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Development of Rotational Speed Control Systems for a Savonius-Type Wind Turbine

An attempt is made here to increase the output of a Savonius rotor by using a flow deflecting plate. When the deflecting plate is located at the optimum position, the rotor power increases nearly 30 percent over that when no deflecting plate is present. The rotor torque was found to become almost zero, when the plate is placed just in front of the rotor. In addition, two systems to control the rotational speed of a Savonius rotor are developed. These permit the rotor to be stopped in strong wind. Operating characteristics of the two control systems are investigated.

Introduction

Savonius-type wind turbines cannot compete with high-speed propeller and Darrieus type wind turbines from the standpoint of aerodynamic efficiency. Nevertheless, they are simple to construct, insensitive to wind direction and self-starting. In considering these advantages, it is clear that Savonius wind turbines would be used more often if their rotor performance could be improved.

Since Savonius published the results of an experimental study of this type of wind turbine in 1931 [1], numerous experimental attempts have been made to improve rotor performance. For example, refer to Bach [2], Khan [3], Sheldahl et al. [4] and Ushiyama et al. [5]. These experimental studies examined factors such as the section shape of a rotor bucket, the number of the buckets and the overlap ratio of the buckets.

On the other hand, an analytical model was developed for performance analysis by Wilson et al. [6]. Similarly, Van Dusen and Kirchhoff [7] presented a vortex sheet model. Although these models have contributed to the improvement of Savonius rotors, a number of important issues have yet to be considered. For example, flow separation from bucket tips of the rotor has been ignored. To remedy this, Ogawa [8] attempted to analyze the flow around the Savonius rotor using a discrete vortex method. As the next step of the research, several experimental studies on the Savonius rotor with various auxiliary devices have been conducted to further enhance the performance. Sabzevari [9] and Sivasegaram [10] used an asymmetrical box with a funnel-shaped wind inlet in which the Savonius rotor was placed. Ogawa et al. [11] investigated rotor performance by the use of the guide vanes placed around the Savonius rotor. Recently, experimental studies to enhance rotor performance by the applicaton of the effects due to mutual interaction between two closely spaced Savonius rotors were performed by Charwat [12] and Ogawa et al. [13].

In the present work, a flow deflecting plate, which consists of a simple flat plate, is used to increase the rotor output. The upstream flow is deflected by the plate, and the velocity of the flow which streams into the concave face of the bucket is increased. The effects of the deflecting plate parameters, i.e., the plate width, A, the distance between the rotor and plate, B, and the azimuthal angle of the plate, θ, are individually examined.

For practical application of a wind turbine, a rotational speed control device or a protection device for strong winds is essential. It is neither reliable nor safe to use only a mechanical braking device, e.g., a disk brake, for speed control. To accomplish rotational speed control of a wind turbine it is necessary to control the aerodynamic force which operates on the rotor. In this study, two systems of rotational speed control are developed by moving the deflecting plate around the

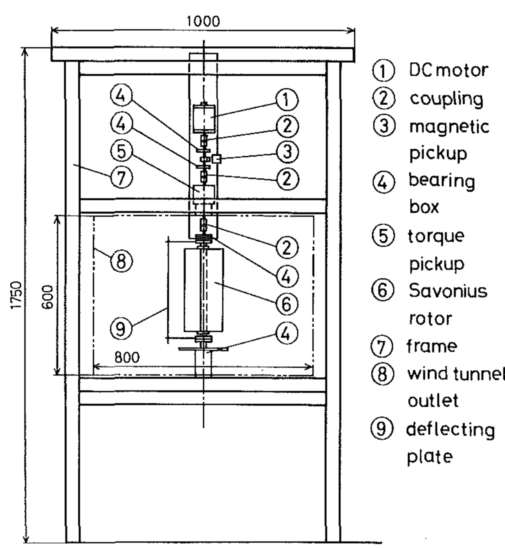

Fig. 1 Test apparatus

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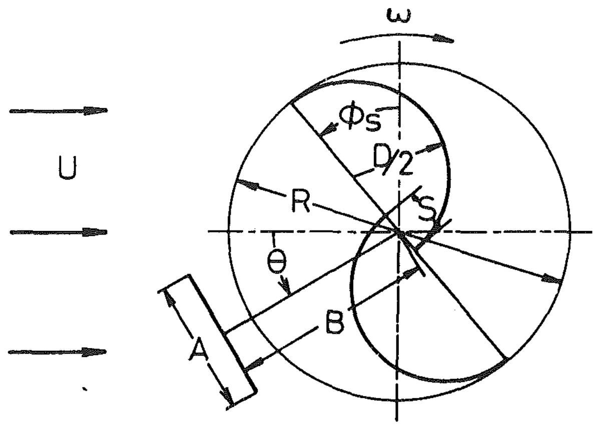

Fig. 2 Configuration of a Savonius rotor and a deflecting plate

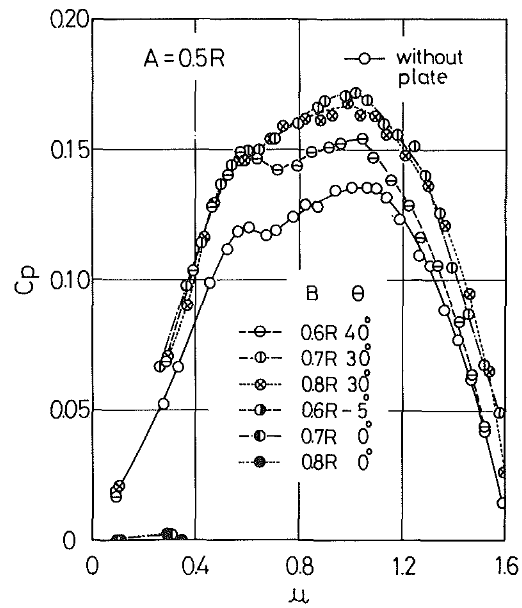

Fig. 3 Effects of B on Cp

rotor, and the characteristics of the control systems are investigated with a wind tunnel.

The Effects of a Deflecting Plate

The test apparatus and instrumentation are shown in Fig. 1. The rotational speed of the rotor is controlled by a DC motor (1), and the motor shaft is connected to the rotor shaft via a torque pickup (5). The number of revolutions is measured by using a magnetic pickup (3) and a counter. The Savonius rotor consists of two buckets with a circular camber (180 deg) and two end plates. The rotor diameter R, rotor height, H, overlap ratio, S/D, and wind velocity, U, are 0.140m, 0.295m, 0.2 and approximately 7m/s, respectively.

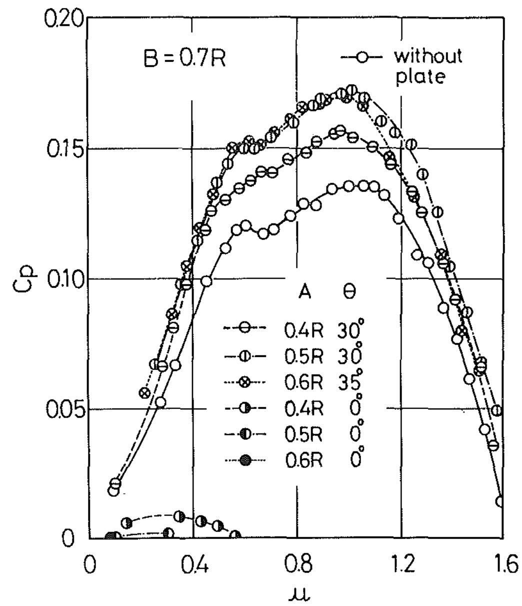

Fig. 4 Effects of A on *Cp*

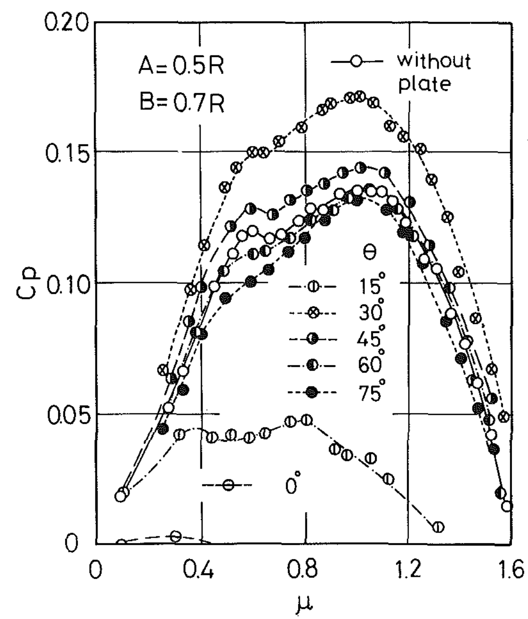

Fig. 5 Effects of θ on *Cp*

Fig. 3, 4, and 5 Uncertainty in $Cp = \pm 0.04$, in $\mu = \pm 0.01$ at 20:1 odds

An attempt to enhance the performance of a Savonius rotor by the application of a deflecting plate was previously reported by the authors [14]. In that study, the effects of the section shape of the deflecting plate on the rotor performance were investigated. It was concluded that a simple flat plate

Nomenclature

- A = width of a deflecting plate, m (Fig. 2)
- B = distance between a deflecting plate and rotor center, m (Fig. 2)
- Cp = power coefficient ($=2T\omega/\rho U^3 RH$)
- D = diameter of a rotor bucket, m
- H = rotor height, m
- n = rotational speed of a rotor, rpm
- R = rotor diameter, m
- r_A, r_B = arm lengths of tail wing (Fig. 7)
- S = overlap distance of two buckets, m
- T = rotor torque, N•m
- U = wind velocity, m/s
- Θ = angle of wind direction
- θ = azimuthal angle of a deflecting plate (Fig. 2)
- μ = tip-speed ratio ($=R\omega/2U$)
- ρ = air density, kg/m^3
- ω = angular velocity of rotation, rad/s

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produced the best results. The current investigation is a followup to the previous study, and the effects of the flat deflecting plate parameters (Fig. 2), i.e., A, B, and θ on the rotor performance are investigated in detail.

Results of the experiments for the determination of best combination of the parameters A, B, and θ are shown in Figs. 3 to 5. Figure 3 presents the effects of varying the distance, B, on the power coefficient, Cp, for a given value of A ($=0.5R$). The optimum value for B was found to be $0.7R$, i.e., Cp becomes smaller for any other B value. The values of Cp for the cases in which $A=0.5R$ and $0.6R$ are nearly the same as is shown in Fig. 4. Based on these results and because a smaller plate is better as an attached apparatus, a deflecting plate with $A=0.5R$ was adopted.

Changes in the angle θ influences the output power considerably as shown in Fig. 5. At $\theta=30$ deg ($A=0.5R$, $B=0.7R$), the maximum value of Cp becomes approximately 27 percent larger than that of the rotor without the deflecting plate, while the output becomes almost zero, when the plate is placed just in front of the rotor ($\theta=0$ deg). Apparently, the aerodynamic force which operates on the rotor can be controlled by moving the deflecting plate around the rotor. The plate should be maintained at $\theta=30$ deg, if the wind velocity or the rotation speed of the rotor is lower than the designed value. In such a case more wind energy can be extracted than when the deflecting plate is not used. In a strong wind, or if the rotor rotates beyond the design speed, the rotor rotation can be decreased by moving the deflection plate towards the $\theta=0$ deg position. In this study, two systems to control the rotational speed of the Savonius rotor are developed by varying the location of the deflection plate.

Control With Tail Wings

Several kinds of tail wings which have been tested in this study are presented in Fig. 6. Figure 6(*a*) shows a single tail wing, that is 0.75R wide and is connected to the deflecting plate. An attempt was made to keep the deflecting plate at $\theta=30$ deg by balancing the aerodynamic forces on the deflecting plate and tail wing. But it was not possible to stop the deflecting plate at $\theta=30$ deg. The plate invariably swung laterally ± 10 deg around $\theta=30$ deg. Subsequently, an attempt was made to stop the deflecting plate at $\theta=0$ deg by changing the setting angle of the tail wing from 135 to 160 deg (Fig. 6(*b*)), but the swinging motion of the deflecting plate and tail wing remained. The reason for this swinging motion is thought to be due to the fact that the tail wing is located in the wake region which is disturbed by the rotating rotor. To circumvent this, as a next attempt, a mechanism which has two tail wings of width $0.5R$ were tested. The length of two arms shown in Fig. 6(*c*) is $0.8R$. In this case, the swinging motion was found to be smaller than that of the case with one tail wing, but it is still present. Figures 6(*d*) and 6(*e*) show the two tail wings system with longer arms ($1.1R$). In each case, the wings are located outside of the wake region and the deflecting plate remains still at $\theta=30$ deg, when the setting angles of wings are 130 and 110 deg. As shown in Fig. 6(*e*), the deflecting plate is moved to the position of $\theta=0$ deg and remains motionless, when the setting angle of the left-hand side tail wing is changed from 130 to 90 deg. Accordingly, it is possible to move the deflecting plate by changing one of the setting angles of two tail wings. In this study, a coil spring is attached to the left-hand side tail wing to change the setting angle automatically at a strong wind as shown in Figs. 6(*d*) and 6(*e*).

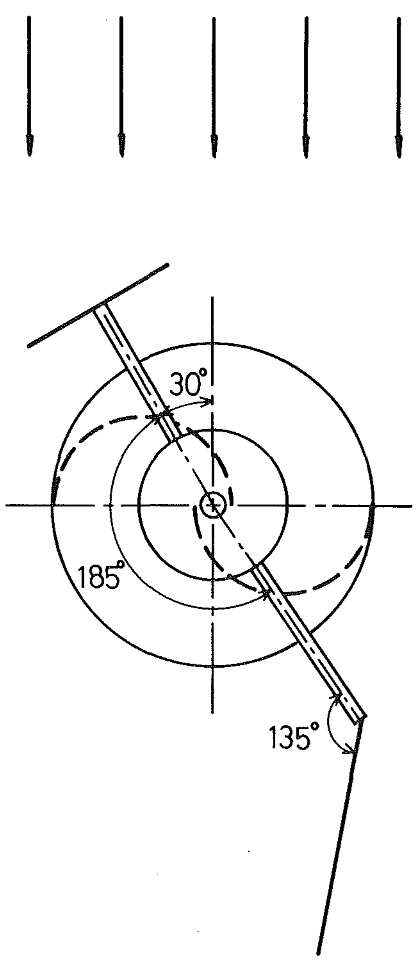

Fig. 6(*a*)

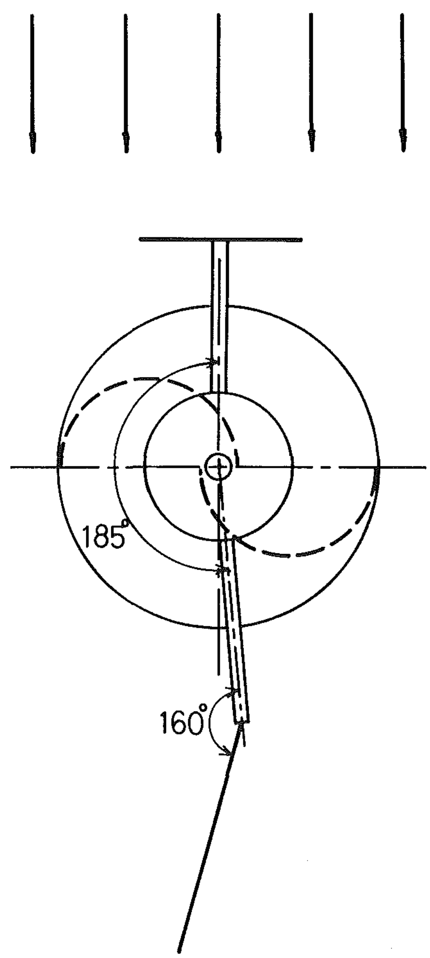

Fig. 6(*b*)

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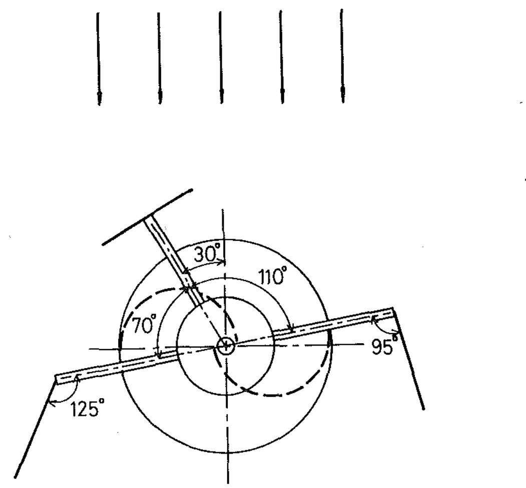

Fig. 6(c)

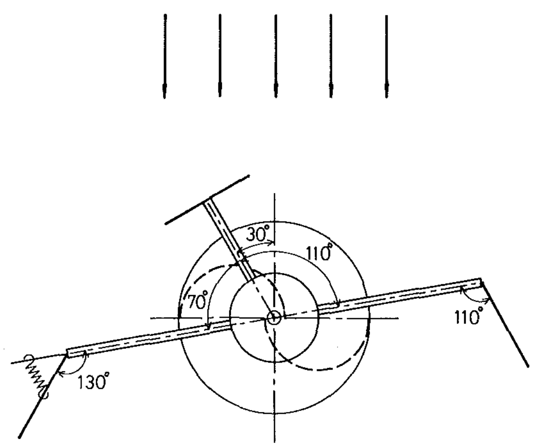

Fig. 6(d)

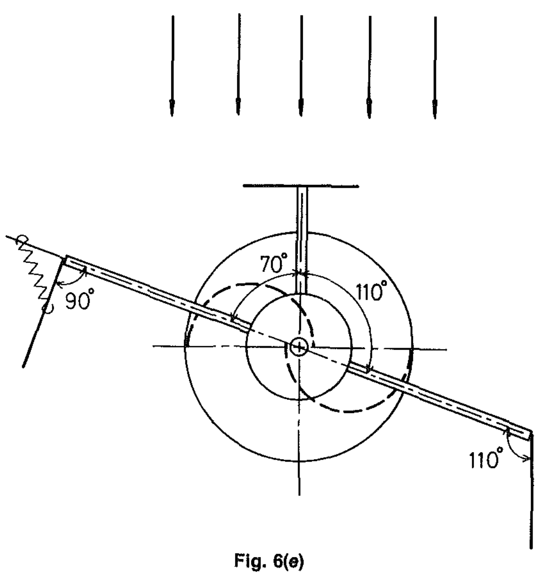

Fig. 6(e)

Fig. 6 Tail wings

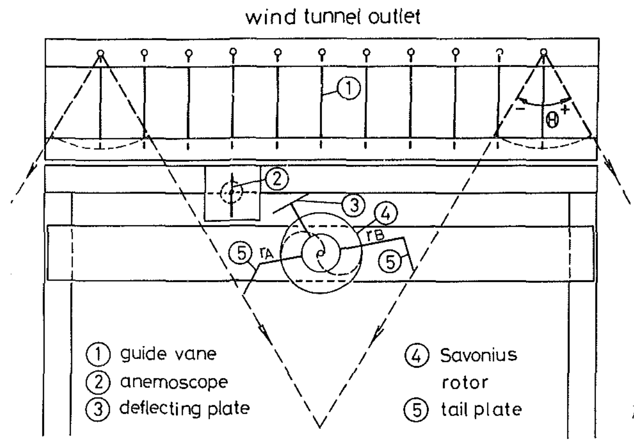

Fig. 7 Experimental devices of rotational speed control

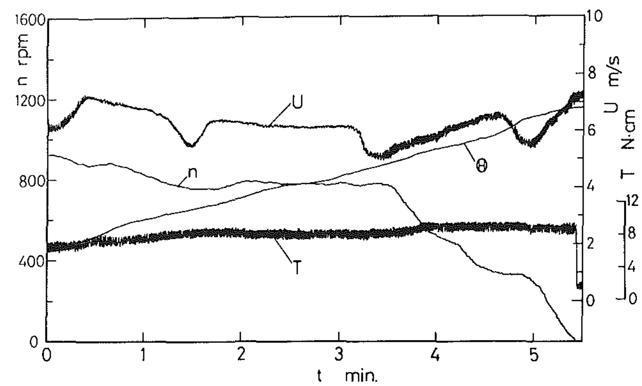

Fig. 8 The change in *n* without control (in case the wind direction, Θ, varies)

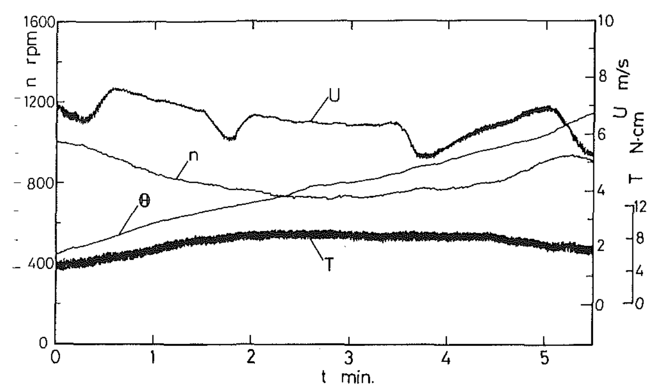

Fig. 9 The control of *n* with tail wings presented in Fig. 6(*d*) (in case the wind direction, Θ, varies)

In Fig. 7, an anemoscope, a Savonius rotor with two tail wings, and the guide vanes to change direction of the wind are presented. The wind direction, Θ, is changed by altering the setting of the guidevanes using a DC motor. The range of the variation in the wind direction is ±25 deg. The wind direction is recorded as the voltage change of the potentiometer which is attached to the axis of the anemoscope. The wind velocity, U, is varied by the damper of a sirocco fan of the wind tunnel and is measured with a hot-wire anemometer.

The change in the rotational speed, n, when the deflecting plate is fixed, the rotor torque, T, the wind speed and the wind direction variations are presented in Fig. 8. The rotational speed begins to decrease as Θ becomes greater than about 5 deg, and n becomes nearly zero when the wind blows directly against the deflecting plate. As shown in Fig. 8, the rotational speed changes markedly, if the deflecting plate does not track the change in the wind direction. The defects in the record of the velocity, U, indicate the wakes after the guidevanes. When the deflecting plate is moved by the tail wings (Fig. 6(*d*)) which follow to the change in the wind direction, the rotational speed does not decrease (Fig. 9). In the case when the wind velocity increases and the deflecting plate is fixed at $\theta = 30$ deg, n increases as shown in Fig. 10.

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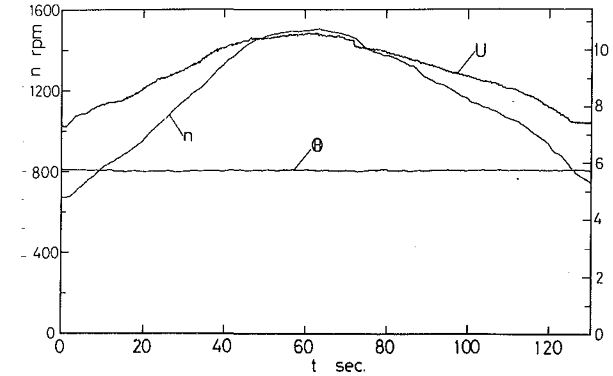

Fig. 10 The change in *n* without control (in case the wind velocity, *U*, increases)

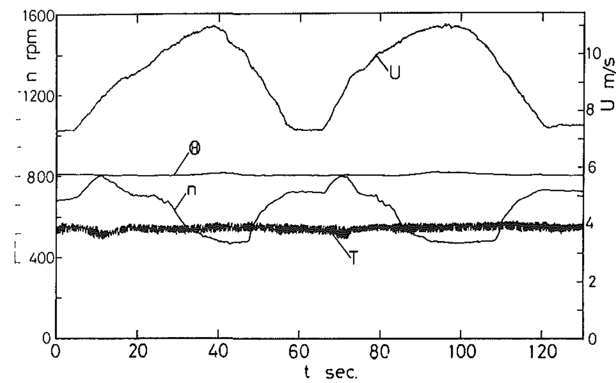

Fig. 11 The control of *n* with tail wings presented in Fig. 6(*d*) (in case the wind velocity, *U*, increases)

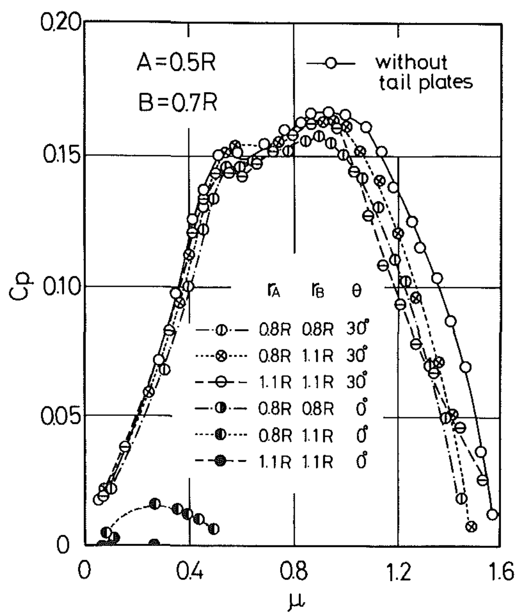

Fig. 12 The effects of tail wings on *Cp* (Uncertainty in $Cp = \pm 0.04$, in $\mu = \pm 0.01$ at 20:1 odds)

Figure 11 presents the characteristics of the control system which is shown in Fig. 6(*d*). When the wind velocity increases, the coil spring lengthens and the deflecting plate moves toward $\theta=0$ deg position (Fig. 6(*e*)). Then, the rotational speed n decreases. It is possible to keep n constant or to let the rotor stop by selecting the spring factor properly. The effects of the existence of tail wings on the power coefficient *Cp* were investigated, and as may be seen in Fig. 12, there is almost no effect on performance.

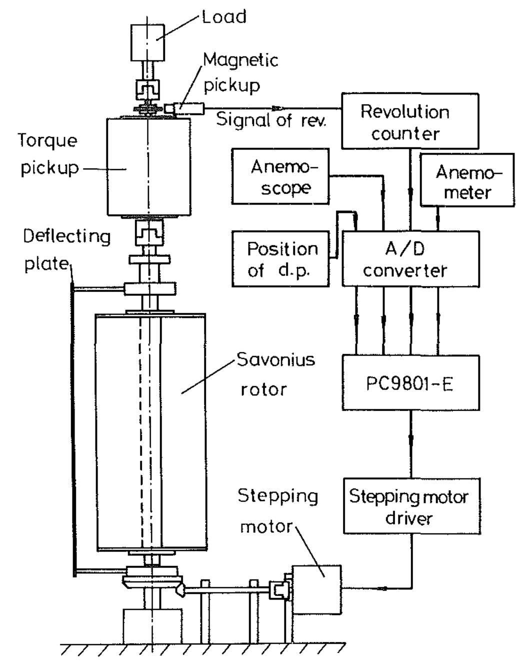

Fig. 13 Schematic of the control system with a stepping motor

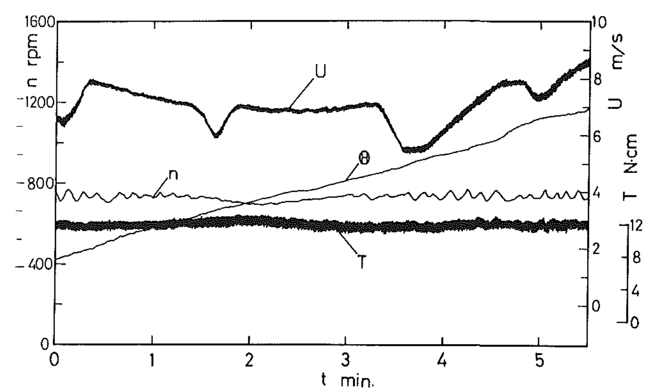

Fig. 14 The control of *n* with a stepping motor (in case the wind direction, Θ, varies)

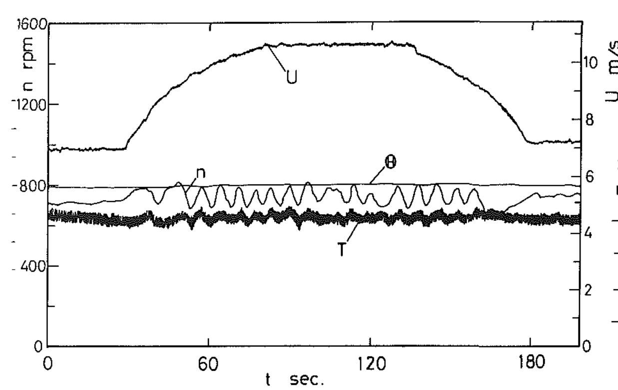

Fig. 15 The control of *n* with a stepping motor (in case the wind velocity, *U*, increases)

Control With a Stepping Motor

In an effort to design a self-regulating control system, a computer controlled system was developed. The rotational speed, wind velocity and the wind direction are fed into a per-

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sonal computer via an A/D converter and processed. A stepping motor is connected with the deflecting plate and moves it on the basis of the processed results (Fig. 13). The characteristics of this system are presented in Figs. 14 and 15. Figure 14 shows the results of the case in which it is programmed for the deflecting plate to move based on the information of the wind direction. The results when the wind direction, Θ, is constant and the wind velocity varies are presented in Fig. 15. As shown in Figs. 14 and 15, the rotational speed, n, is kept almost constant, and it is proved that more precise control than that with tail wings is possible.

Conclusions

In this study, experiments to improve the performance of a Savonius wind turbine rotor by using a flat deflecting plate are conducted. The effects of the deflecting plate on the power coefficient are investigated in detail. It was found that the rotor power was approximately 27 percent greater than that of a rotor without the deflecting plate, when the plate with $A = 0.5R$ and $B = 0.7R$ is placed at $\theta = 30$ deg. The rotor torque was shown to vary considerably with the azimuthal angle, θ, of the deflecting plate. Two systems to control the rotational speed by using the deflecting plate were developed. Experimental attempts of mechanical control with tail wings revealed that this is an effective means to control rotational speed, especially as one of the protection devices for strong winds. It was also shown that the other system, a computer controlled closed loop system, is also applicable and more appropriate for precise control than that with the tail wings.

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