill with wooden slat arm (Fig.5). The slats were connected to a bar alongside the mast and were held in position by metal springs. By adjusting the tension of the spring, the slats could be opened when the wind's speed

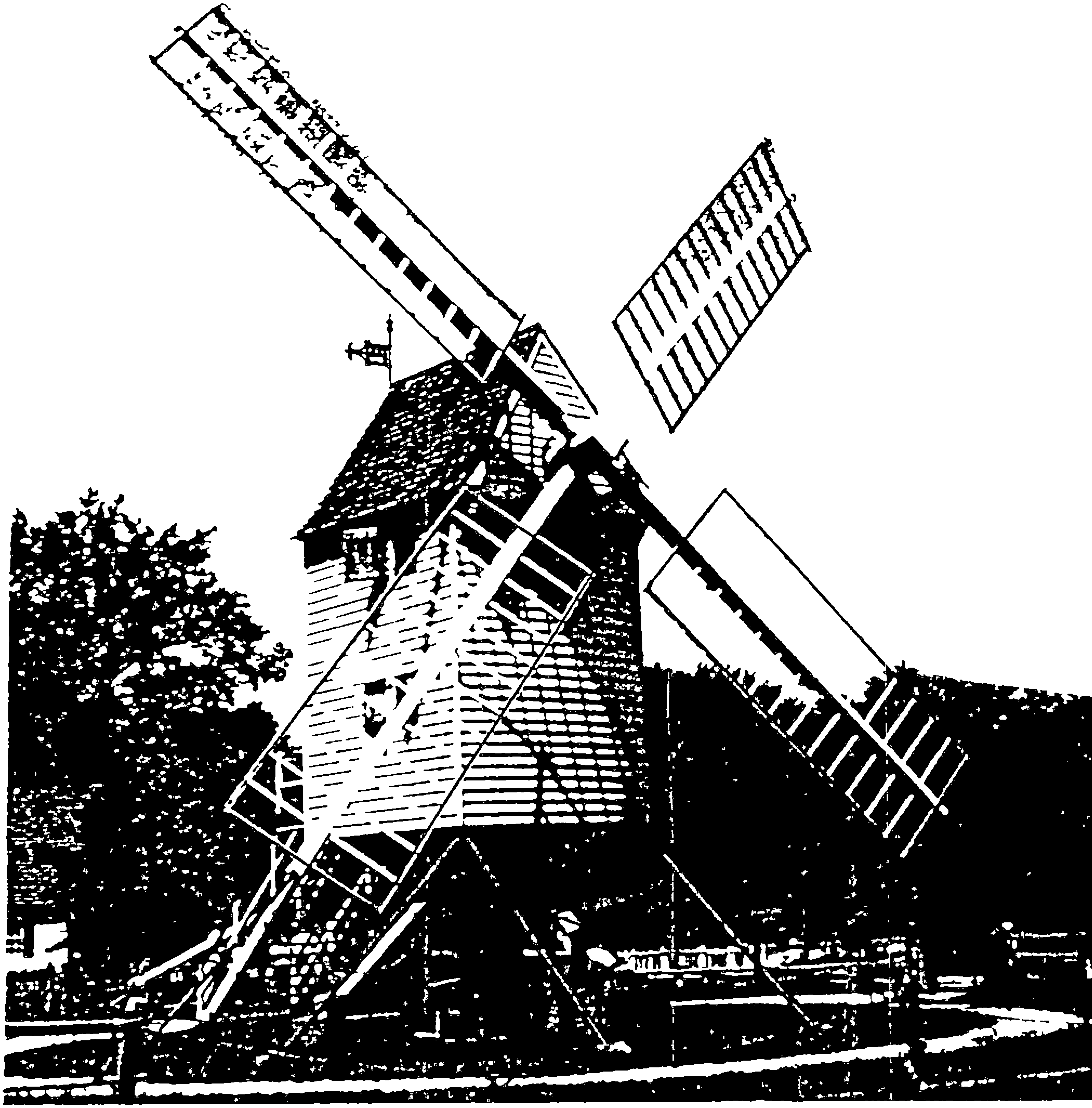


Fig.5 Andrew Meikkle's horizontal axis wind mill

increased in order to prevent the sails from whirling too fast. When the wind died down, the slats would close providing greater wind catching area. Sir William Cubitt (1790) improved Meikkle's design. He attached a weight to the wind mill which will fall up or down due to centrifugal force, depending upon the speed of the rotor; the action of the weights adjusted the vanes and a more stable operation is achieved at changing wind speeds. Cubitt's design became quite popular in Denmark and Germany as well as in British Isles.

Edmund Lee (1800) discovered that he could maintain the wind mill sails in the direction of wind by attaching a secondary rotor with several blades to the tower at a 90 degree angle to the main sails. When wind changes its direction, the main rotor could not catch wind due to change in direction, the secondary rotor starts rotating and forces the main rotor to the wind direction.

Jacob (1925) introduced a three bladed aeroplane type propeller. The speed of the propeller was controlled by a fly ball governor that operated variable pitch speed control. A propeller diameter of 4.5 m produced 400 to 500 kW-hr per month at a wind speed 10 to 32 km/hr for two or three days each in a week.

Dr. Ulrich Huller introduced fibre glass blades for the rotor in 1960. 34.5 m fibre glass blades were fixed on a simple hollow pipe tower supported by guy wires. The blade pitch could be changed at higher speeds to keep the propeller rotation constant.

Carry (1973) developed Alchemy sail wing rotor capable of actuating at lower wind speeds (5 km/hr). The sails used in this design was of Genoa sail cloth with a special ultra violet resistant coating. At very high wind speeds sails can be furled by wrapping the rest around the mast and securing it with a long chord.

Sherman (1975) had developed a horizontal axis sail wing wind mill with khakhi cloth sails. A reciprocating pump attached to the wind mill was found to lift 1,635 l/hr at a wind speed of 7 km/hr against a head of 9.2 m.

Sweeney (1976) had developed Bishops wind mill with bamboo mat sail. It had six sails made of triangular mat woven from split bamboo and reinforced with nylon chord. The design contained a manually activated quick release sail stretching device at each loop connection. The rotor was connected to a chain pump capable of pumping 950-1200 l/min against a head of 6 metres.

Dick (1977) had developed a horizontal axis multi directional metal bladed wind mill. Six metal blades of 24 - 28 gauge galvanised sheet metal had been used for the rotor construction. Power was transmitted from rotating hub to an eccentric wheel by friction. The conventional piston pump attached to this system was found to lift 1,135 l/hr against a head of 12.2 m at a wind speed of 32.2 kmph.

Fraenkal et. al. (1978) had described ITDG (Intermediate Technology Development Group) model multi bladed wind mill made of metal. It was specially designed for bore hole water pumping. A double acting piston pump was developed for low head high volume pumping which discharged 10.6 l/stroke.

VITA (Volunteers for Technical Assistance) (1979) had developed a wind mill with trapezoidal sails made of heavy canvas. Curtain rings helped securing the sails to the spocks and ribs. The canvas was coated with paint to ensure a longer life. A self priming double acting pump attached to this machine was found to discharge 8,000 l/hr.

2.5.1.2 Vertical axis rotors

Richard, H. Braasch, Sandia laboratories (1975) developed a darrieus vertical axis wind turbine of 17 m rotor blade diameter. It was an experimental prototype with two blades made of 0.6 m aluminium extrusion. It was tested from March 1977 to June 1979 and was found to generate 60 kW at a wind speed of 50 km/hr.

C.F. Wood, DAF INDAL Ltd., fabricated a darrieus, vertical axis wind mill. The rotor had two aluminium blades of 24 m diameter. It was reported to have a rated output of 200 kW at a wind velocity of 22 km/hr.

Robert B. Allen of Dynergy Co-operation developed a three bladed, 5 m diameter darrieus rotor. The rated wind speed was found to be 38 km/hr and rotor speed at the rated speed was 243 rpm. Cut in speed of the rotor was 16 km/hr. Power developed at the rated speed was 3.3 kW. Blades were constructed out of extruded aluminium.

Jhon Vara developed a cyclo turbine vertical axis wind machine (Fig.6). Rotor had three blades of 4.5 m diameter and 2.4 m height. It was reported to develop 1.2 kW at 32 km/hr wind velocity. It was found suitable for very small systems in rural and remote areas.

Kostowaski (1977) had fabricated a savonius rotor of two stage wing with two 45 gallon oil drums and two plywood discs. It had two stages of rotor and a manual braking device.

Bremont J stated that the savonius rotor was selected as the most suitable wind mill for water pumping in regions of light wind ie. 4 - 5 m/s. A wheel and chain power transmission was adopted because it was cheap and would easily be manufactured and repaired locally. A pump connected with

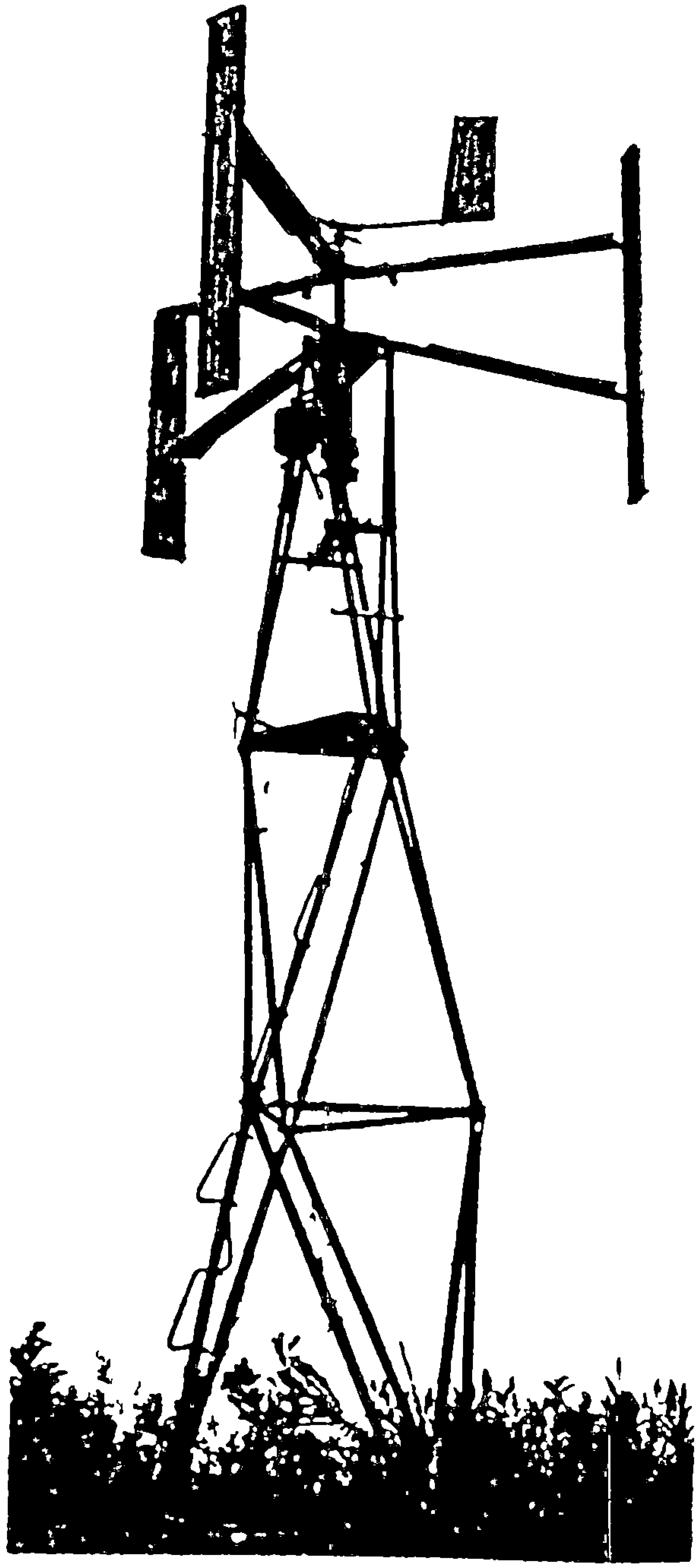


Fig.6 Cyclo turbine model C2E

this wind mill was found to discharge 4,835 l/day against a head of 6 m.

Salazar (1979) had discussed twin type savonius wind mill developed at International Rice Research Institute, Manila. The rotor of the model was made of 45 gallon oil drum cut into half lengthwise. The shape was slightly modified to obtain more aerodynamic efficiency.

Electro G.m.b.h. developed a savonius vertical axis wind mill with an ac generator. It had a wooden savonius rotor with six, 0.45 m diameter blades. The overspeed was controlled by centrifugal weights. The rated output was 50 watts at 60 km/hr wind velocity and the rated rotor speed was 120 - 500 rpm. It was used for battery charging and lighting.

2.5.2 Work done in India

2.5.2.1 Horizontal axis rotors

National Aeronautical Laboratory, Bangalore, developed a wind mill named WP-2 to meet the demand of domestic and minor irrigation water pumping. It operated in the wind region of 6 - 9 km/hr. A single acting plunger pump with brass cylinder was attached to the wind mill through an eccentric mechanism. It was found to lift 650 gallons/hr from a head of 15 m at a wind speed of 9 km/hr.

Tewari (1977) had developed NAL wind mill to meet the demand of wind region having a wind speed of 7 - 12 km/hr. The rotor was having six canvas cloth sails connected with nylon rope. The protection of the sail was achieved by thin nylon rope snaps. A pump attached to this wind mill was found to discharge 6,000 to 11,000 litres of water per hour against a head of 6.9 m at a wind speed of 7 km/hr. This model was further modified with twisted wire loops, elastic members and a braking device.

Geetha Guru and Seshadri (1980) developed ANILA wind mill and won National Research Development Co-operation award. It was a bidirectional sail device with a rotor made of high density polythene sheet backed by fishnet. The wind pump was capable of discharging 1,750 l/hr from a depth of 8 m at a wind speed of 20 km/hr. The cut in speed was identified as 10 km/hr. They further improved this design by replacing the existing shaft with an iron shaft, mounted on a swivelling box.

Institute of Engineering and Rural Technology (1981) popularised the Apoly-12-PU-500 wind mill (Fig.7). This model could be employed for a wide variety of uses like minor irrigation, drinking water supply, brine pumping and so on. The rotor had twelve blades fixed around the main shaft of 50 mm diameter. An automatic safety device was provided to prevent the damage in very high wind speeds (above 25 km/hr). Its cut in speed was 7.5 km/hr. A wooden

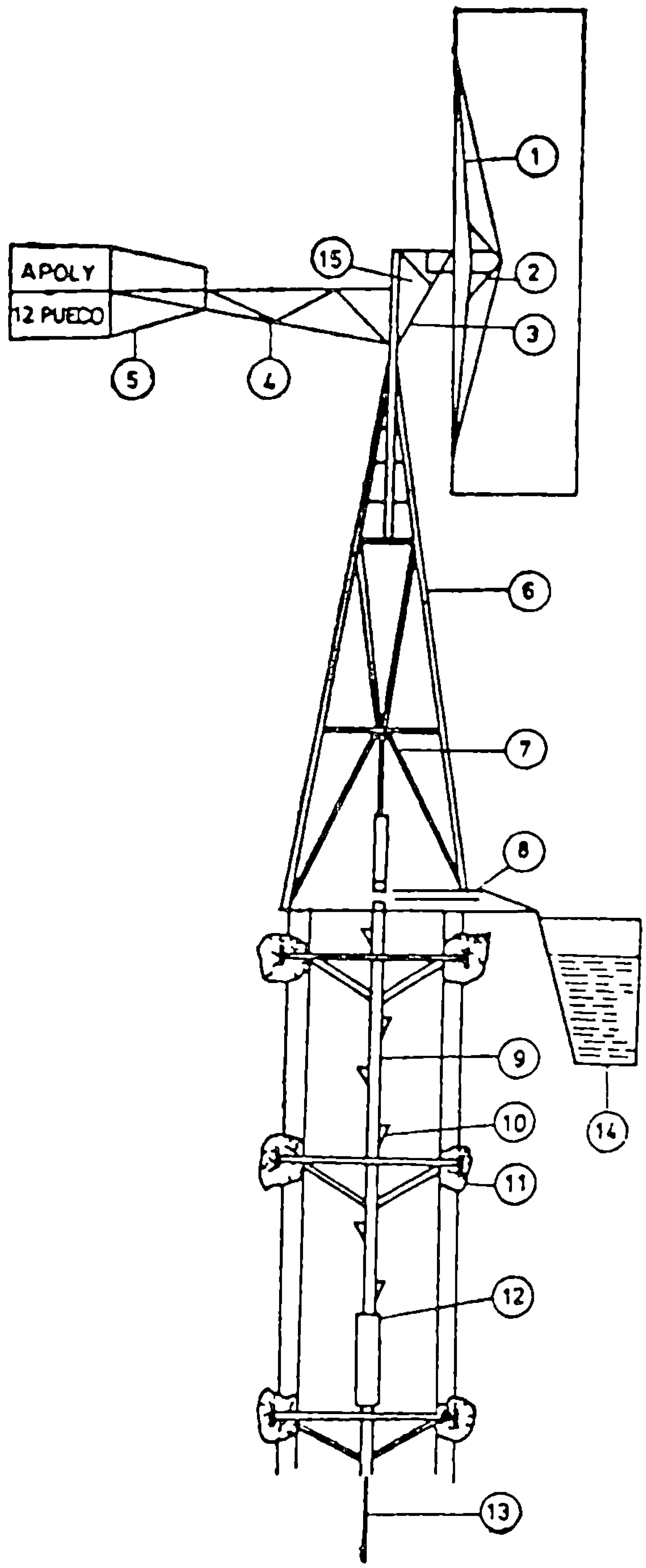


Fig.7 Side view of APOLY-12-UP-500 wind mill
1. Rotor; 2. Shaft; 3. Head construction; 4. Tail; 5. Tail vane; 6. Tower; 7. Pumprod; 8, 9. Discharge and delivery pipe; 10. Steps; 11. Bridge; 12. Pump; 13. Suction pipe; 14. Storage tank; 15. Help vane security system.

pump attached with the wind mill was found to discharge 180 l/min at 25 km/hr wind speed.

Tamil Nadu Agricultural University (1985) had developed a wind mill with 3 blades of 1,257 mm length (Fig.8). Blades were made of 20 guage G.I. sheet. Two sets of moped chains and sprockets were provided for power transmission. A Lucas 12 V dynamo, fitted with the wind mill, was found to develop 7.6 watts at 14 km/hr wind. When the wind speed was increased to 18 km/hr power developed was increased to 18 watts and at 25 km/hr it produced 51 watts.

Tamil Nadu Agricultural University (1986) designed a low cost wind mill also for farms and rural areas. The rotor consisted of radial spokes made of casurina poles fitted to a 1/2 inch G.I. pipe shaft through clamps. Sails were made of used synthetic gunny. Rotor diameter was 4 m. Two bearings, made of hard wood, and pre-treated with waste engine oil over 40 hours, served as main bearings through which the central axis worked. A pump fitted with this model was found to discharge 86 litres of water per minute at a wind velocity of 18.9 km/hr.

Central Institute of Agricultural Engineering (1988) designed and developed a multibladed horizontal axis wind rotor. It was an eight bladed design with 5 m rotor diameter. Blades were mounted on individual spokes made of

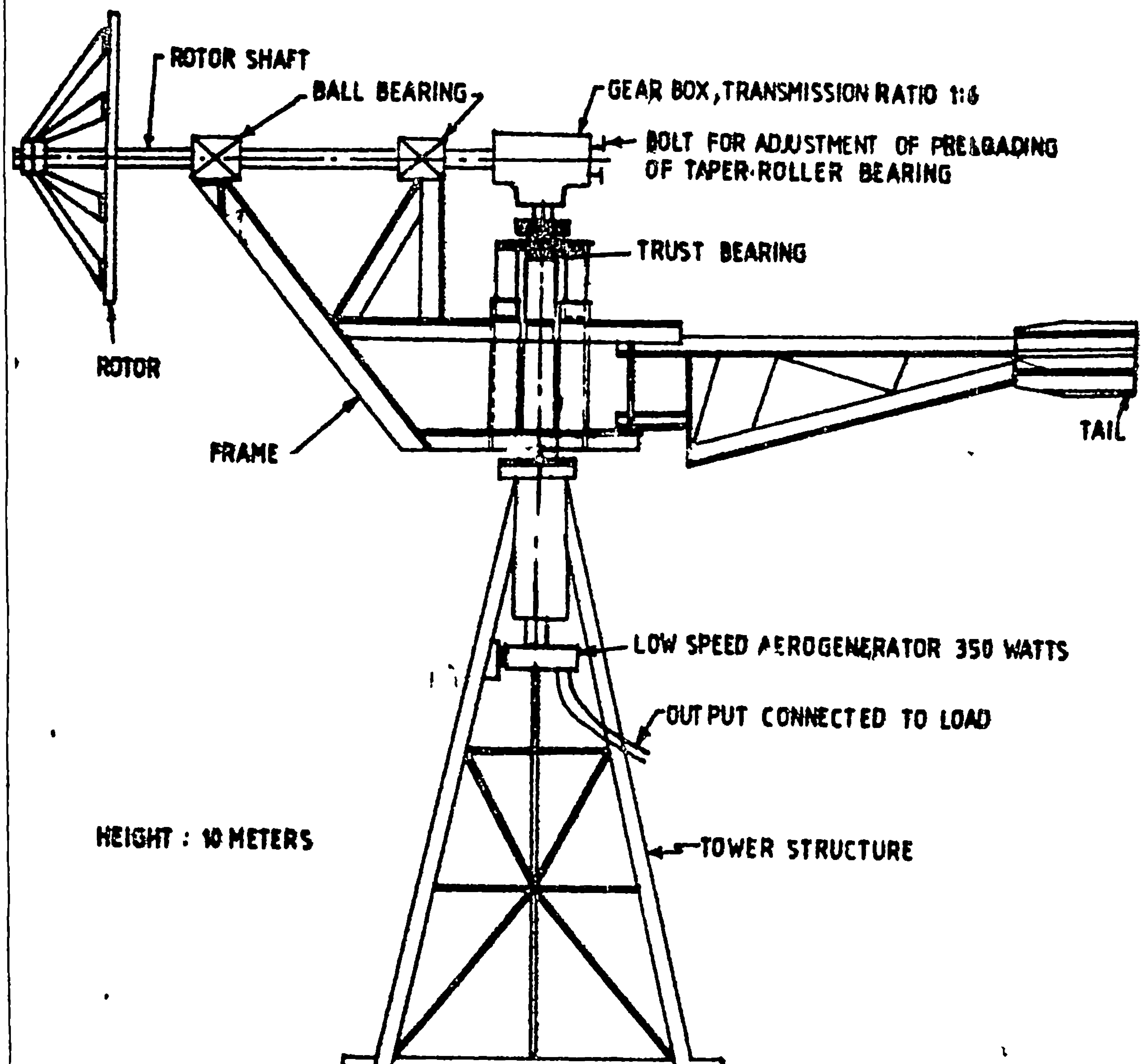


Fig.8 Side view of TNAU wind mill

25 mm diameter mild steel pipes. Rotor was mounted on a 7.5 m high truss type tower. Power transmission of the wind mill was such that, rotory power could be obtained at the ground level. The maximum coefficient of power of the machine was found to be 0.325 at a tip speed ratio 2.4.

Kerala Agricultural University (1988) developed a low cost wind pump. The rotor had five blades of 5 m diameter. It had a cut in speed of 5 km/hr and furling speed 40 km/hr. The overall cost of the machine was reduced by using unserviceable automobile parts which are available at a fairly low price. Strong and light bamboo poles were used as radial support for the sails. It had a rated power of 0.5 hp at a wind velocity of 18 km/hr. A single stage, self priming centripetal pump of 25 x 25 mm was attached to it.

2.5.2.2 Vertical axis rotors

Govind Raju et. al. (1975) have described the geometry of savonius rotor sail made of galvanized iron pipes and plywood sheets. The framework was covered with jute canvas to form the sails. A positive displacement pump, connected to the wind mill, made of pneumatic tyre and disc was found to discharge one litre per stroke against a static head of 20 m.

Shankar of National Aeronautical Laboratory, Bangalore, (1977) studied vertical axis wind turbines based on the Darrieus principle. He developed a performance analysis which permitted estimation of characteristics of such machines. A model with curved wooden blades was designed, fabricated and tested. Both the theory and results of the test confirmed the low starting torque of the turbine. Wind tunnel tests were performed on the model. Finally a straight bladed turbine was designed and constructed. It was concluded that darrieus turbines are likely to be useful in large systems used for electrical power generation. However, for direct water pumping purposes it is not suitable.

Vivekananda Mukhopadhyay (1979) fabricated a vertical axis tilting blade wind mill for rural areas (Fig.9). In this, a pair of rectangular blades were hinged from either side of a horizontal rod, attached to a vertical shaft which acts as the power shaft and is supported by bearings and guy cables. Several pairs of blades were mounted on a single hub and such sets were mounted in several tiers on a tall vertical shaft. Each of the blades had a flap rigidly fixed at the top at an angle to the plane of the blades. It helped the blades to tilt up and down to vertical and horizontal positions alternatively. There was also an arrangement to arrest the tilting motion of the blades about the horizontal rods, at horizontal and vertical positions, by proper

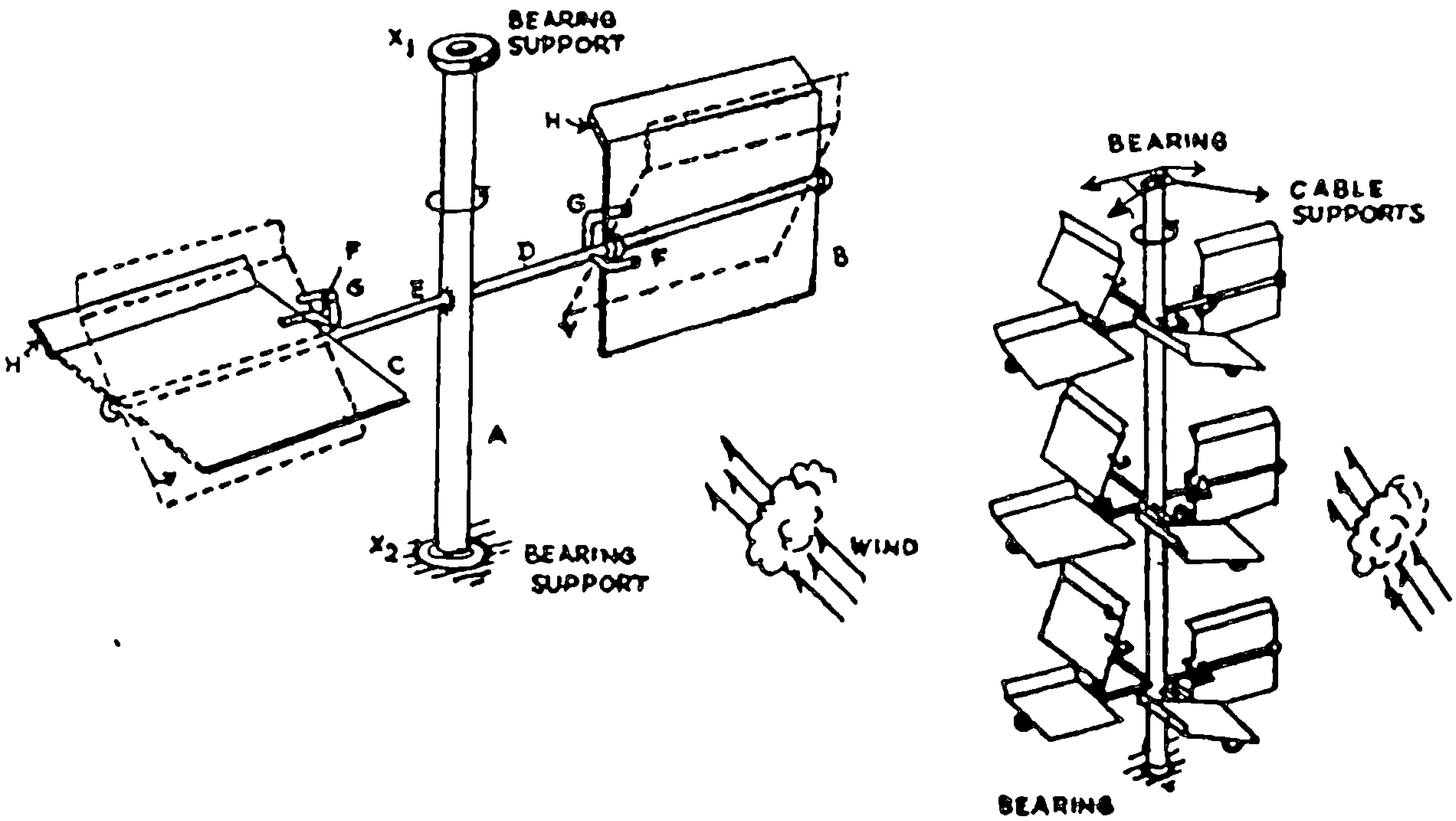


Fig.9 The three tire tilting wind mill

stoppers. Under testing, the maximum power coefficient of the rotor was reached at a tip speed ratio of 0.4. The design was found to produce a maximum power of about 350 watts in 7 m/s wind. Under the optimum operating condition, the mill took 4.5 seconds for one revolution.

Ravi Varma (1979) had fabricated a small working model of a vertical axis wind mill (Fig.10). The clamps fitted on the poles held the main shaft of the turbine in position through bearings. The top position of the turbine comprises vanes of hollow conical shape, held in position by arms set in through fixed collars. This arms will turn to fixed angles on their axis. The tower height was about 15 m. This model was found to produce about 5.5 hp/square meter of the vanes at a wind velocity of 80 km/hr.

Tamil Nadu Agricultural University (1986) developed a wind mill aided cold storage (Fig.11). A 0.55 m^3 capacity cold storage plant was operated by a vertical axis savonius wind mill having three sets of blades. The blades were made up of 20 guage aluminium sheets having dimension of 144 cm height and 100 cm radius. They were fitted in a tower one below the other. Power obtained at the base through the main shaft was transmitted to the compressor through suitable gear arrangements.

Muhammad _et. al._ (1988) developed a savonius wind mill model with a deflector augmentor. The rotor had a diameter

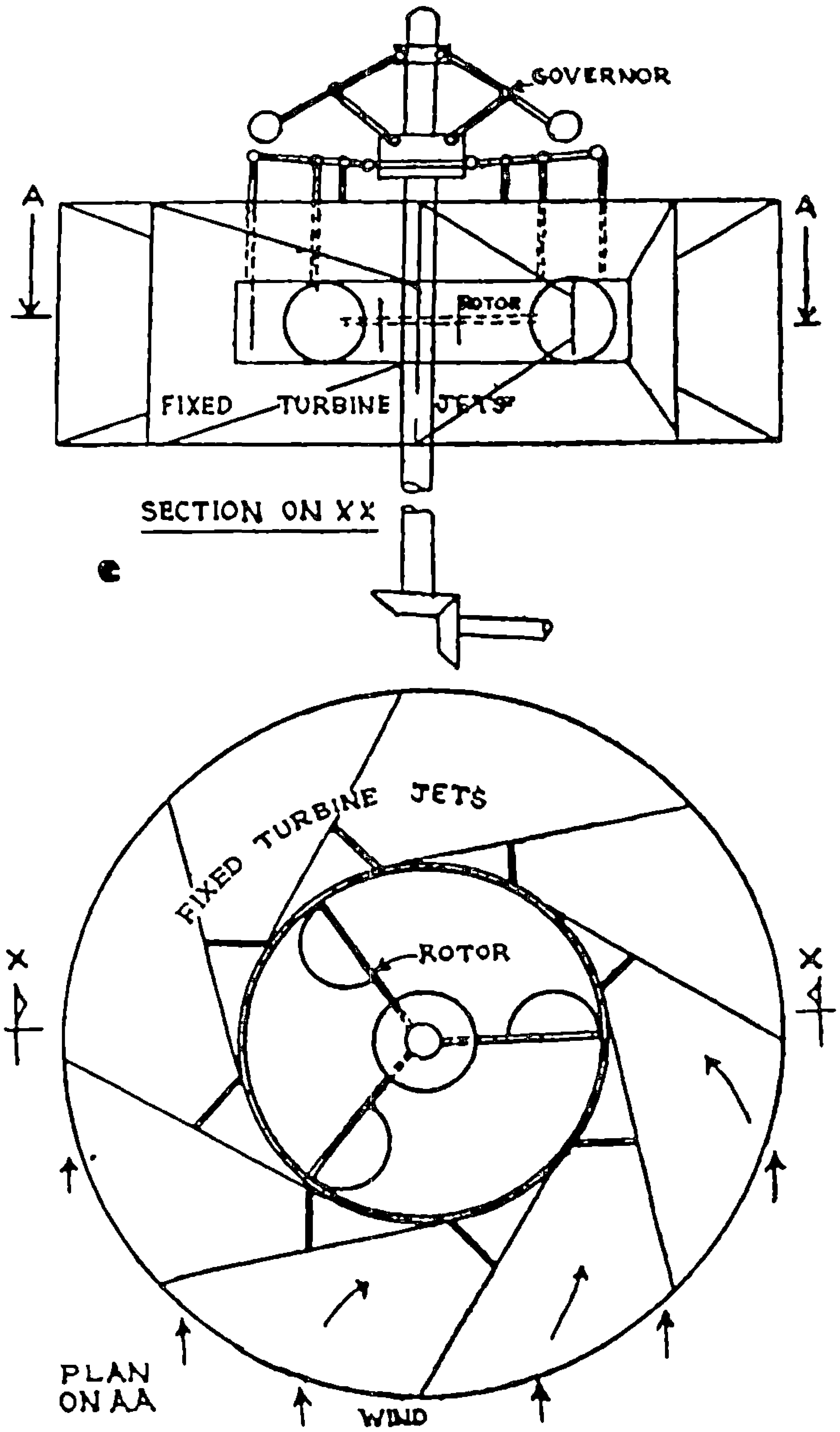


Fig.10 Vertical axis wind mill fitted with governor mechanism

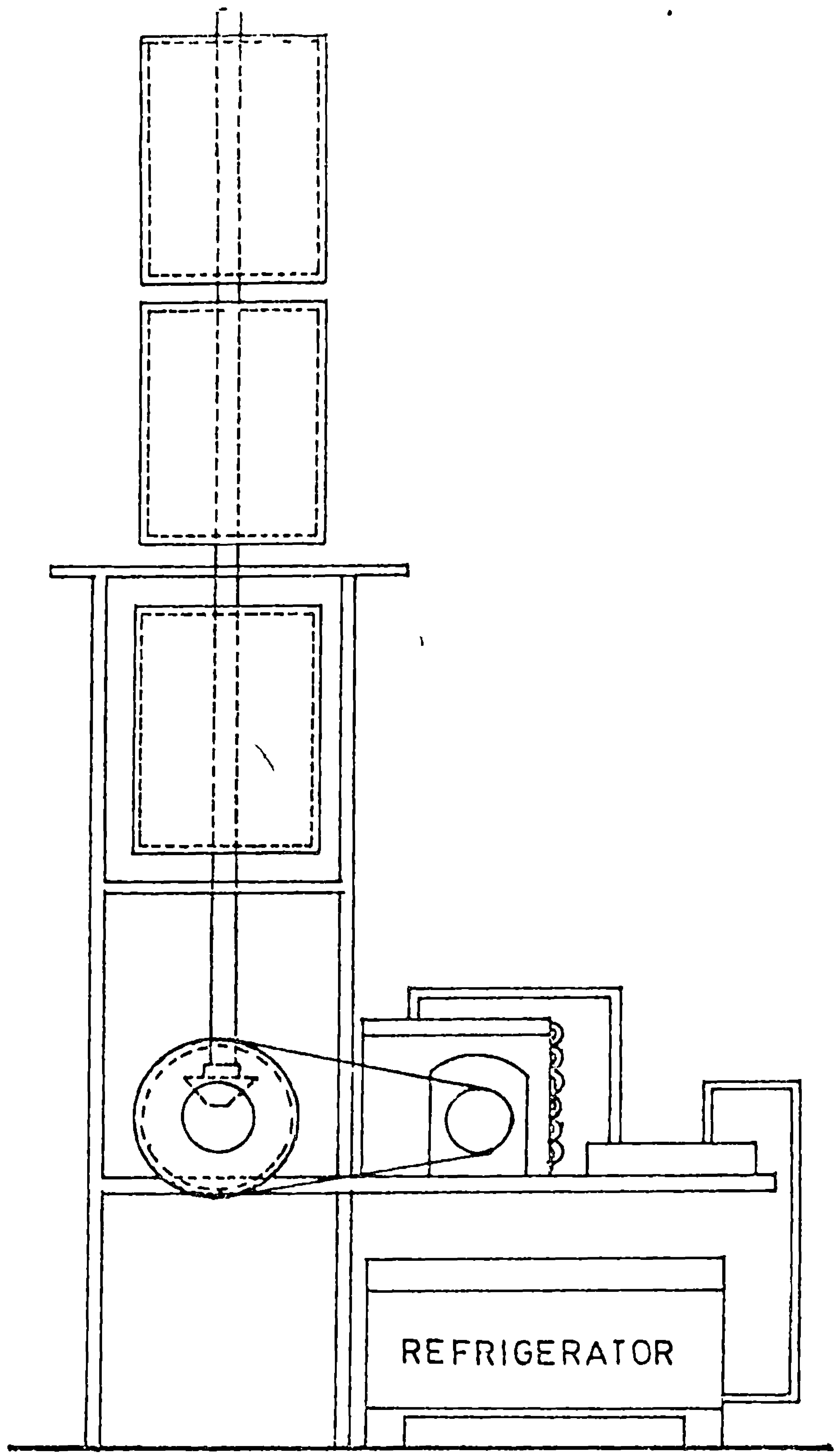


Fig.11 Wind mill operated cold storage

of 30 cm and the deflector was fixed at an angle 45° with the wind direction. A tail vane was provided to balance the deflector. The preliminary observations of this version showed encouraging performance.

Wind Energy Research Centre, CIAE, Bhopal (1988) fabricated a savonius rotor. It had two rotors 1.9 m high, placed one over other at 90° out of phase so that wind from any direction could be made use of. A 1.15 m pipe was used as the shaft. The pipe was fitted between two taper roller bearings and connected to the foundation through a universal joint. Three stay wires placed at 120° supported the structure at the top. This machine was tested for the generation of its power and torque characteristics. The wind mill was loaded to different levels of torque at various wind speeds. Test results showed that a maximum power coefficient of 0.12 was obtained at a tip speed ratio of 0.85. For tip speed ratio of 0.7 and above the efficiency of more than 10 percent is obtained. Below 0.7 the efficiency reduced very steeply.

MATERIALS AND METHODS

MATERIALS AND METHODS

The design details and selection criteria for the components of the savonius wind mill are presented in this chapter.

The functional requirements of the wind mill are defined as follows:

a) It should develop 0.2 hp at a wind velocity of 3.9 m/s ie. 14 km/hr.

b) Power coefficient and torque coefficient should be as high as possible.

c) It should have low cut in velocity.

d) Weight of the structure should be minimum.

e) Cost of the wind mill should not exceed Rs.10,000/-.

f) The number of components should be least for higher reliability, easy manocurvability and maintenance.

3.1 Design of the wind mill

3.1.1 Rotor

Preliminary rotor sizing was done with the elementary

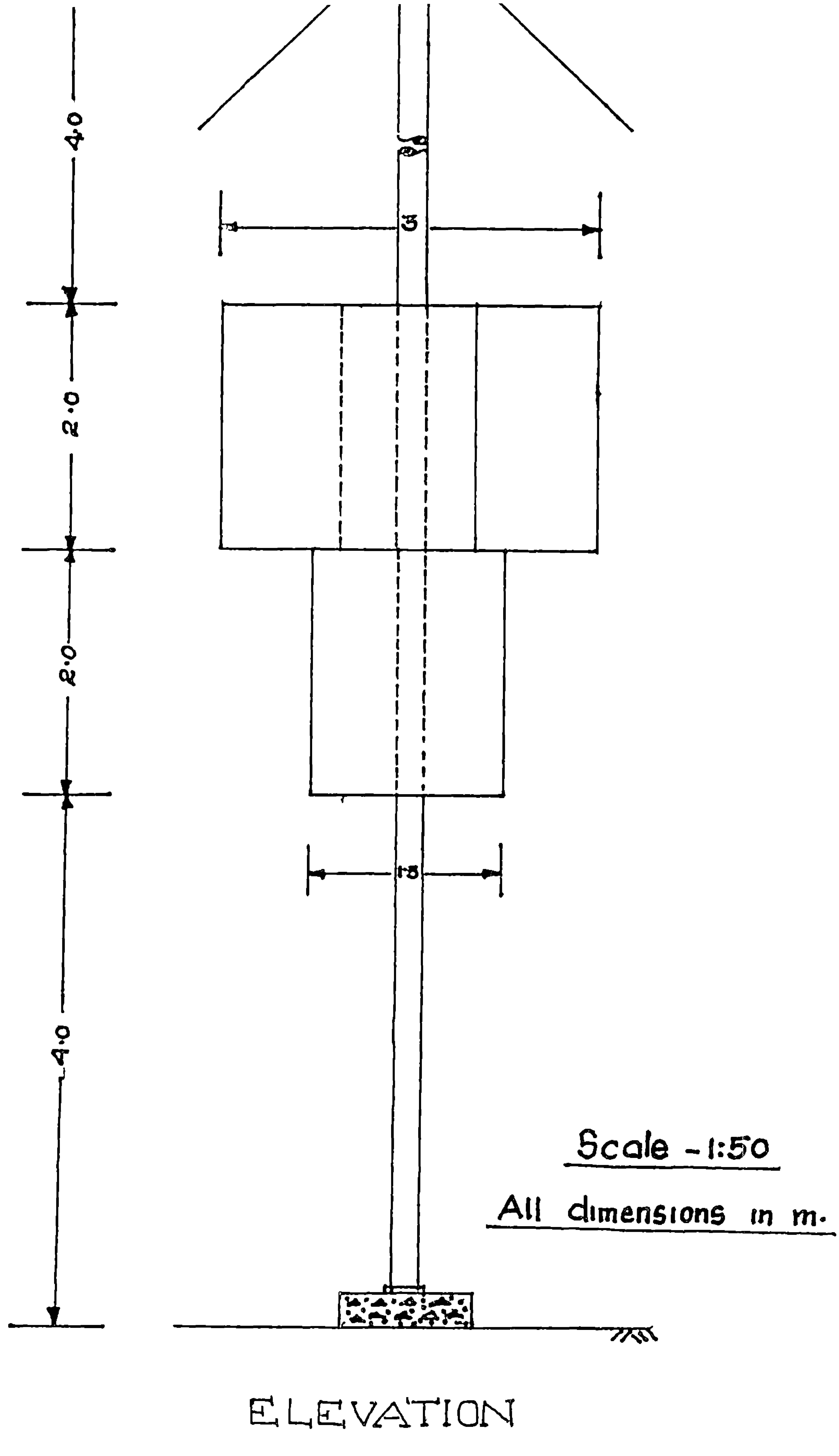
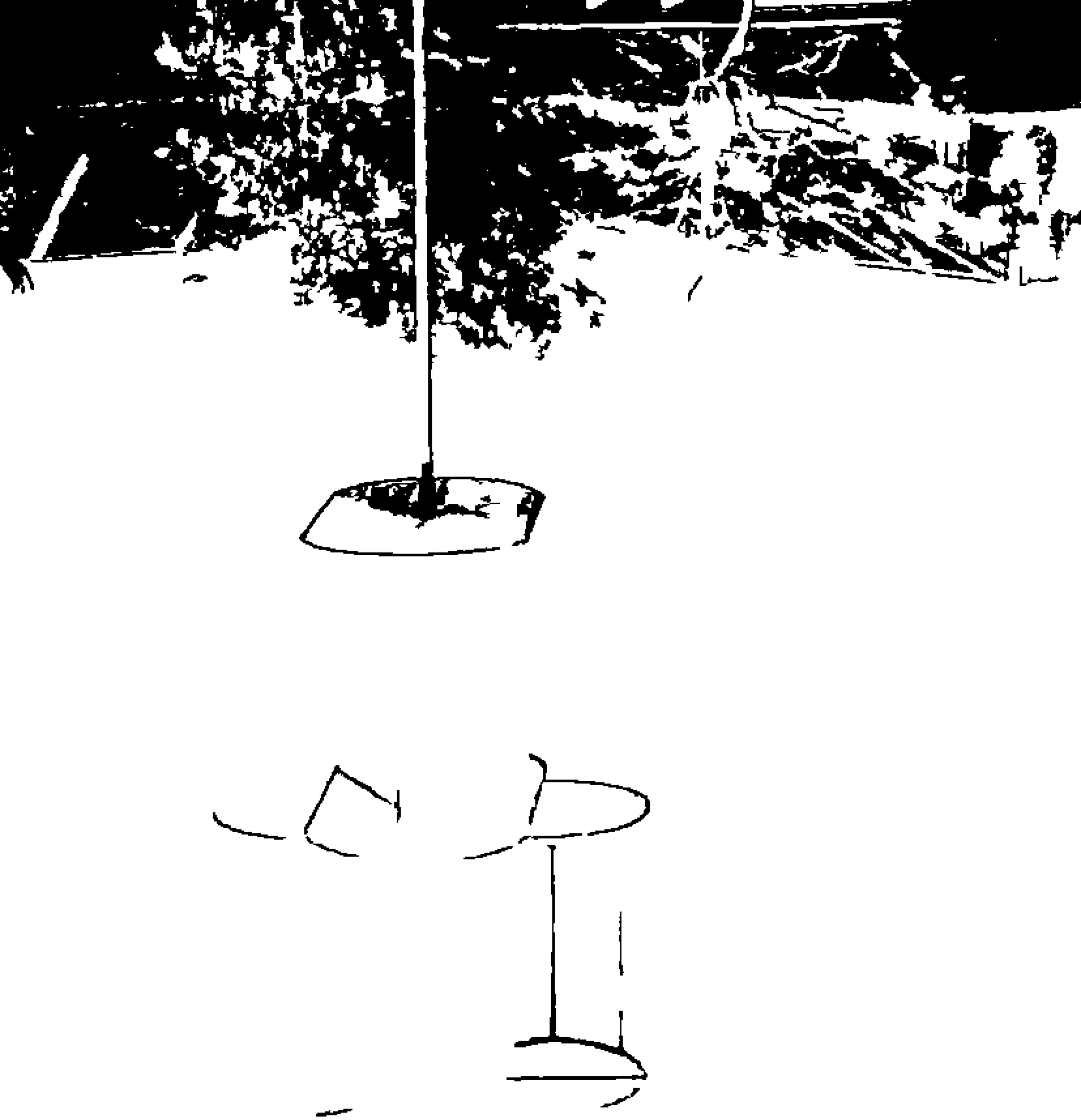


Fig.12 Front view of the Savonius wind mill

Plate I Vertical axis Savonius windmill with two rotors fixed at 90 degree out of phase



actuator disc theory. Power output of the ideal rotor is given by

$$P^1 = 1/2 \rho A C_p V_o^3$$

or

$$A = 2 P^1 / \rho C_p V_o^3$$

where

P^1 - Power output, kg.m/s

ρ - Mass density of air, kg/m^3

A - Rotor swept area, m^2

C_p - Power coefficient

V_o - Wind velocity, m/s

Air density varies according to the temperature and altitude. For the standard atmosphere, the density below 6,096 m altitude is closely approximated by the relation,

$$\rho^* = \frac{\rho'}{g}$$

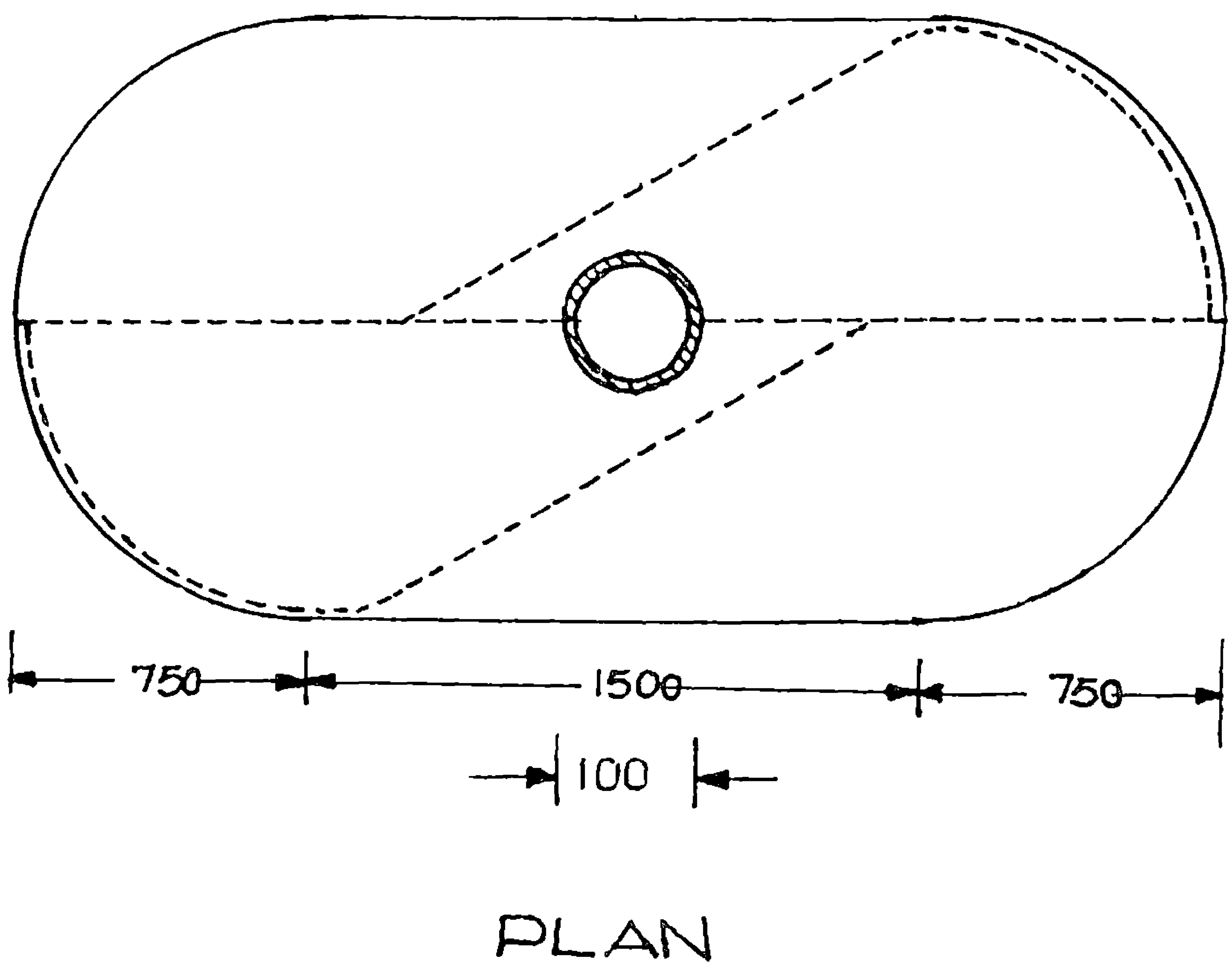
$$\rho' = \rho_o e \exp(-0.297 h/304.8)$$

where

ρ_o = 1.22496 kg/m^3

h - Height in m

ρ' - Weight density of air



All dimensions in mm.

Scale 1:25.

Fig.13 Top view of the Savonius wind mill

Plate II Rotor of the Savonius windmill

Air temperature defined for the standard atmosphere is a linearly decreasing function of altitude and is given by

$$T = 15 - 1.983\ (h/304.8)\ ^{\circ}C$$

where

h - Height, m

Although theoritical maximum value of rotor power coefficient Cp is 0.59259, real rotors achieve considerably lower coefficient of performance. For most of the machines, a power coefficient of the order of 0.2 to 0.35 could be possible with good design features.

If the drive train and generator efficiencies are to be considered the equation is further modified as,

$$A = \frac{2\ P^{1}}{\rho\ C_p \eta_d \eta_g V_o^{3}}$$

where

A - Area of rotor, m^2

η_d - Drive efficiency

η_g - Generator efficiency

A savonius rotor producing a power of 0.2 hp at a wind speed of 14 km/hr (3.9 m/s) is designed. Power coefficient of the rotor with concentrator is expected as 0.35. Density of air at the site was assumed as 1.294 kg/m^3. Area of the rotor required to develop the given power is calculated as

$$A = \frac{2 \times 75 \times 0.2}{0.1319 \times (3.93)^3 \times 0.34} = 12 \text{ sq.m.}$$

Instead of a single rotor it is better to make two rotors of 3 x 2 m size and fix them at 90 degree out of phase (Plate II).

3.1.2 Main rotor shaft

Savonius wind mill is basically a drag machine. Force experienced by the rotor will be drag force. Drag force can be computed by the formula

$$D = C_d A \frac{\rho V_o^2}{2}$$

where

D = Drag force, kg

A = Area of the rotor, m^2

ρ = Mass density of air, kg/m^3

V_o = Wind velocity, m/s

C_d = Coefficient of drag

Value of C_d for the rotor under consideration can be taken as 2.5. For a safe design, wind velocity is taken as 15 m/s. So the drag force exerted on the rotor is

$$2.5 \times \frac{12 \times 0.1319}{2} (15)^2 = 450 \text{ kg}$$

Shaft is designed for a total load of 450 kg. This load is distributed along 4 m length, therefore load per meter length is 112.5 kg. Forces acting on the shaft are as shown in Fig.14.

$$12R_1 = 450(6)$$

or

$$R_1 = 225 \text{ kg}$$

$$R_1+R_2 = 450 \text{ kg}$$

therefore

$$R_1 = 225 \text{ kg}$$

$$R_2 = 225 \text{ kg}$$

where R_1 and R_2 are the reactions at the support of the shaft.

Owing to the symmetry of the structure, maximum bending moment will be acting at the centre, that is 6 meters from the points of reactions. At this section shear force will be zero.

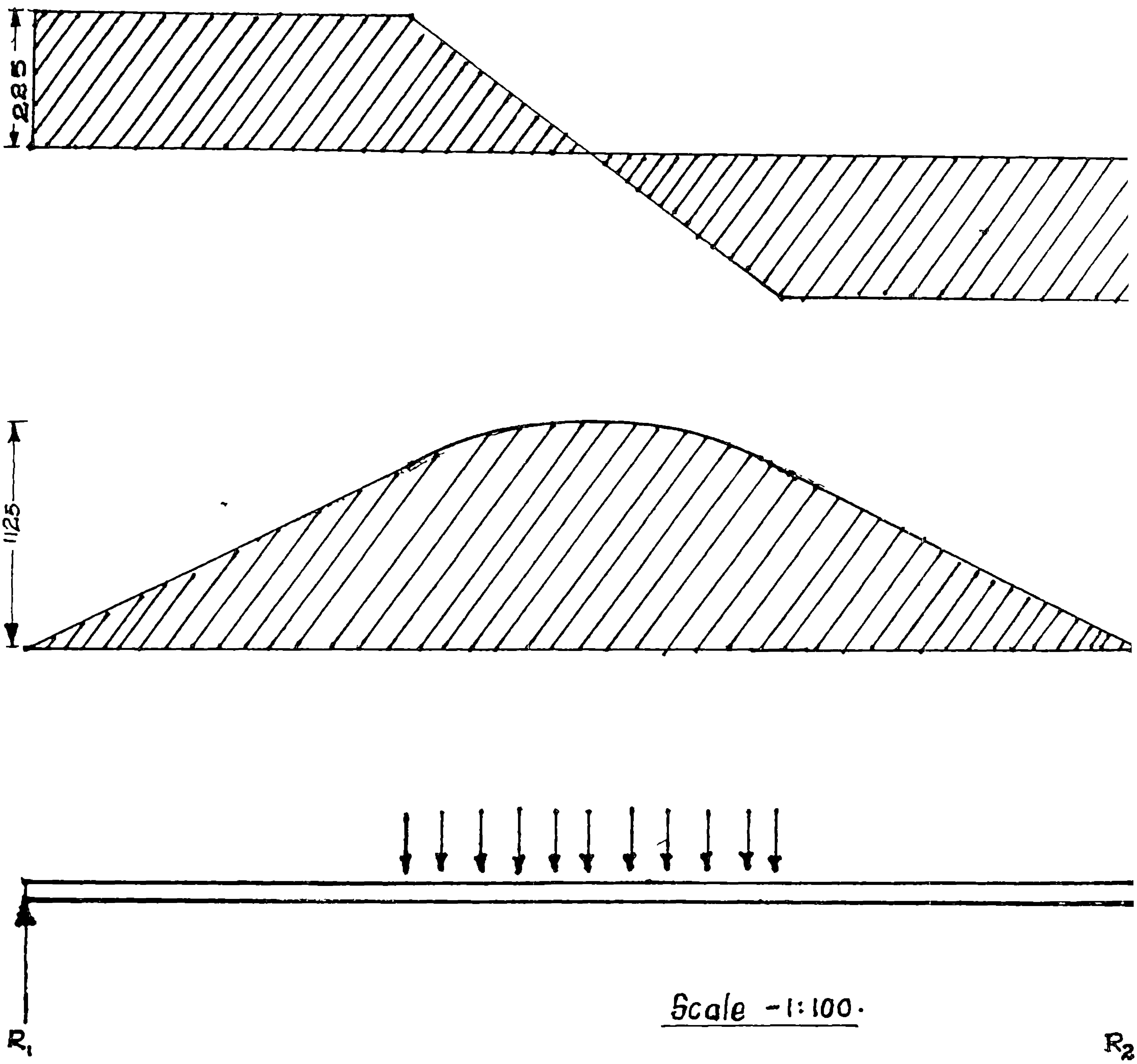


Fig.14 Analysis of forces on the shfat

Bending moment at X X section

$$M_x = R_1 X - W\,(x-4)\,\frac{(x-4)}{2}$$

where

M_x = Bending moment at section X X, kg.m

x = Distance of the Section X X from R_1

R_1 = Reaction at support 1, kg

W = Load per meter length of the pipe, kg/m

Because of the symmetry of loading maximum bending moment occurs at the centre, ie. when x = 6 m.

$$M_{max} = 225 \times 6 - 112.5 \times 2 \times \frac{2}{2}$$

$$= 1125 \text{ kg.m} = 112500 \text{ kg-cm}$$

Section modulus is given by

$$Z = \frac{M}{f}$$

where

Z - Section modulus

m - Bending moment

f - Safe stress

f can be taken as 1,650 kg/cm^2 for G.I. pipes.

$$Z = 112500/1650$$

$$= 68.18 \text{ cm}^3$$

For a pipe of 100 mm outer diameter and 85 mm inner diameter, section modulus is given by

$$I = \frac{\pi}{64}\,(d_2^{\,4} - d_1^{\,4})$$

and

$$Z = I/Y$$

where

d_2 = Outer diameter, cm

d_1 = Inner diameter, cm

Y = $D_2/2$

Z = Section modulus, cm^3

If pipe of same thickness having outer diameter of 85 mm is inserted inside the outer pipe the total thickness will be 15 mm.

So d_2 is 100 mm and d_1 is 70 mm

$$I = \frac{22}{7}/64\ (10^4 - 7^4)$$

$$= 373.01$$

$$Z = 373.01/5 = 74.6\ cm^3$$

Section modulus of the pipe is higher than the required section modulus. Hence a pipe of 100 mm diameter and 15 mm thickness can be used as the shaft.

3.1.3 Bearing

Nature of the load that the bearing has to take is combined thrust and radial load. The inner diameter of the bearing should be 100 mm to match with the shaft. Therefore, two taper roller bearings of 100 mm inner diameter (No.30220) was selected. Outer diameter of this bearing was 180 mm.

The static and dynamic load that can be taken by the bearing is 15,600 kg and 16,000 kg respectively. Since the expected load on the bearing is less than these values, bearings are safe. The maximum permissible speed of the bearing is 2500 rpm. The maximum expected speed is in the order of 70 - 100 rpm. Hence the bearings are safe as far as speed is concerned.

3.1.4 Stay wires

Total wind load as explained in section 3.1.2 is 450 kg. Point of action of this load from ground level can be calculated taking moments about the ground.

$$D = \frac{3 \times 2 \times 7 + 2 \times 1.5 \times 5}{3 \times 2 + 2 \times 1.5} = 6.33 \text{ m}$$

where

D - Distance from the ground, m.

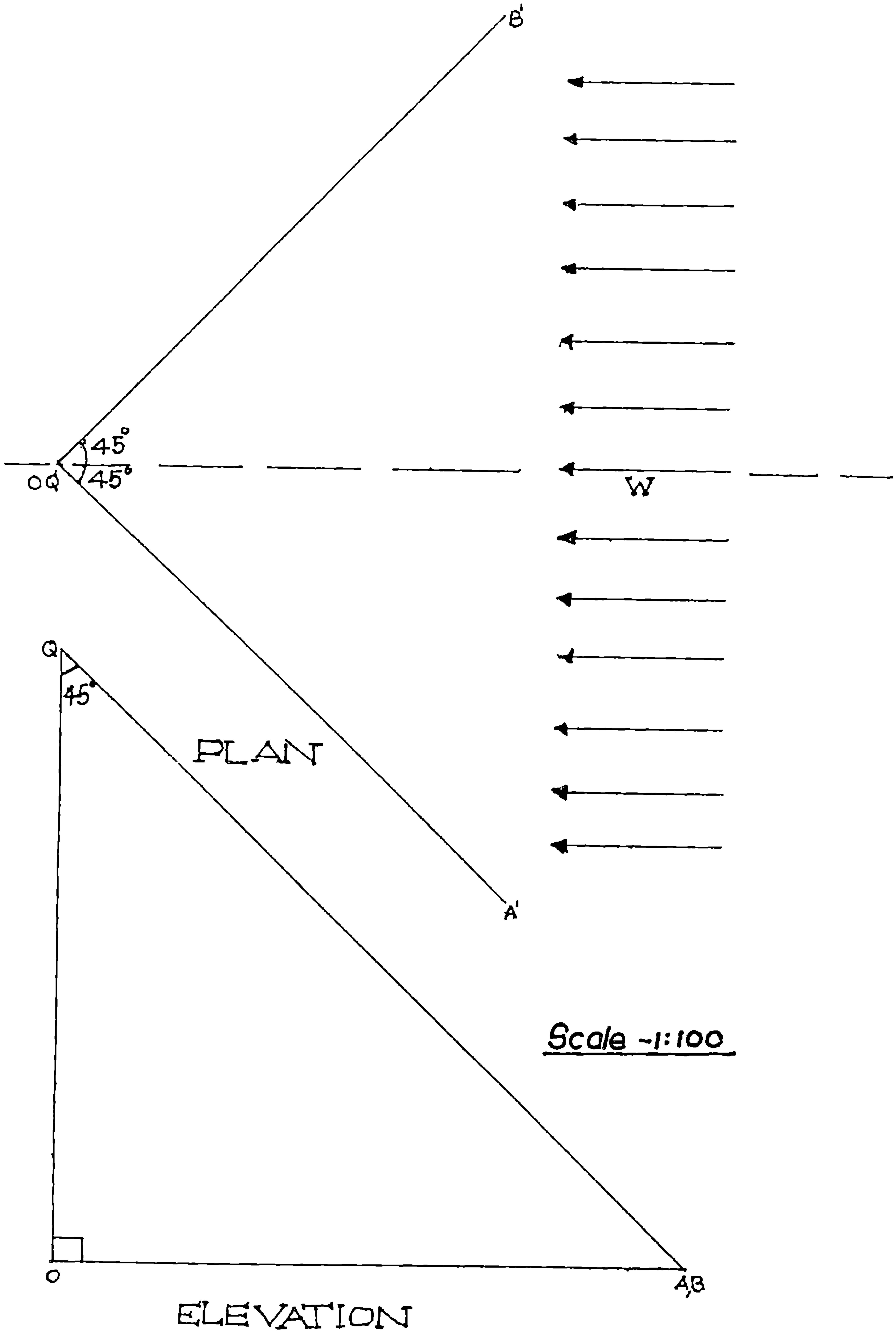


Fig.15 Analysis of forces on the stay wires

Four cables are provided, equidistant at 90 degree angle between the adjacent stays and 45 degree inclined to the shaft. Cables are provided in such a way that maximum horizontal pull due to the wind load is taken by the stays. Under the most unfavourable condition, the total load is assumed to be taken by one stay opposite to the wind direction. In equilibrium condition, from Fig.15

$$P_{OA} \times \cos 45 = 450 \text{ kg}$$

or

$$P_{OA} = 636.4 \text{ kg}$$

Taking allowable stress on the cable as 1,800 kg/cm^2, area of the stay

$$= \frac{636.4}{1800} = 0.35 \text{ cm} = 3.5 \text{ mm}$$

Four mild steel stays of 4 mm size are selected.

3.1.5 Foundation

Foundation of 1 m x 1 m x 1 m is provided to accommodate the bearing and instrumentation (Fig.16). The dimensions are checked for the safety of foundation as follows:

Self weight of foundation $P_1 = 2400 \times 1 \times 1 \times 1$
$= 2400$ kg

therefore

Density of concrete = 2400 kg/m^3

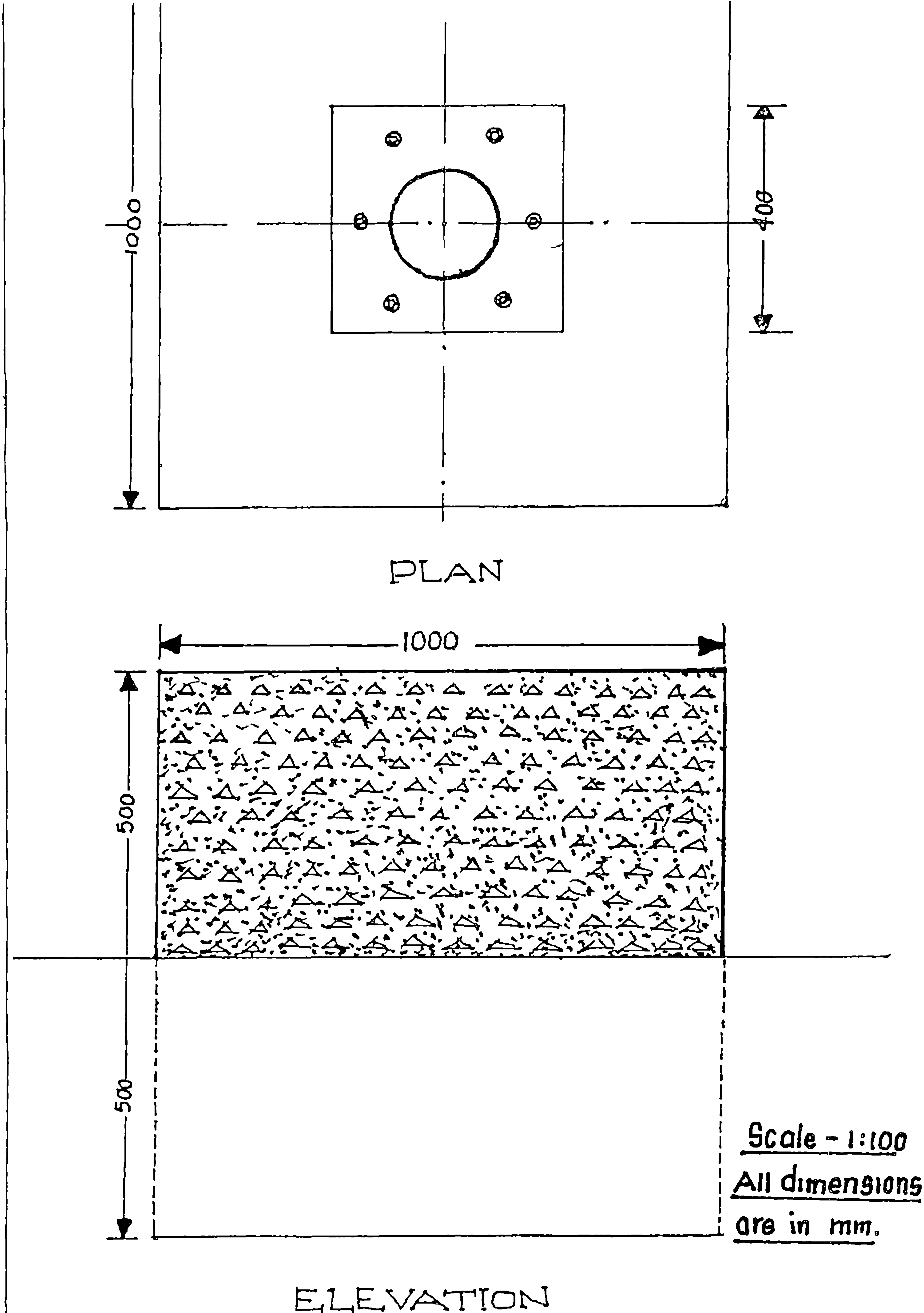


Fig.16 Foundation of the wind mill

Downward lead in the stay wire at the most unfavourable condition of wind (P_2)

$$P_2 = 450 \times 2 \times \cos 45$$

$$= 900 \times 0.7$$

$$= 630 \text{ kg}$$

Weight of structure (P_3) = 500 kg

Total weight = P1 + P2 + P3 = (630+500+2400) kg

= 3530 kg 3.53 tonnes

Upward pressure in the soil $= \frac{3530}{1 \times 1} = 3.53$ tonnes/m^2

Allowable upward pressure in the soil can be taken as 12 tonnes/m^2 which is quite higher than the calculated value 3.53 t/m^2. Hence the structure is safe.

$$\text{Net upward pressure } P = \frac{P_2 + P_3}{A}$$

Where

P_2 - downward load ~~is~~ on the staywire, kg

P_3 - Self weight of the structure, kg

A - Face area of the foundation, m^2

$$P = \frac{630 + 500}{1 \times 1} = 1,130 \text{ kg/m}^2$$

Bearing plate of 40 cm x 40 cm size was selected. Pressure on the concrete foundation,

$$= \frac{1130}{0.4 \times 0.4} = 7062.5 \text{ kg/m}^2$$

$$= 0.7062 \text{ kg/cm}^2$$

This is within permissible limit of concrete. Bending moment at the section

$$= 1130 \times 1 \times \frac{0.32}{2} = 51 \text{ kg}$$

$$\text{Tensile stress developed} = \frac{51}{0.5 \times 1 \times 0.67}$$

$$= 158 \text{ kg/m}^2$$

The permissible value is 2,000 kg/m^2 which is quite higher than the calculated value of 153 kg/m^2. Hence the foundation is safe.

3.1.6 Deflector Augmentor

A deflector augmentor of 4 m x 2 m was fabricated. Model studies showed that an angle of 60 degrees between the deflector and wind direction gives satisfactory results.

The effective wind facing area A^1 of the deflector is given by

$$A^1 = A \sin \theta$$

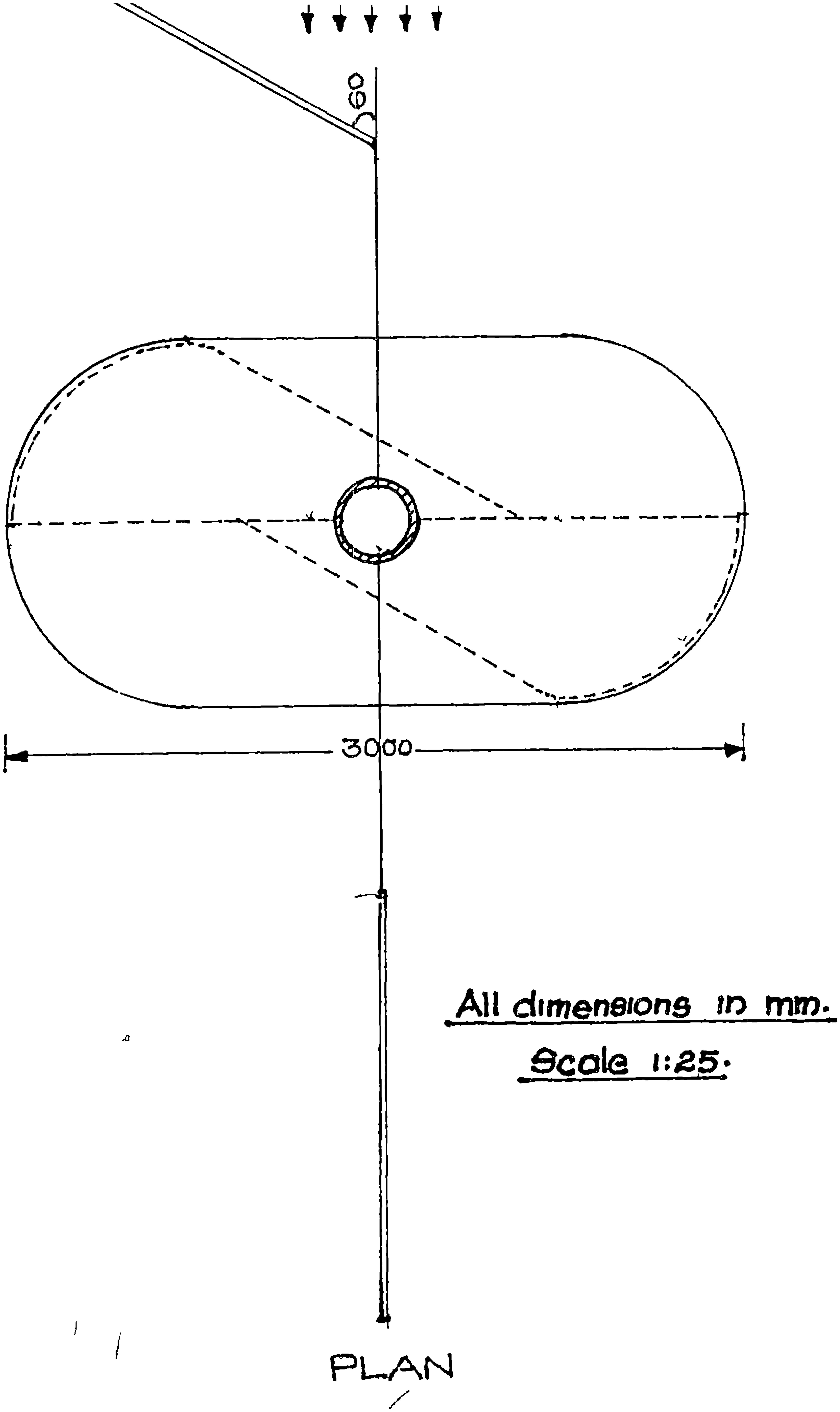


Fig.17 Wind mill with Deflector Augmentor

where

A = Total area of the deflector, m^2

θ = Angle at which the deflector is set with the wind direction.

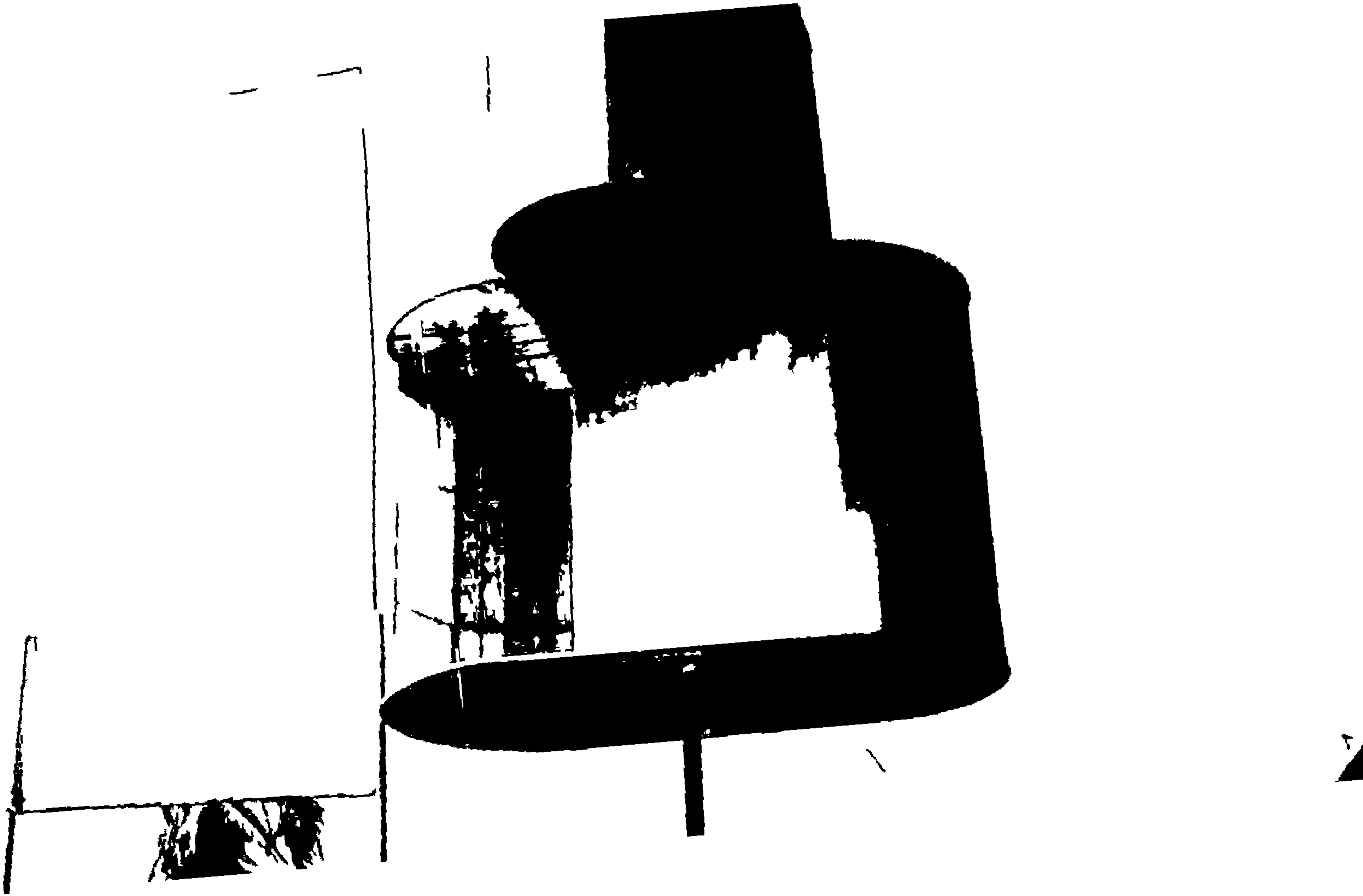
So $A^1 = 8 \sin 60 \times 6.93\ m^2$

Tail of the deflector should have the same effective area as the wind facing part so that it will orient itself according to the direction of wind. Weight of the deflector should be balanced by the weight of the tail. So a tail as shown in Fig.17 was designed.

Analysis of wind data at the site showed that prevailing wind direction is almost constant from west to east. So deflector fixed in this direction will also serve the purpose. Due to lack of time, a self orienting deflector could not be fabricated and attached. Instead of that, a fixed deflector facing east to west direction was fabricated and fixed with the wind mill. Size of the structure was 8 m^2. It was placed at an angle of 60 degrees with the wind direction (Plate III).

Wind mill was tested as in Section 3.5 with and without the deflector augmentor.

Place III Savonius windmill with the deflector augmentor



3.2 Fabrication

Components of the wind mill are fabricated as per the design discussed in Section 3.1. Two rotors of 3 m x 2 m size were made. 25 mm x 25 mm x 3.125 mm mild steel angle iron was used for the fabrication of the rotor framework. Nylon ropes of 10 mm diameter were weaved across the structure to support the canvas sail.

Canvas cloth was used to cover the structure since it reduces the cost of production and weight. It was fixed on the angle iron frame using nylon threads. Two lengths (6 m) of G.I. pipe of 100 mm outer diameter are welded together to form the shaft. Another pipe was inserted at the joint to ensure the strength. Rotor is fixed on the shaft by clamps made of 50 mm mild steel flats. Stoppers were provided to avoid slipping of clamps over the shaft.

Two taper roller bearings (No.30220) of 100 mm inner diameter and 180 mm outer diameter were selected. Lower bearing fits into the bearing case welded to the bottom bearing plate. Top bearing was fitted in the bearing case positioned by the stay wires.

Four mild steel stay wires of 4 mm size were used to support the structure at top. They are equally spaced and have an angle of 45° with the shaft. Top end of the wires are tied to the hooks welded around the top bearing case. Lower end is anchored to the ground through suitable turn buckles for tightening the stay wires.

Foundation is made as per the design with a size of 1 m x 1 m x 1 m. A flat brakedrum of 150 mm diameter is fixed at a distance of 4 m from the lower end of the shaft for power transmission. The mid rotor height is fixed at 6 m above the ground.

3.3 Installation of the wind mill

Department of Science and Technology of State Government had identified Kuttippuram as one of the areas of high wind potential. Present model under study was decided to be installed at Kelappaji College of Agricultural Engineering and Technology, Tavanur, situated near Kuttippuram. Wind data of Tavanur, analysed by the wind energy scheme, Kelappaji College of Agricultural Engineering and Technology, also showed encouraging results.

While selecting the site, the effect of obstructions like barriers, buildings, trees etc. was considered. Topography of the land was also taken as another criteria for selection of site. A site near the College Hostel is selected and the wind mill was installed.

3.4 Experimental set up

Test set up to measure the various parameters is discussed below.

3.4.1 Wind velocity

OTA KEIKI vane type anemometer was used to measure the wind velocity. It gives the total distance travelled by the wind in metres. In order to get the velocity, the readings should be divided by the time interval in which the readings are taken.

$$\text{ie. } V = \frac{L}{T}$$

where

V - Wind velocity, m/s

L - Distance travelled in metres read from the anemometer, m

T - Time interval, s

In order to get the accurate value of wind velocity the anemometer should face the wind direction. For this, a self adjusting device was fabricated (Plate IV). It will direct the anemometer against the wind. It consisted a G.I. pipe with a ball bearing fitted at its end. A 1.25 mm mild steel rod is fixed on the bearing which carries a tail at its one end and anemometer at the other end as shown in

Plate IV A self aligning device for measuring wind velocity

the figure. When wind blows, the tail adjusts itself, directing the anemometer against the wind.

3.4.2 Torque

Torque was calculated by measuring the forces in the tight and slack side of the belt, passing over the brake drum which is fixed on the shaft as shown in Plate V. For measuring the forces, two spring balances were used.

One end of each of the balances were hooked to the free end of the belt and other end was fixed stationary.

When the shaft was rotated by wind, force was transmitted to the balances through the belts. Force on tight side was read on balance 'A' and that on slack side, 'B'. Effective force was the difference between these two readings.

$$F = F_A - F_B$$

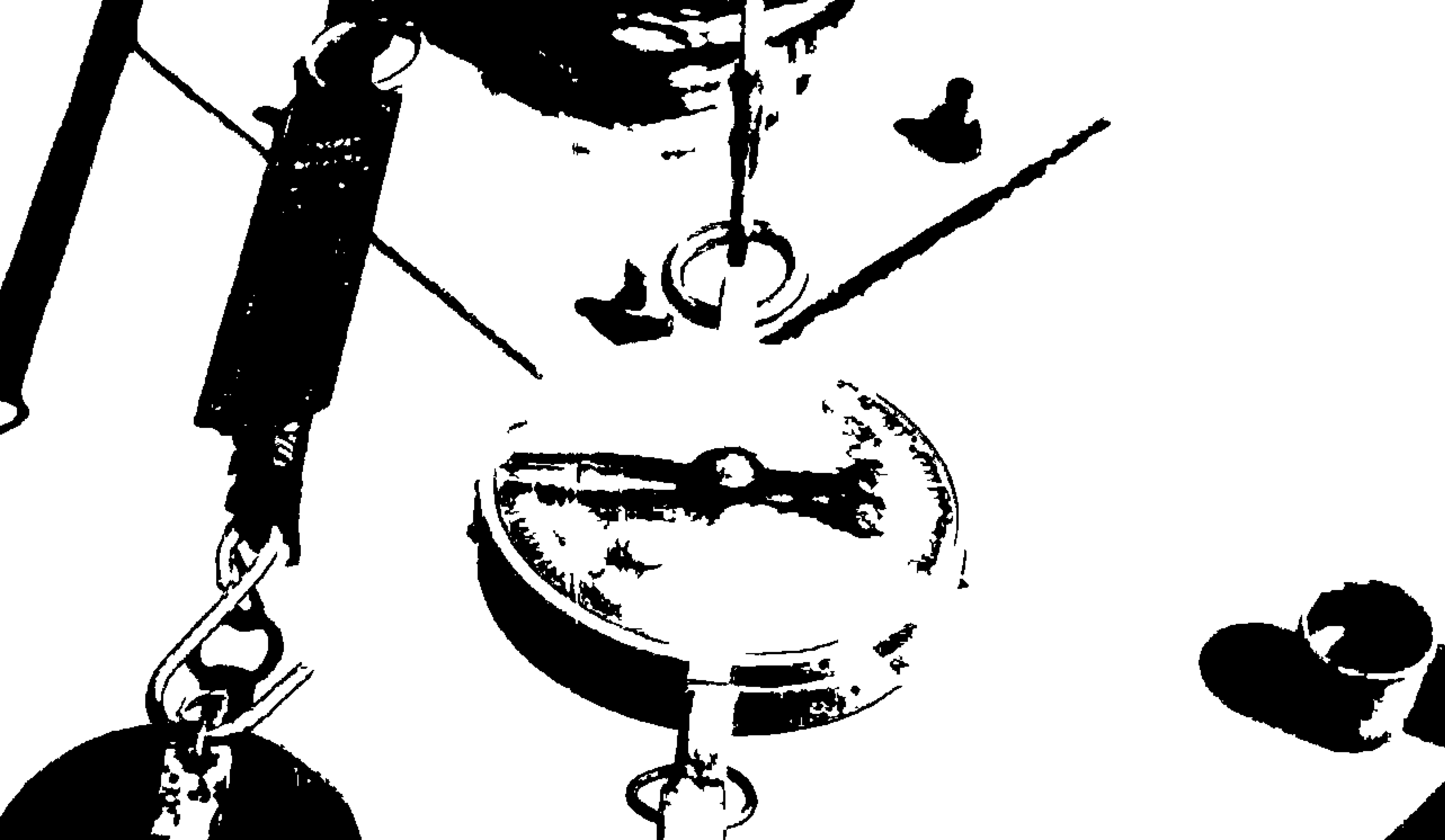
where

F - Effective force on the brake drum, kg.

F_A - Force on the tight side of the brake drum, kg.

F_B - Force on the slack side of the brake drum, kg.

Plate V   Set up for measuring torque



Torque produced by the shaft is given by

$T = F \times r$, where r is the effective radius of brake drum, m.

3.4.2 Speed

Power developed by the wind mill varies directly as the rpm of the rotor. Contact type tachometer was used for rotor speed measurement.

A rubber disc adapter was used with the tachometer to take the readings. Peripheral velocity of the shaft was obtained by dividing the dial reading by ten. Speed of the shaft could be calculated from the peripheral velocity using the relation

$$N = V/\pi D$$

N = Speed of the shaft, rpm

V = Peripheral velocity, m/s

D = Diameter of the shaft, m

3.5 Experimental procedure

3.5.1 Power

Power developed by the wind mill was calculated by the expression

$$P = 2\pi NT/4500$$

where

P^1 = Power developed, hp

N = Speed of the rotor, rpm

T = Torque, kg.m

N and T were obtained as discussed under Sections 3.4.1 and 3.4.2. Thus P^1 was calculated.

3.5.2 Power coefficient (C_p)

Power coefficient is defined as the ratio of power delivered to the turbine to the total power available in the crossectional area of the wind stream.

$$C_p = P^1/P_T$$

C_p = Power coefficient

P^1 = Power delivered to the turbine

P_T = $1/2\ \rho\ AV_o^3$

ρ = Mass density of air

V_o = Steady state wind velocity

A = Cross sectional area of the turbine

P^1 and P_T were calculated and power coefficient was determined for different wind velocities.

3.5.3 Tip speed ratio

Tip speed ratio is defined as the ratio of the speed at which the rotor tip moves, to the wind speed.

$$\lambda = \frac{R\Omega}{V}$$

where

λ = Tip speed ratio

R = Blade tip radius, m

Ω = Rotor angular velocity, rod/s

V = Wind velocity, m/s

Speed at which the rotor perimeter moves can be calculated by

$$S = N\pi D/60$$

where

S - Peripheral speed of rotor, m/s

N - Speed of the rotor, rpm

D - Diameter of rotor, m

3.5.4 Torque coefficient

Torque coefficient is the ratio of actual torque produced by the turbine to the maximum torque that can be produced by it.

$$C_T = T/T_{max}$$

where

C_T = Torque coefficient

T = Actual torque, kg.m

T_{max} = Maximum torque, kg.m

$$T_{max} = \rho A V^2 (V \lambda)/2\omega = \frac{P \lambda}{\omega}$$

where

ρ - Mass density of air, kg/m^3

A - Area, m^2

V - Velocity of wind, m/s

λ - Tip speed ratio

ω - Angular velocity, rad/s

Shaft power is the power delivered from the turbine P^1.

So, $P^1 = T\omega$

But $P^1 = C_p \times P_T$

Thus $C_p P_0 = C_T P_0$

$$C_T = C_p/\lambda$$

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The results of the performance evaluation of the savonius wind mill explained in the preceding chapter with and without the deflector augmentor are discussed in this chapter.

4.1 Savonius wind mill without the deflector augmentor

4.1.1 Torque characteristics

The wind mill was tested in the field at different wind velocities and the corresponding torque obtained is presented in Table 2. From the table it is seen that the maximum torque produced was 2.651 kg.m at a wind velocity 4.154 m/s.

4.1.2 Rotor speed

The speed of the wind mill obtained from the field evaluation is shown in Table 2. It ranged from 2.97 rpm to 30.48 rpm in a wind velocity range of 2.418 m/s to 4.154 m/s.

4.1.3 Tip speed ratio

Table 3 summarises the variation of tip speed ratio

Table 2. Torque, rotor speed, power developed and power available at the rotor crosssection at different wind velocities.

Sl. No.	Torque (kg.m)	Rotor speed (rpm)	Power developed (hp)	Power available at the rotor crosssection (hp)	Wind velocity (m/s)
1	0.863	2.972	0.0036	0.149	2.418
2	0.908	3.880	0.0049	0.169	2.522
3	1.203	5.429	0.0091	0.175	2.552
4	1.170	5.246	0.0086	0.199	2.666
5	1.140	4.961	0.0079	0.232	2.802
6	1.627	7.590	0.0172	0.239	2.831
7	1.643	8.618	0.0198	0.250	2.873
8	1.268	7.562	0.0138	0.253	2.882
9	1.845	10.063	0.0259	0.252	2.878
10	1.485	7.357	0.0153	0.254	2.888
11	1.683	10.033	0.0236	0.271	2.950
12	1.710	11.450	0.0273	0.297	3.042
13	2.067	11.772	0.0340	0.312	3.091
14	1.628	9.997	0.0227	0.325	3.133
15	1.492	9.716	0.0202	0.326	3.139
16	1.973	12.522	0.0345	0.332	3.156
17	2.212	13.795	0.0426	0.338	3.176

Contd....

Table 2 contd....

Sl. No.	Torque (kg.m)	Rotor speed (rpm)	Power developed (hp)	Power available at the rotor crosssection (hp)	Wind velocity (m/s)
18	2.130	13.243	0.0394	0.345	3.199
19	2.250	14.420	0.0450	0.339	3.180
20	2.250	15.340	0.0482	0.360	3.242
21	2.374	16.136	0.0535	0.374	3.284
22	2.428	18.466	0.0626	0.417	3.407
23	2.415	18.862	0.0636	0.442	3.472
24	2.521	21.050	0.0741	0.504	3.628
25	2.572	22.128	0.0794	0.520	3.665
26	2.617	24.615	0.0899	0.588	3.819
27	2.261	26.907	0.0984	0.683	4.016
28	2.628	27.784	0.1019	0.684	4.017
29	2.631	30.478	0.1119	0.756	4.154

with wind velocity. From the table it can be seen that it varies from 0.193 to 1.152 at different wind velocities.

4.1.4 Power characteristic

Power developed by the savonius wind mill at different wind velocities are compared with the power available in the crosssectional area of the rotor and presented in Table 2. From the table, it can be seen that power developed by the wind mill ranged from 0.00385 hp at 2.418 m/s to 0.119 hp at 4.154 m/s wind velocity. Total power available in the crosssectional area of the rotor at these wind velocities were 0.1492 hp and 0.7564 hp respectively.

4.1.5 Variation of coefficient of power with tip speed ratio

The coefficient of power and the corresponding tip speed ratios are given in Table 3. A graph is plotted between coefficient of power and tip speed ratio (Fig.18). From the figure it can be seen that the maximum power coefficient is 0.155 at a tip speed ratio of 1.0. This is comparable with the results obtained elsewhere in the country. Fig.18 shows that power coefficient increases up to a tip speed ratio of 1.0. Below the tip speed ratio of 0.75, the fall in efficiency was very steep. Therefore, the tip speed ratio range in which the rotor should run is

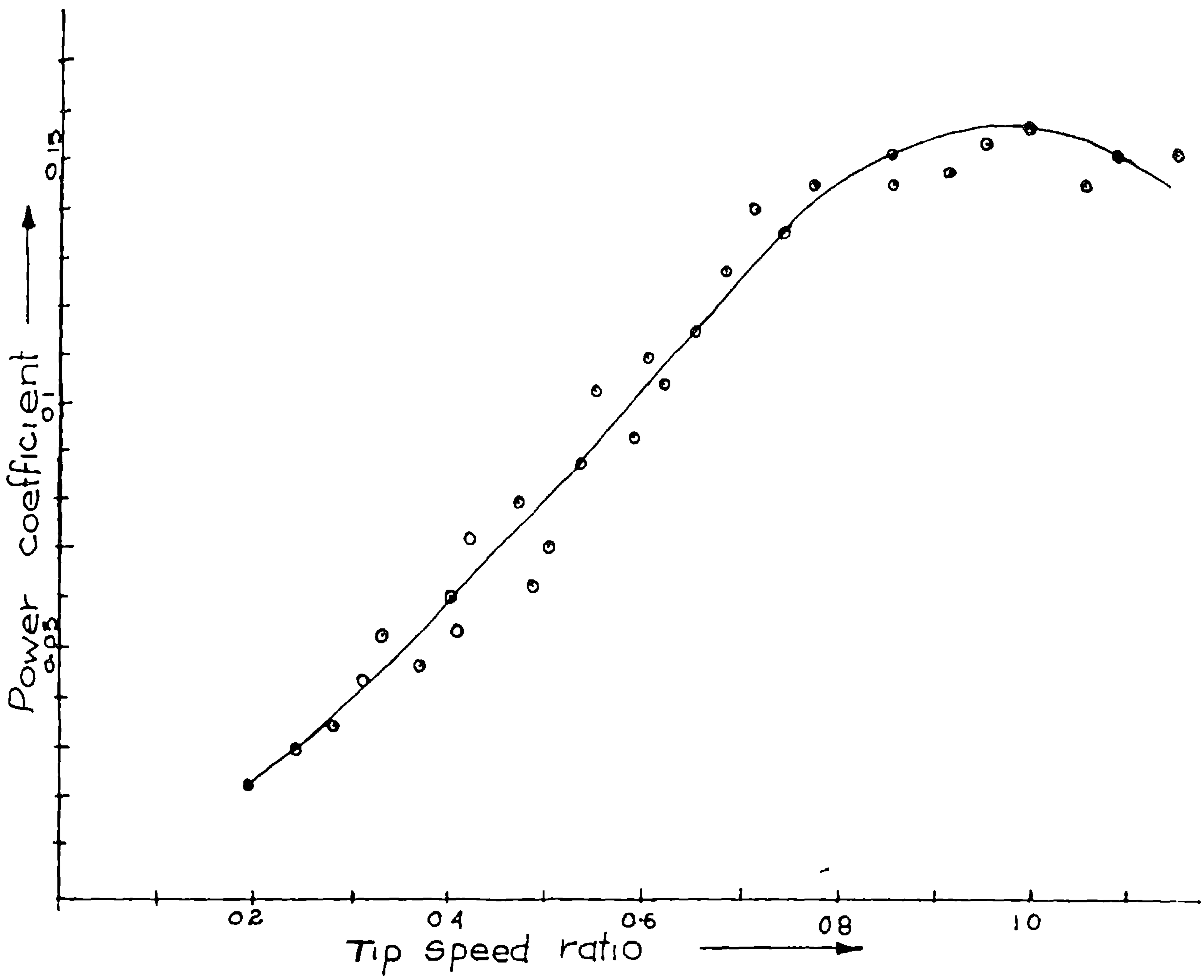


Fig.18 Variation of power coefficient with tip speed ratio

Table 3. Rotor tip speed, tip speed ratio, coefficient of power and coefficient of torque at different wind velocities.

Sl. No.	Wind velocity (m/s)	Rotor tip speed (m/s)	Tip speed ratio	Co-efficient of power	Co-efficient Torque
1	2.418	0.466	0.193	0.024	0.124
2	2.522	0.607	0.241	0.029	0.120
3	2.552	0.852	0.334	0.052	0.155
4	2.666	0.826	0.310	0.043	0.138
5	2.802	0.779	0.278	0.034	0.122
6	2.831	1.169	0.420	0.062	0.171
7	2.873	1.353	0.471	0.079	0.166
8	2.878	1.580	0.549	0.103	0.188
9	2.882	1.187	0.412	0.053	0.128
10	2.888	1.152	0.400	0.062	0.150
11	2.950	1.575	0.534	0.087	0.163
12	3.042	1.798	0.591	0.092	0.156
13	3.091	1.848	0.598	0.109	0.182
14	3.133	1.569	0.501	0.070	0.139
15	3.139	1.526	0.486	0.062	0.128
16	3.156	1.966	0.623	0.104	0.167
17	3.176	2.166	0.682	0.126	0.185

Contd....

Table 3 contd....

Sl. No.	Wind velocity (m/s)	Rotor tip speed (m/s)	Tip speed ratio	Co-efficient of power	Co-efficient Torque
18	3.199	2.079	0.650	0.114	0.175
19	3.180	2.764	0.712	0.110	0.196
20	3.242	2.409	0.743	0.134	0.180
21	3.284	2.532	0.771	0.143	0.185
22	3.407	2.899	0.851	0.150	0.176
23	3.472	2.961	0.853	0.144	0.168
24	3.628	3.305	0.911	0.147	0.161
25	3.665	3.474	0.948	0.153	0.161
26	3.819	3.866	1.012	0.153	0.151
27	4.016	4.361	1.052	0.144	0.137
28	4.017	4.363	1.086	0.149	0.137
29	4.154	4.785	1.152	0.148	0.128

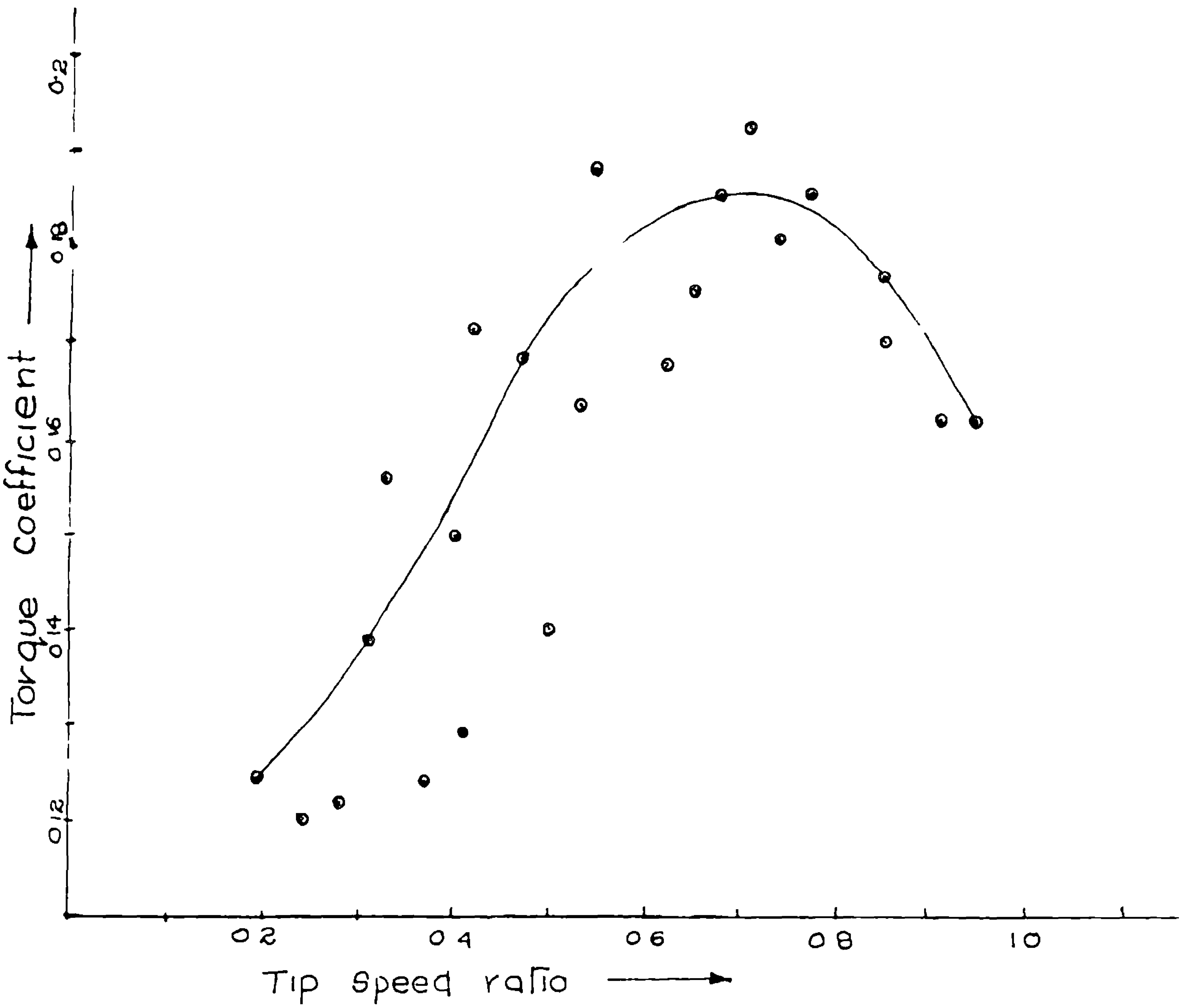


Fig.19 Variation of torque coefficient with tip speed ratio

0.75 to 1.0. The rotor obtained the maximum power coefficient at lower tip speed ratio, because it was a drag device.

4.1.6 Variation of the coefficient of torque with the tip speed ratio

Table 3 summarises the variation of coefficient of torque with tip speed ratio. A graph is plotted between coefficient of torque and tip speed ratio (Fig.19). From the figure it is seen that the maximum coefficient of torque was 0.185 at a tip speed ratio of 0.75. This is comparable with the results obtained elsewhere also. The torque coefficient varies from 0.165 to 0.185 at a tip speed ratio range of 0.45 to 0.75.

From the test results it can be concluded that from power as well as torque point of view, the optimum tip speed ratio of the rotor is in the range of 0.5 to 0.9.

4.2 Savonius wind mill with deflector augmentor

4.2.1 Torque characteristics

Torque produced by the savonius wind mill attached with the deflector augmentor at different wind velocities are presented in Table 4. Torque produced was found to be increased when the deflector augmentor was attached to the

Table 4. Torque, rotor speed, power developed and power available at the rotor crosssection at different wind velocities.

(Rotor with deflector augmentor)

Sl. No.	Wind velocity (m/s)	Torque (kg.m)	Rotor speed (rpm)	Power developed (hp)	Power available at the rotor crosssection (hp)
1	1.456	1.125	1.409	0.0024	0.032
2	1.502	1.443	2.344	0.003	0.035
3	1.696	1.686	3.521	0.008	0.051
4	1.741	1.367	3.249	0.006	0.055
5	1.890	1.256	3.575	0.006	0.071
6	1.901	1.486	4.855	0.010	0.071
7	1.949	1.896	6.230	0.016	0.078
8	1.967	1.712	5.688	0.014	0.080
9	1.975	1.813	6.201	0.016	0.813
10	2.056	1.723	6.822	0.016	0.092
11	2.162	1.626	6.857	0.015	0.106
12	2.243	2.217	9.771	0.032	0.119
13	2.463	2.314	13.083	0.042	0.157
14	2.495	2.137	13.078	0.039	0.164
15	2.522	2.412	14.633	0.049	0.169

Contd....

Table 4 contd....

Sl. No.	Wind velocity (m/s)	Torque (kg.m)	Rotor speed (rpm)	Power developed (hp)	Power available at the rotor crosssection (hp)
16	2.790	2.387	19.190	0.064	0.229
17	2.864	2.488	21.269	0.073	0.247
18	3.107	2.562	25.923	0.092	0.316
19	3.140	2.677	27.000	0.102	0.327
20	3.452	2.783	34.738	0.135	0.434
21	3.724	2.886	40.582	0.164	0.545
22	4.169	2.936	53.379	0.218	0.765

wind mill. A maximum torque of 2.936 kg.m was obtained at a wind velocity of 4.16 m/s.

4.2.2 Rotor speed

Table 4 shows the rotor speed and corresponding wind velocities. Rotor speed of the wind mill ranged from 1.4 rpm at 1.45 m/s wind velocity to 53.38 rpm at 4.16 m/s wind velocity. For the same wind velocity wind mill fitted with the deflector augmentor gave a higher rotor speed than the wind mill without the deflector augmentor.

4.2.3 Tip speed ratio

The wind mill was found to work in a higher tip speed ratio when deflector augmentor was attached to it. Tip speed ratio showed a variation from 0.152 to 2.01. Values of tip speed ratio at different wind velocities are tabulated in Table 5.

4.2.4 Power characteristics

An increase in power developed was noted when augmentor was attached to the wind mill. Table 4 presents the power developed by the wind mill and the actual power available in the crosssectional area of the rotor. It can be seen that the rotor with the augmentor produced a power of 0.218 hp at a wind velocity of 4.169 m/s. Total power

Table 5. Rotor tip speed, tip speed ratio, coefficient of power and coefficient of torque at different wind velocities.

(Rotor with deflector augmentor)

Sl. No.	Wind velocity (m/s)	Rotor tip speed (m/s)	Tip speed ratio	Co-efficient of power	Co-efficient Torque
1	1.456	0.221	0.152	0.068	0.447
2	1.502	0.368	0.245	0.132	0.539
3	1.696	0.553	0.326	0.161	0.494
4	1.741	0.510	0.293	0.113	0.386
5	1.890	0.561	0.297	0.088	0.296
6	1.901	0.762	0.401	0.139	0.339
7	1.949	0.978	0.502	0.211	0.420
8	1.967	0.843	0.454	0.169	0.372
9	1.975	0.974	0.493	0.193	0.391
10	2.056	1.070	0.521	0.179	0.343
11	2.090	1.358	0.650	0.250	0.385
12	2.243	1.534	0.684	0.254	0.371
13	2.463	2.054	0.834	0.268	0.321
14	2.495	2.053	0.823	0.238	0.288
15	2.522	2.297	0.911	0.291	0.293

Contd....

Table 5 contd....

Sl. No.	Wind velocity (m/s)	Rotor tip speed (m/s)	Tip speed ratio	Co-efficient of power	Co-efficient of Torque
16	2.790	3.013	1.080	0.279	0.283
17	2.864	3.339	1.166	0.298	0.255
18	3.107	4.069	1.310	0.293	0.224
19	3.140	4.365	1.390	0.312	0.224
20	3.452	5.454	1.580	0.311	0.196
21	3.724	6.731	1.711	0.300	0.175
22	4.167	8.381	2.010	0.286	0.142

available at the crosssectional area of the rotor, at this wind velocity, was 0.765 hp.

4.2.5 Variation of power coefficient with tip speed ratio

Coefficient of power and corresponding tip speed ratios are presented in Table 5. A graph is plotted between coefficient of power and tip speed ratio (Fig.20). From the figure it can be seen that a maximum power coefficient of 0.32 was obtained at a tip speed ratio of 1.54. This indicates that the power coefficient is almost doubled when deflector augmentor was attached to the wind mill. Power coefficient increased up to tip speed ratio of 1.58 and after that it declined. In the range of tip speed ratio 0.8 to 1.58, an increase in efficiency of 16 percent was obtained. Below the tip speed ratio 0.8, fall in the efficiency was very steep. Therefore the tip speed ratio range at which the rotor should run is 0.8 to 1.54, as far as coefficient of power is concerned.

4.2.6 Variation of torque coefficient with tip speed ratio

Table 5 shows the variation of torque coefficient with tip speed ratio. A graph is plotted between coefficient of torque and tip speed ratio (Fig.21). Coefficient

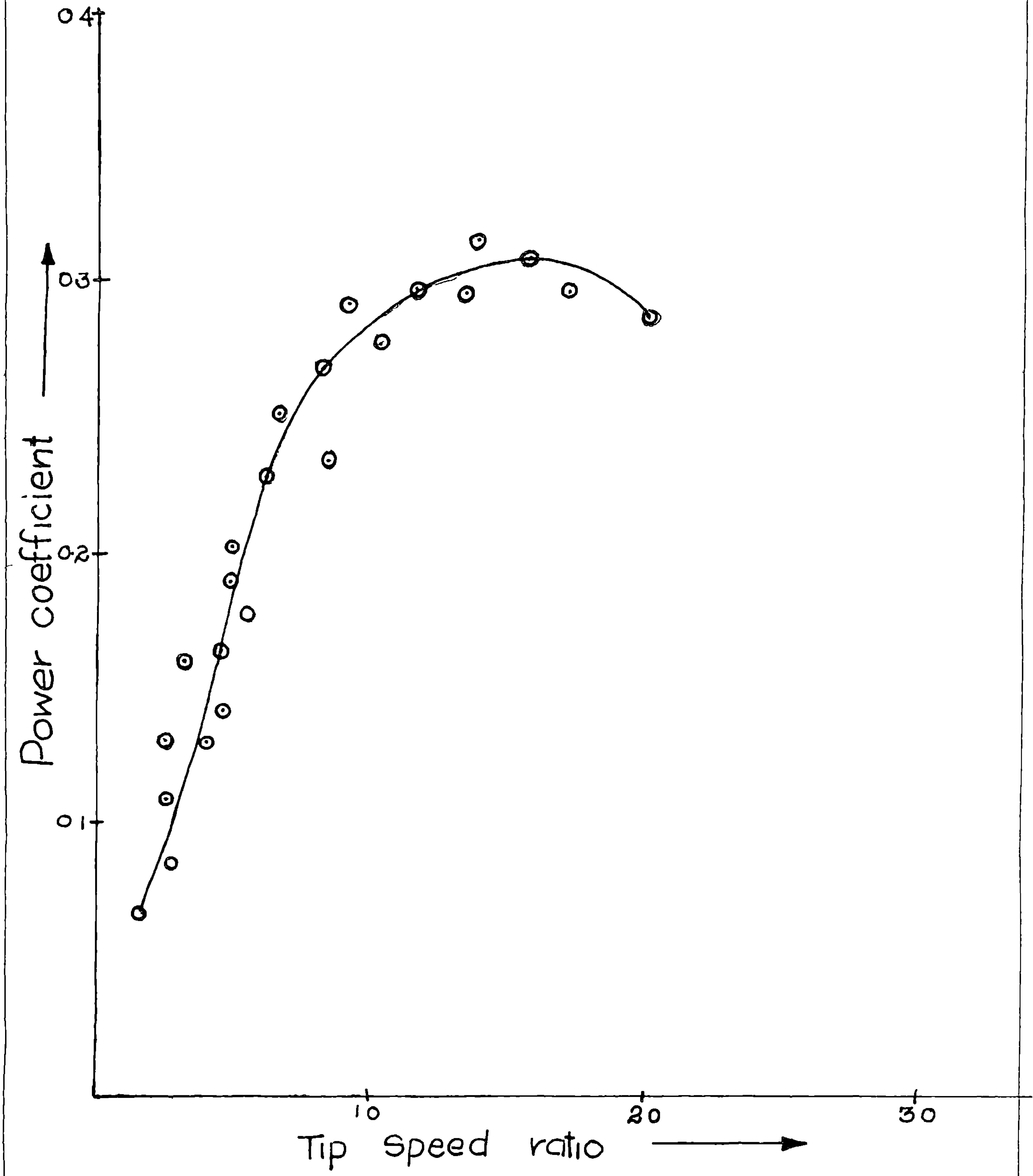


Fig.20 Variation of power coefficient with tip speed ratio

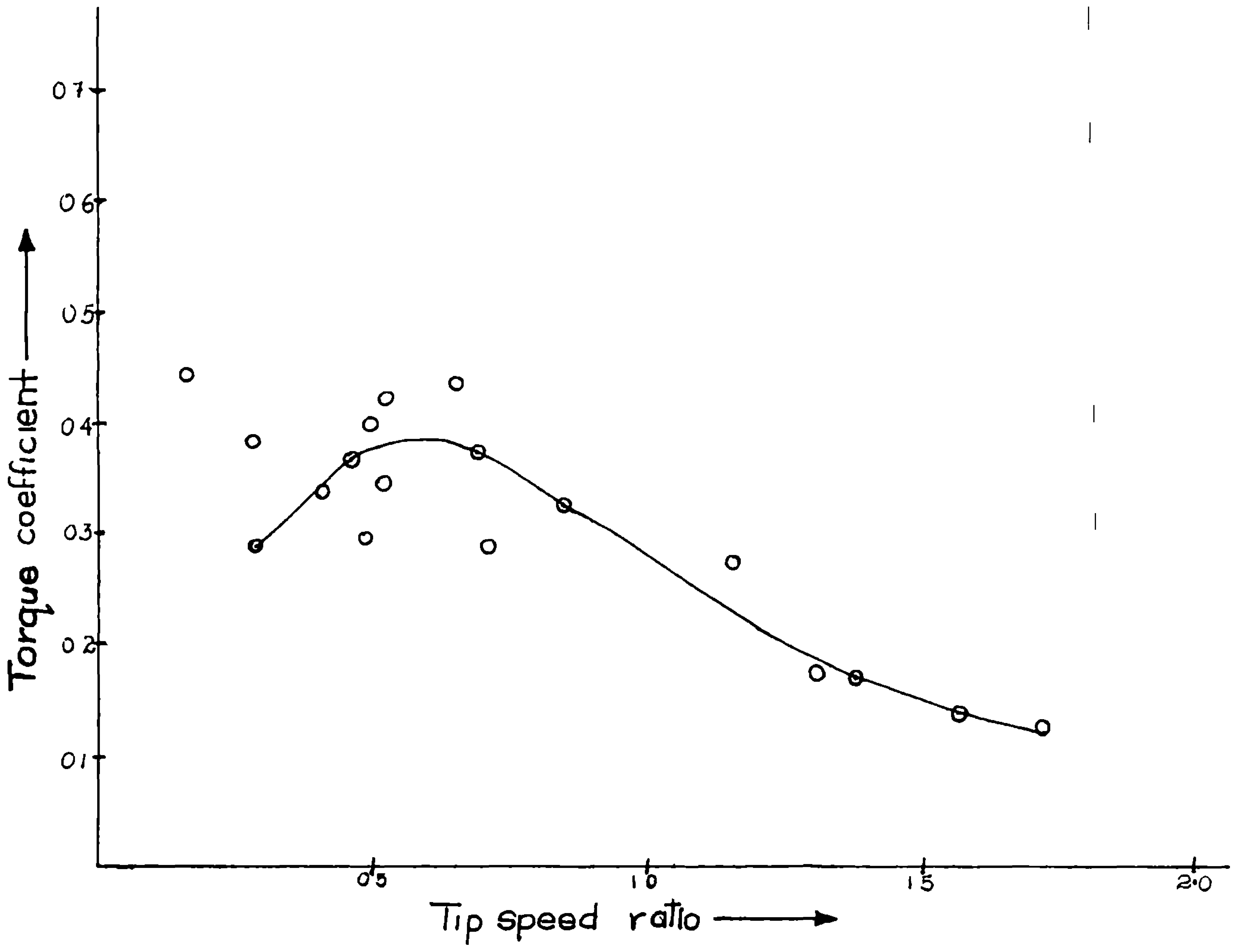


Fig.21 Variation of torque coefficient with tip speed ratio

of torque attained a maximum value of 0.385 at a tip speed ratio of 0.56. At a tip speed ratio range of 0.4 to 0.56, torque coefficient varied from 0.325 to 0.385. This range can be recommended as the optimum tip speed ratio as far as torque coefficient is concerned. Torque coefficient increased from 0.185 to 0.385 when deflector augmentor was attached to the wind mill. This result is quite encouraging.

4.3 Effect of the deflector augmentor

By introducing the deflector augmentor, power coefficient could be increased by 106.5 percentage and torque coefficient could be increased by 108 percentage. This is illustrated in Fig.22. Moreover, the cut in velocity of the wind mill was considerably reduced from 2.4 m/s to 1.4 m/s and the wind mill worked at higher tip speed ratios. The speed of the rotor and the torque produced by it were also increased.

The effect of the deflector augmentor as seen from Fig.17 is to give a shade to the convex half of the rotor and to divert this wind to the concave half of it. As the rotor experiences the torque due to the difference in the coefficient of drag, when the convex and concave sides of the cylindrical rotor parts faces the wind, the effect of shading is improving the performance considerably as evidenced from the test results.

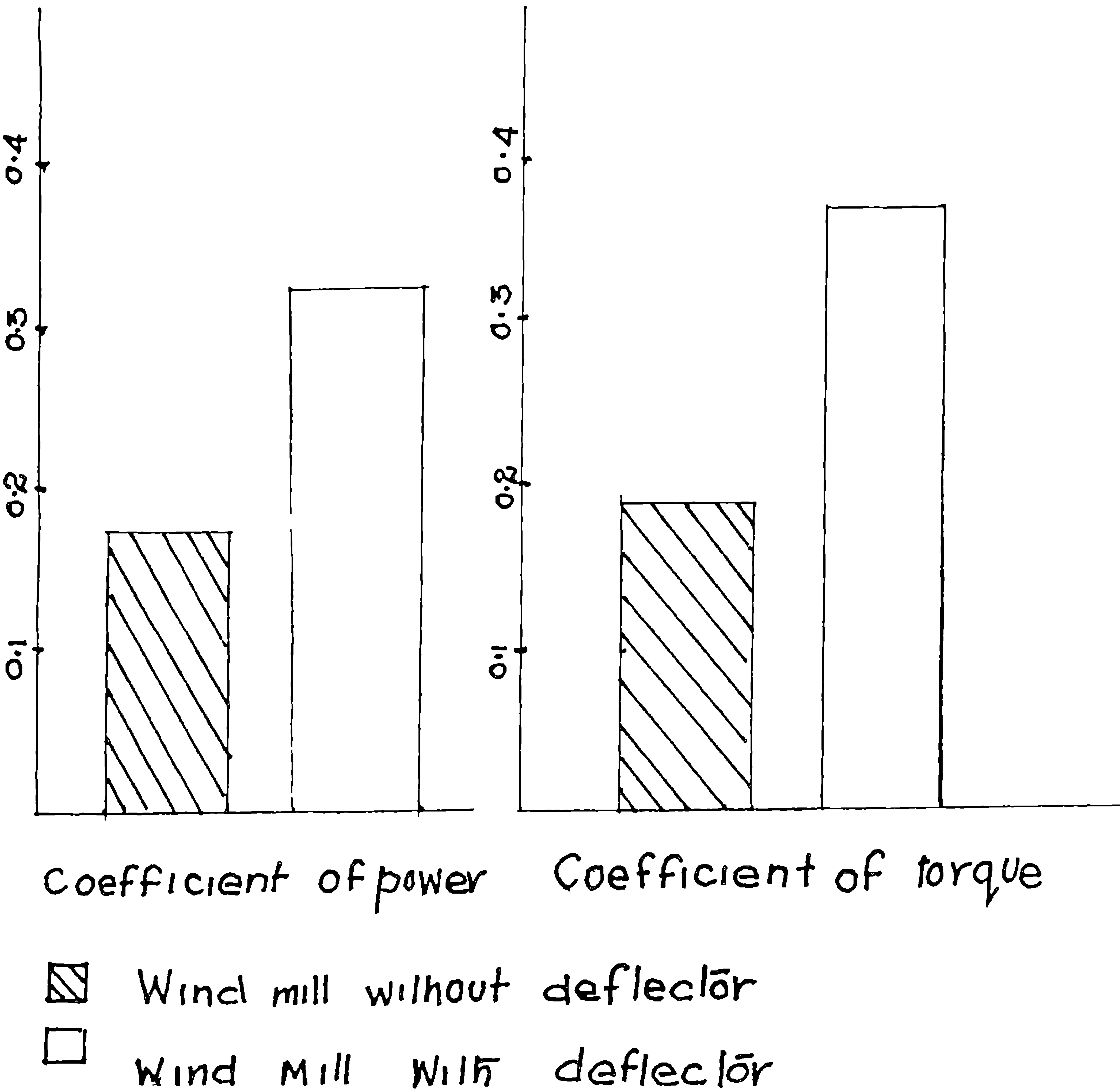


Fig.22 Effect of deflector augmentor on windmill performance

4.4 Cost analysis

The operating cost of the wind mill was worked out on the basis of assumptions and calculations given in Appendix   Total hours of working of the wind mill in a year was assumed to be 3,000. Life of the wind mill was taken as 15 years and in every two years the canvas has to be replaced. Operating cost of the wind mill was calculated as Rs.1.43 per bhp hr. Operating cost of the wind mill is compared with that of diesel and electric power. It was found to be comparable with the diesel power and slightly costlier than electric power.

SUMMARY

SUMMARY

Since conventional energy sources are running out, they must be supplemented by renewable energy sources. A wide variety of renewable energy sources are available and wind energy is one among them. Wind energy has got reasonable potential for water pumping in many parts of Kerala. Savonius rotors are found most suitable for water pumping.

The conventional savonius rotors have the disadvantage that they have low coefficient of power. A deflector augmentor attached to the savonius rotor was expected to increase the power coefficient considerably. Hence a savonius rotor with a deflector augmentor was designed, fabricated and tested at Kelappaji College of Agricultural Engineering, Tavanur. The features of the wind mill are discussed below:

1. The wind mill was expected to produce 0.2 hp at 14 km/hr wind velocity.

2. The wind facing area of the rotor was calculated as 12 m^2. Two rotors of 2 m x 3 m diameter were fabricated and they were fixed one below the other at 90 degree out of phase. The frame was made up of 25 mm x 25 mm x 3 mm mild steel angles and covered with canvas cloth. Nylon ropes of 5 mm size were weaved across the structure to support the canvas sail.

3. The size of the shaft was designed considering the wind load acting on it, giving adequate factor of safety. Two 100 mm pipes of 6 m length were joined together to form the main shaft. Another pipe was inserted at the joint to reinforce the shaft to get designed crosssectional area.

4. Two taper roller bearings (No.30220) were selected for the wind mill. Bearing cases were made up of 50 mm x 5 mm mild steel flats.

5. Concrete foundation was designed considering the effective load on it. The size of the foundation was 1m x 1m x 1m. A 0.4 m x 0.4 m base plate was fixed on it using six bolts of 25 mm diameter.

6. Four stay wires of 4 mm size anchored the wind mill from the top. Stay wires are placed at 45 degree inclined to the shaft. Stays are placed equidistant to form 90 degree angle between adjacent stays.

7. A deflector augmentor of 4 m x 2 m size was fabricated and fixed at an angle 60° with the wind direction. The effective wind facing area of the deflector 6.93 m^2.

Wind mill was installed near the College hostel and tested with and without the deflector augmentor. Test results obtained are summarised below:

I. Wind mill without the deflector augmentor

1. The wind mill produced a torque of 2.631 kg.m at a wind velocity 4.154 m/s.

2. Rotor speed ranged from 2.97 rpm to 30.48 rpm at a wind velocity range of 2.418 m/s to 4.154 m/s.

3. The tip speed ratio varied from 0.193 to 1.152.

4. Wind mill produced a power of 0.119 hp at a wind velocity 4.154 m/s.

5. The maximum power coefficient of 0.155 was attained at a tip speed ratio of 1.0. Power coefficient increases up to the tip speed ratio of 1.0, and then showed a reducing trend. Below the tip speed ratio of 0.75 fall in the efficiency was very steep.

6. Maximum torque coefficient attained was 0.185 at a tip speed ratio of 0.75. Torque coefficient showed a sharp decline below the tip speed ratio of 0.45.

7. The optimum tip speed ratio of the wind mill, from power as well as torque point of view, was in the range of 0.5 to 0.9.

II. Wind mill with the deflector augmentor

1. Wind mill produced a torque of 2.936 kg.m at a wind velocity of 4.16 m/s.

2. Rotor speed was found to range from 1.4 rpm to 53.8 rpm at a wind velocity range of 1.45 m/s to 4.16 m/s.

3. Wind mill was found to work in a tip speed ratio range of 0.193 to 2.01.

4. It produced a power of 0.210 hp at a wind velocity of 4.169 m/s.

5. The maximum power coefficient attained by the wind mill was 0.32 at a tip speed ratio 1.54. After this value, the power coefficient decreased. Below the tip speed ratio 0.8, the fall in efficiency was very steep.

6. Coefficient of torque attained a maximum value of 0.385 at a tip speed ratio 0.50. Torque coefficient is found to be reduced at tip speed ratios higher than 0.56. Below the tip speed ratio 0.4, fall in the torque coefficient was very steep.

7. The optimum tip speed ratio of the wind mill with the deflector augmentor, from power as well as torque point of view, was in the range of 0.5 to 1.5.

Effect of the deflector augmentor on the wind mill performance was studied by comparing the results obtained from testing the wind mill with and without the deflector augmentor.

1. Power coefficient was found to increase by 100 percent.

2. Torque coefficient was found to increase by 100 percent.

3. Wind mill was found to work in higher tip speed ratios.

4. The cut in speed of the wind mill was found to be reduced from 2.4 m/s to 1.4 m/s.

The cost of operation of the wind mill is Rs.1.43 per bhp hr. It is comparable with the diesel power and found slightly costlier than electric power.

Following suggestions are made for the further improvement of the wind mill.

1. The permanently fixed deflector may be replaced by a self orienting deflector augmentor.

2. Canvas sails may be replaced by aluminium sails to increase the life of the rotor.

3. A set of matching devices for loading such as pumps, aerogenerators and that sort may be coupled and evaluated.

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APPENDICES

Appendix - I

Instrumentation

a) Specifications of the anemometer

Make	-	OTA KEIKI, Japan
Serial Number	-	232412
Number of blades	-	8
Range	-	0 to 1,00,000 m
Possible measuring wind speed	-	1 to 15 m/s

b) Specifications of spring balances

Balance A

Make	-	Rebure, Germany
Range	-	0 to 50 kg

Balance B

Make	-	Kamal, India
Range	-	0 to 20 kg

c) Specifications of the hand tachometer

Make	-	Prestige, India
Serial Number	-	007629
Type Number	-	630
Range	-	30 to 50,000

Appendix - II

Calculation of operating cost of the wind mill

1. Assumptions

Life of the wind mill	..	15 years
Life of canvas cloth	..	2 years
Salvage value	..	10% of the initial cost
Repair and maintenance	..	1% of the initial cost
Rate of interest	..	8%

2. Investments

Cost of frame work of the rotor	..	Rs.2,000/-
Cost of G.I. pipe for the shaft	..	500/-
Cost of bearings	..	1,000/-
Cost of canvas for the life period	..	2,000/-
Foundation	..	1,000/-
Fabrication charges	..	1,000/-
Total	..	Rs.7,500/-

3. Calculations

Cost of wind mill	..	Rs.7,500/-
Life	..	15 years
Working hours	..	3,000/year

1. Depreciation per hour $= \frac{0.90}{LxH}$

$= \frac{0.9 \times 7500}{15 \times 3000} =$ Rs.0.15/-

2. Interest per hour $= \frac{0.55C}{H} \times i$

$= \frac{0.55 \times 7500}{3000} \times \frac{8}{100}$

= Rs.0.11/-

3. Maintenance per hour $= \frac{7500}{3000} \times \frac{1}{100}$

= Rs.0.025/-

Therefore total cost per hour = Rs.0.285

Cost per bhp hour = Rs.1.425

Appendix - III

Calculation of cost of using electric power

Assuming cost of 5 hp motor	=	Rs.4,000/-		
Life	=	10 years		
Working hours	=	1,500/ year		
1. Depreciation/hr	=	$\frac{0.9 \times 4000}{10 \times 1500}$	=	Rs.0.24
2. Interest/hr	=	$\frac{0.55 \times 4000}{1500} \times \frac{8}{100}$		
			=	Rs.0.117
3. Repair and maintenance/hr	=	$\frac{4000}{1500} \times \frac{6}{100}$	=	Rs.0.16
4. Energy cost/hr assuming 50 paise/unit	=	50 x 7.5	=	Rs.3.75
5. Standing charges per hour assuming Rs.1,500/- per year	=	$\frac{1500}{1500}$	=	Rs.1/-
Therefore total cost per hour			=	Rs.5.267
Cost per bhp hour			=	Rs.1.054

Appendix - IV

Calculation of cost of using stationary oil engines

Cost of the engine	=	Rs.7,000/-
Life	=	10 years
Working hours	=	1,500

1. Depreciation/hr $= \frac{0.9 \times 7000}{10 \times 1500} =$ Rs.0.42

2. Interest/hr $= \frac{0.55 \times 7000}{1500} \times \frac{8}{100}$

   = Rs.0.20

3. Repair and maintenance $= \frac{7000}{1500} \times \frac{6}{100} =$ Rs.0.28

4. Housing charges/hear $= \frac{200}{1500} =$ Rs.0.13

5. Fuel cost/hr assuming 1.5 litres/hr and Rs.4.50/litre = Rs.6.75

6. Lubrication charges assuming 30% of fuel charge = Rs.2/-

Therefore total cost per hour = Rs.9.80

Cost per bhp hour $= \frac{9.8}{5}$

= Rs.1.96

DESIGN, FABRICATION AND TESTING OF A SAVONIUS TYPE WINDMILL WITH A DEFLECTOR AUGMENTOR

By

SATYAJITH MATHEW

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of
the requirement for the degree
MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING
Faculty of Agricultural Engineering
Kerala Agricultural University

Department of Farm power Machinery and Energy
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Tavanur - Malappuram

1989

ABSTRACT

The study was conducted with the objectives of developing and testing a savonius wind mill and analysing the effect of a deflector augmentor on the performance characteristics of the rotor.

The wind mill was consisted of two rotors of 2 m x 3 m size fixed one below the other at 90 degree out of phase. A 100 mm galvanised iron pipe of 12 m length acts as the shaft. The shaft passes through two '30220' taper roller bearings. Lower bearing was fixed on a 1 m x 1 m x 1 m foundation and the upper bearing was positioned by four 4 mm guy wires. The guy wires were equidistant and forms an angle of 45 degree with the shaft.

This wind mill was tested under field conditions. Power developed by the wind mill was calculated by measuring the torque and rotor speed, and power delivered to the rotor was calculated by taking corresponding wind velocity. The coefficient of power and coefficient torque were calculated for different tip speed ratios. The wind mill was found to attain a maximum coefficient of power 0.155 at a tip speed ratio 1.0. Maximum torque coefficient attained was 0.185 at a tip speed ratio 0.75. Optimum tip speed ratio of the wind mill was found to be in a range of 0.5 to 0.9.

A deflector augmentor of 6.93 m^2 effective wind facing area was fixed at an angle of 60 degree with the wind direction. Wind mill was again tested with the deflector augmentor. Power coefficient was found to attain a maximum value of 0.32 at a tip speed ratio 1.54. The maximum torque coefficient was 0.385 at a tip speed ratio of 0.56. Optimum tip speed ratio of the wind mill with tha deflector augmentor was found to be in a range of 0.5 to 1.5.

When the deflector augmentor was attached to the wind mill, power coefficient was increased by 106.5 percent and torque coefficient was increased by 108 percent. The wind mill was found to work in higher tip speed ratios. The cut in velocity was reduced from 2.4 m/s to 1.4 m/s.

Cost of operation of the wind mill was Rs.1.45 per bhp.hr which is comparable with diesel and electric power.

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