Sailwing Rotor for Pumping Water in Bangladesh

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ABSTRACT

A vertical axis sailwing rotor having six sails is fabricated using locally available materials and technology. It is coupled with a locally manufactured diaphragm pump to pump water for diff-ferent total static pressure heads. It is observed that the rotor can be manufactured easily and it can pump a reasonable amount of water even at low and variable wind speed. The starting wind speed for the system is found to be about 1.5 m/s (3.35 mph) and the maximum overall efficiency is about five percent.

INTRODUCTION

Recently, due to the energy crisis, renewed interest in wind energy has developed. Golding [1] mentioned that windmills were used in Babylon and China during 1700 to 2000 B.C., in Persia around 644 A.D., and in Europe from the 8th century A.D. Windmills are used for grinding grains, pumping water, and generating electricity.

Through the use of wind energy systems over the centuries, the propeller-type wind turbine has reached the highest state of development. Recent advances in wind turbine technology, however, have identified alternatives to the propeller-type wind turbine that appear to have competitive economic potential. One such alternative is the vertical-axis sailwing rotor mill.

The vertical-axis wind turbine has several advantages over the propeller-type wind turbine, namely:

1. it is able to accept wind from any direction;
2. no bevel gearing is required, as the shaft is vertical;
3. it has a simpler tower construction;
4. it requires less maintenance cost; and,
5. it is comparatively easier to fabricate.

The operational principle of the vertical-axis sailwing rotor is that when wind strikes the sailwing, it takes up the shape of an airfoil with a concave surface facing into the wind. After half rotation, the concave surface of the sailwing switches to the other side automatically. So a positive torque is developed for all positions of the rotor. One advantage of a sailwing rotor is that it is self-starting.

Encouraging results were obtained by Brian Hurley [2], who pointed out that the rotor might be constructed with three to eight sails. An increase in the number of sails helps the rotor to start at low wind speed. However, the maximum power does not vary significantly with the number of sails.

CONSTRUCTION OF THE SAILWING ROTOR

The rotor consists basically of twelve rotor arms, six sail frames and six sails (Fig. 1). Six arms are equally spaced and welded to a 30 cm diameter and 6.35 mm thick plate. This plate is fitted at the top of a 3.175 cm outside diameter steel pipe. Similarly, another six arms are fitted at the bottom of the pipe with the help of the same type of circular plate. The length of each arm is 1.52 m. The steel pipe which acts as a vertical shaft is also 1.52 m long. The arms are made of steel conduit pipe having 2.54 cm outside diameter and 1.59 mm thickness. Six sail frames are also made with the help of 1.91 cm outside diameter and 1.59 mm thick steel conduit pipe. The height of each sailframe is 1.3 m and the length of its extended parts are 90 cm. These sail frames are fitted to the outer ends of the rotor arms. Each sail frame is fitted to two rotor arms respectively as shown in Fig. 1. Six sails made of jute sack instead of costly canvas are fitted to the sail frames (Fig. 2). The dimension of each sail is 1.22 m x 0.76 m (Fig. 3).

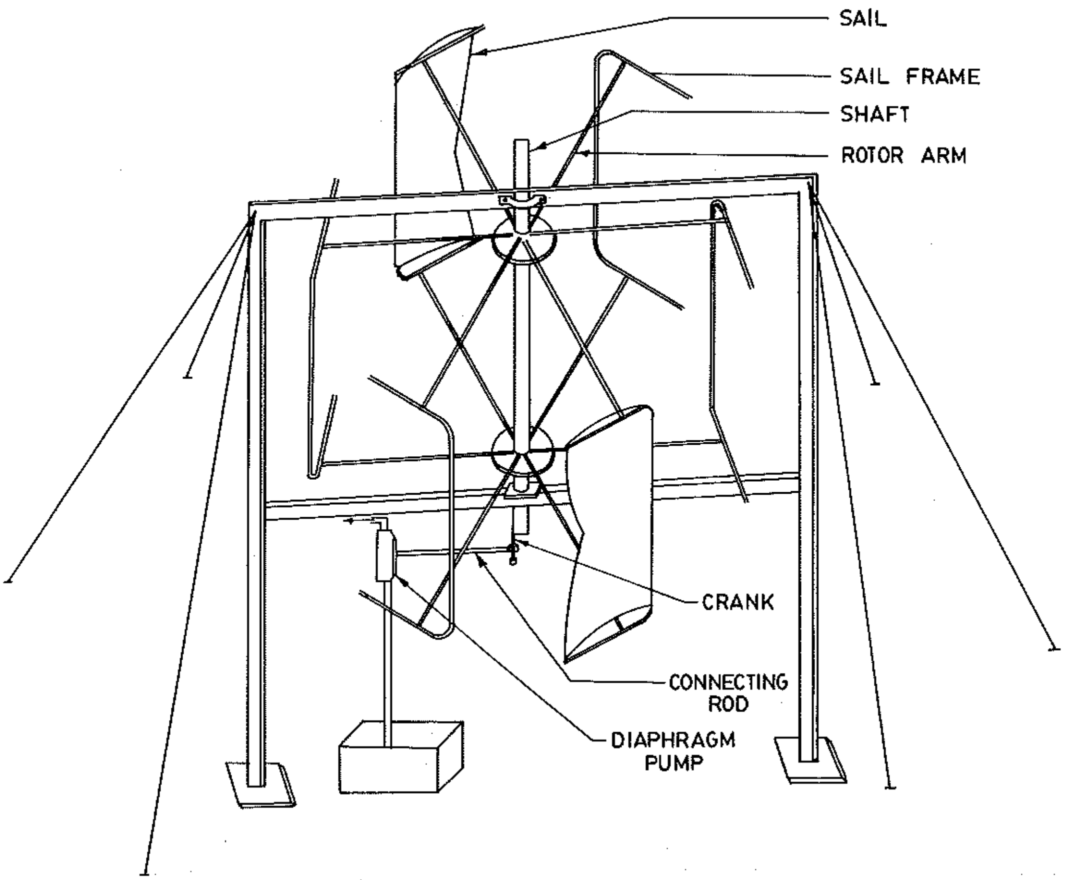

Fig. 1 Schematic diagram of sailwing rotor showing only two sails.

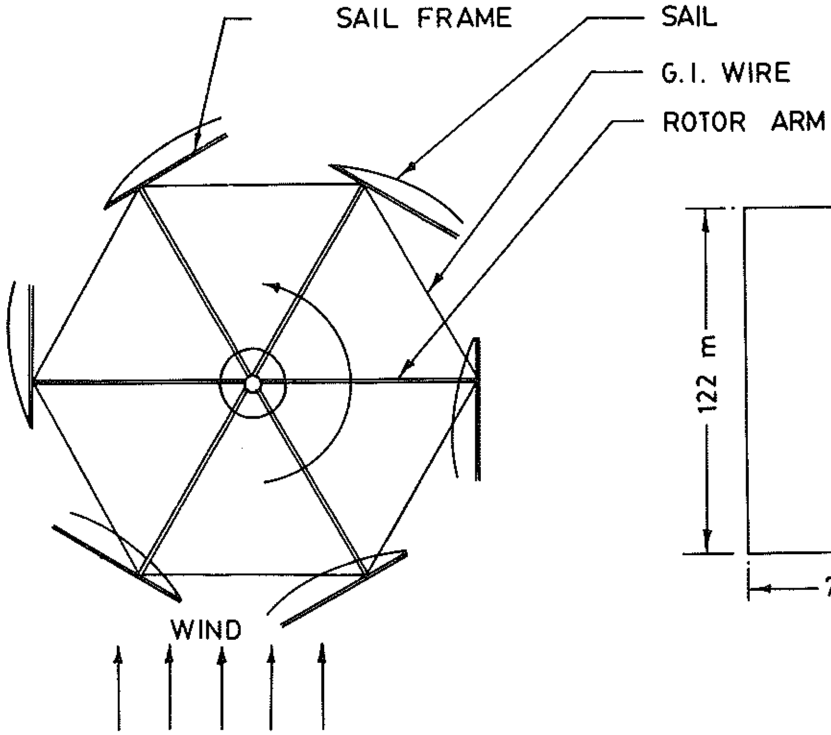

Fig. 2 Changing position of sail

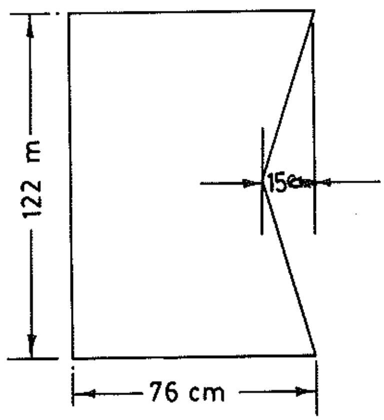

Fig. 3 Dimension of sail

The rotor is supported with the help of 3.18 cm x 3.18 cm angle frames and all the structures are made of this type of steel frame. A standard ball bearing is used at the top of the vertical shaft which is fastened to the cross angle frame by bearing casing and bolts. The shaft is extended 20 cm through the thrust bearing. At the end of the shaft, a crank is fitted. The crank is made of a 9.53 mm diameter and 7.62 cm long mild steel rod, half of which is threaded. The rod is threaded to keep the connecting rod in position by using two nuts. The crank is joined eccentrically to the shaft by arc welding. In this way, a belt and pulled mechanism is avoided. The length of the stroke is 3.81 cm. At the bottom of each vertical angle pole, there is a 30 cm x 30 cm x 3.18 mm square steel plate which is welded to the pole.

A diaphragm pump (Fig. 4) manufactured locally is connected to the crank by a 60 cm long and 7.94 mm diameter mild steel rod. A circular metal piece made of 2.54 cm diameter and 1.11 cm thick plate, having a 1.11 cm diameter hole at the center is fitted at one end of the connecting rod. This end is connected to the crank and the other end is welded to a 12.7 cm diameter and 6.25 mm thick mild steel plate. This plate is fitted to the diaphragm by bolts. Instead of the usual preshaped rubber diaphragm, a leather diaphragm is used which has greater strength and longer life than the rubber diaphragm. Anybody can replace the leather diaphragm without going to the manufacturer by using the ordinary soft leather used for making shoes. The diameter of the diaphragm is 19 cm. The pump is fixed to the lower cross frames by steel angles and bolts.

The whole structure is kept in position by 1.59 mm diameter galvanized iron wires.

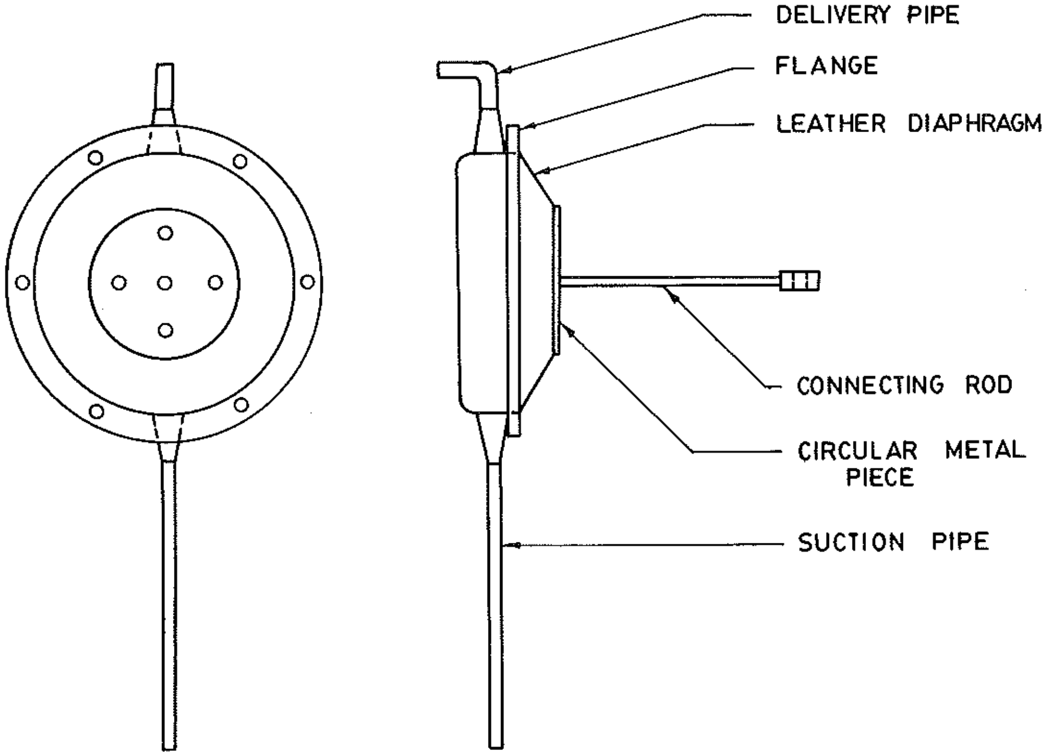

Fig. 4 Schematic diagram of diaphragm pump

RESULTS AND DISCUSSION

The experiment was carried out on the roof of the Mechanical Engineering Building, Bangladesh University of Engineering & Technology, Dacca. The variations in the discharge of the diaphragm pump with wind speed are shown in Fig. 5. The static lift was changed by changing the suction lift only. It was observed that for this system the starting wind speed is about 1.5 m/s (3.35 mph). This is encouraging from the point of view that most areas of Bangladesh, especially the areas far away from the coast, generally have low wind speed.

The discharge was found to be higher for lower lift at a given wind speed. With the increase in the wind speed, the discharge increases for both the lifts, but the rate of increase is lower at higher wind speeds. It appears that if the wind speed is increased further, the discharge approaches some maximum value. By extrapolation the maximum discharge for 1.5 m lift may be of the order of little more than 5 litres per minute, whereas for 1.2 m lift it will be much higher than 6 litres per minute.

The overall efficiency of the system, η, is plotted against the water discharge rate, Q (Fig. 6). Overall efficiency is defined as

$$\eta = Q\rho_w \, gH / \tfrac{1}{2}\rho_a A V^3$$

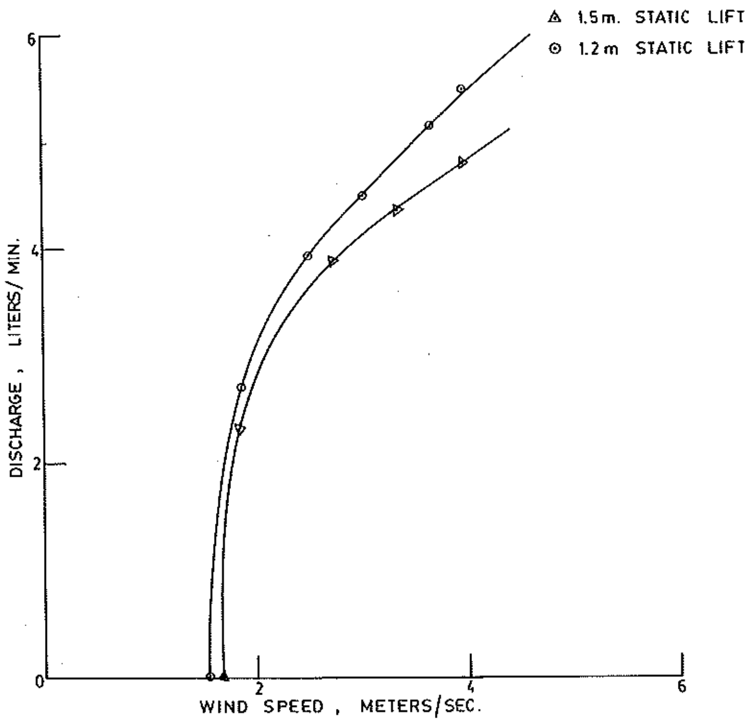

Fig. 5 Variation of water discharge with wind speed.

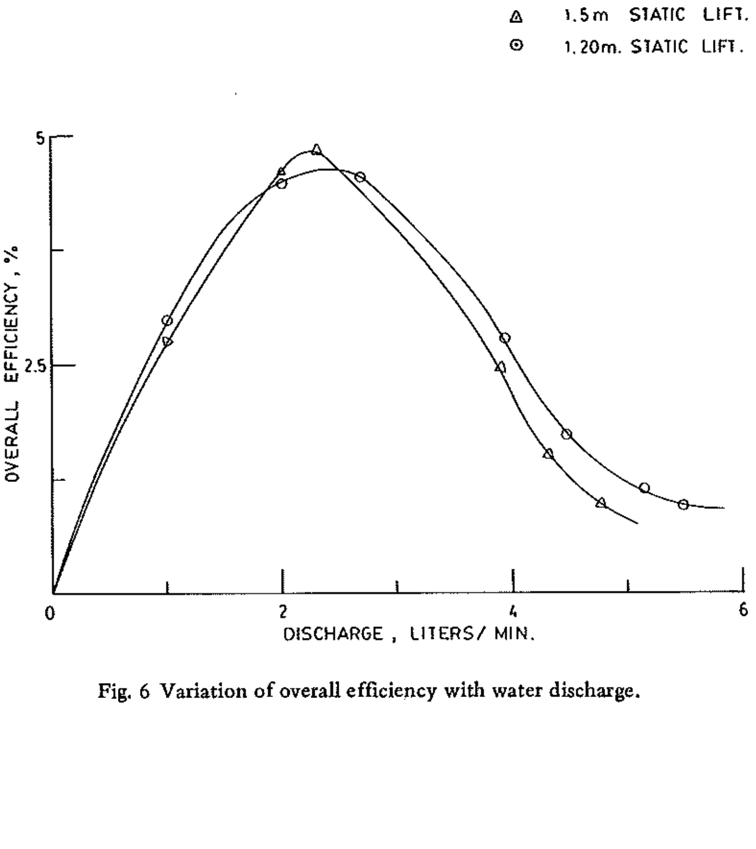

Fig. 6 Variation of overall efficiency with water discharge.

where Q = water discharge rate, m^3/s
ρ_w = water density, kg/m^3
H = total static pressure head, m
ρ_a = air density, kg/m^3
V = wind speed m/s

The overall efficiency is obviously the product of the rotor efficiency, η_r, and the pump efficiency, η_p. It is seen that η increases from zero to a maximum value and then decreases with the increase in Q. A maximum of about 5% is obtained at Q of about 2 litres per minute. Recalling that the efficiency limit for the rotor as given by Betz [3] is 59.3%, and considering that η is the product of η_r and η_p and that diaphragm pumps in general are of lower efficiency, 5% overall efficiency is quite encouraging. Again, attention may be drawn to the fact that the maximum value of η occurs at lower values of Q, i.e. at lower wind speeds. This observation is important in consideration of the low wind speed inside the country for a good period of the year. It was also found that for the same discharge, η is in general slightly higher for the lower lift.

Fig. 5 shows that for a given discharge lower wind speed is needed for lower lift. Now from the definition of η, η is proportional to H/V^3, indicating the relative effects of the variables on the overall efficiency. Furthermore, it is predicted that if the pump efficiency is assumed to be approximately constant, the maximum rotor efficiency (power coefficient) occurs in the rotor tip speed ratio (rotor tip speed/wind speed) range of 0.7 to 0.8. The variation of overall efficiency with wind speed is shown in Fig. 7.

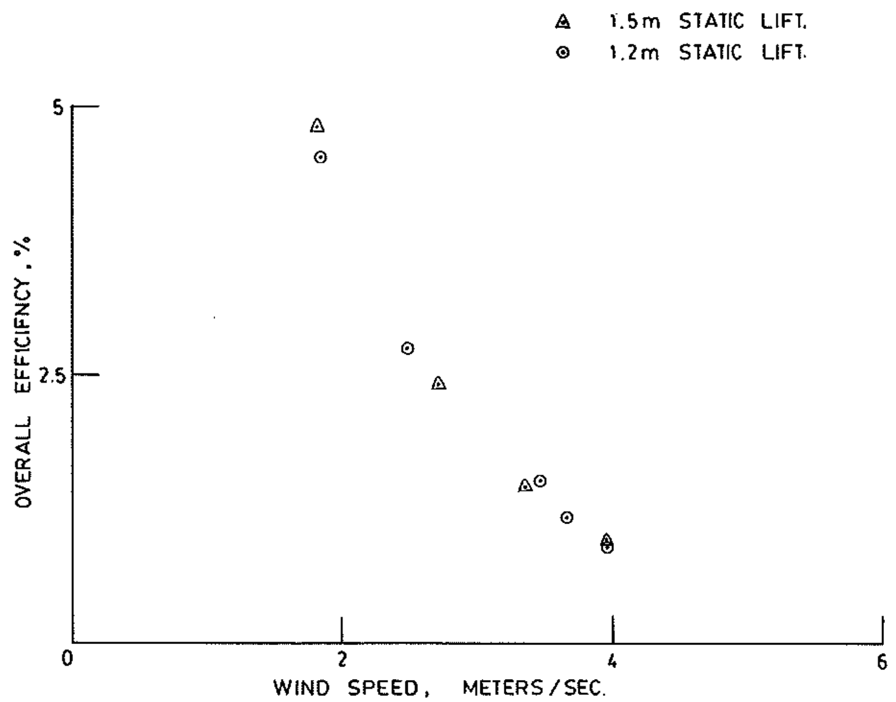

Fig. 7 Variation of overall efficiency with wind speed.

Further work is needed before commenting on the possibility of a large-scale utilization of this type of wind turbine for irrigation purposes in the rural areas of Bangladesh. The effects of wide variation of suction head on the discharge are to be investigated. The delivery head should also be varied. The number of sails may have some effect on the overall performance. Other types of positive displacement pumps may be tried. Alternative indigeneous materials are to be considered for fabrication. Above all, design optimization and field tests are required.

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3. BETZ, A. (1928), Windmills in the Light of Modern Research, *U.S. National Advisory Committee for Aeronautics, Technical Memorandum No. 474,* p. 27.