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Effects of end plates with various shapes and sizes on helical Savonius wind turbines

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ABSTRACT

We experimentally studied the effects of end plates with various shapes and sizes on the aerodynamic performance of helical Savonius wind turbines with twist angles of 180° and two semicircular buckets. To apply the blockage correction method and investigate the effect of end plate, four different helical Savonius wind turbines were tested at a subsonic open-circuit type wind tunnel. The adapted Maskell's blockage correction method suggested by Alexander was adopted for the wind turbine model installed in a closed test section of the subsonic wind tunnel. In order to clarify the end plate effect, power and torque coefficients were measured with various end plate shapes and areas. The use of both upper and lower end plates significantly increases the power coefficient by 36% compared with no end plates. We found that the Maskell's blockage correction method for straight Savonius wind turbines is applicable to helical Savonius wind turbines for small blockage ratios ranging from 3 to 8.3%. It was also observed that the power coefficient increases linearly in proportion to the area of the end plate.

1. Introduction

Savonius wind turbines have many advantages, including a high starting torque, a simple design, and an ability to operate in any wind direction, though they have low aerodynamic efficiency. Thus Savonius wind turbines are widely used in micro and small scale wind turbine applications, such as domestic and residential power generation. Much work has been done studying the aerodynamic characteristics and effects of geometric design parameters in Savonius wind turbines [1–3]. However, conventional (or straight) Savonius wind turbines have a negative torque at certain rotation angles and a large torque variation. To improve the torque characteristics, multi-stage, out of phase Savonius wind turbines have been proposed, but the use of a multi-stage blade reduces the power coefficient [4,5].

At present, some researchers have proposed helical Savonius wind turbines with twist angles of 90° and 180° and have investigated the effects of geometric parameters such as the overlap ratio, aspect ratio and shaft interface [6–8]. Helical Savonius wind turbines have a positive static torque coefficient for all rotor angles and better performance than conventional Savonius wind turbines.

The use of end plates is the simplest method to increase the aerodynamic performance of Savonius wind turbines. Many researchers have experimentally studied the influence of end plates in conventional Savonius wind turbines without blade twist [9–11]. In particular, Ushiyama and Nagai [10] suggested optimal design configurations for Savonius rotors with straight buckets. They carried out a parametric study of the aspect ratio, the overlap and separation gap between rotor buckets, the presence or absence of rotor end plates, and the influence of bucket stacking, but they did not apply blockage correction (although they conducted the experiments at an open test section about 1 m downwind from the exit of the wind tunnel to avoid blockage effects).

In the wind tunnel experiments, the end plate effects of the helical Savonius wind turbines are hard to identify whilst those of the straight Savonius wind turbines are frequent. In particular, partially blocked non-circular end plates rather than circular ones are expected in the industry to decrease the cost and weight of the rotor. Power performance with the various shapes of the end plate then becomes one of the most contested points. Because the Savonius wind turbine is the typical drag type, the drag forces at the advancing and retreating sides generate negative and positive torque respectively. We presume that the role of the end plate is to prevent spill-over flow at both ends of the bucket, and

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Nomenclature

AR	aspect ratio; H/D
A_C	cross-sectional area; πR^2
A_E	end plate area
BR	blockage ratio
C_t	torque coefficient; $T/(\mathrm{qSR})$
C_{ts}	static torque coefficient; $T_S/(\mathrm{qSR})$
C_P	power coefficient; $P/(\mathrm{qSU})$
D	rotor diameter
ER	end plate area ratio; A_E/A_C
H	rotor height
h	height of wind tunnel test section
P	power
q	dynamic pressure; $\rho U^2/2$
R	rotor radius
Re	Reynolds number
S	rotor swept area
T	torque
T_S	static torque
U	wind speed
w	width of wind tunnel test section
ρ	density of air
λ	tip speed ratio; $\Omega R/U$
Ω	angular speed

consequently increases the momentum transfer from the air stream. The advancing bucket can reduce the drag force related to the negative torque of the rotor by eliminating the end plate itself. In other words, partially blocked non-circular end plates applied just for the retreating side bucket would be sufficient to absorb the momentum from the impinging air stream. This idea would fulfill the industry's demand. The above concept is the main background of this study even if it is physically valid.

Therefore the aim of this study is to experimentally investigate end plate effects using various shapes and sizes of end plates on the aerodynamic performance of helical Savonius wind turbines. This is the first study to conduct such an investigation. The end plate effects were determined in a subsonic open-circuit type wind tunnel with a closed test section of 1000 mm × 1500 mm. Four different helical Savonius wind turbines with identical aspect ratios, twist angles of 180°, and two semicircular buckets were fabricated from fiber reinforced plastics. All of the bucket shapes had no separation gaps or overlaps between the two semicircular buckets. The adapted Maskell's blockage correction method for the straight Savonius wind turbine model suggested by Alexander [12,13] was chosen and verified for the helical Savonius wind turbine model.

2. Experimental model and apparatus

2.1. Model of helical Savonius wind turbines

Fig. 1 shows the configuration of the helical Savonius wind turbine with a twist angle of 180°, two semicircular buckets, and the main shaft without overlap or a separation gap. Four different helical Savonius wind turbines with identical aspect ratios of 2.0 (diameter × height: 150 mm × 300 mm, 200 mm × 400 mm, 250 mm × 500 mm, and 350 mm × 700 mm) were fabricated to study the influence of the blockage ratio of the wind turbine model. Table 1 lists the details of the rotor diameter, rotor height, rotor aspect ratio, shaft diameter, and blade thickness. The blades were made from a fiber reinforced plastic which was a composite material of a polymer matrix reinforced with glass fibers.

The helical Savonius wind turbines were designed as shown in Fig. 2. The end plates were fabricated from an acrylic plate of 5 mm thickness. To study efficiency according to end plate shape, the diameter of the end plate was the same as the diameter of the wind turbine. In a conventional Savonius wind turbine without a blade twist, the optimal diameter of the end plate for obtaining a maximum power coefficient is 1.1 times the turbine diameter [9,14]. The end plate area ratios, *i.e.*, the ratio of the end plate area to the cross-sectional area (A_E/A_C) of the turbine (diameter 250 mm) are listed in Table 2.

The static torque coefficient C_{ts}, the torque coefficient C_t, the power coefficient C_p, and the tip speed ratio λ of the turbine are given by.

$$C_{ts} = \frac{T_S}{\mathrm{qSR}} \tag{1}$$

$$C_t = \frac{T}{\mathrm{qSR}} \tag{2}$$

$$C_p = \frac{P}{\mathrm{qSU}} = \lambda \times C_t \tag{3}$$

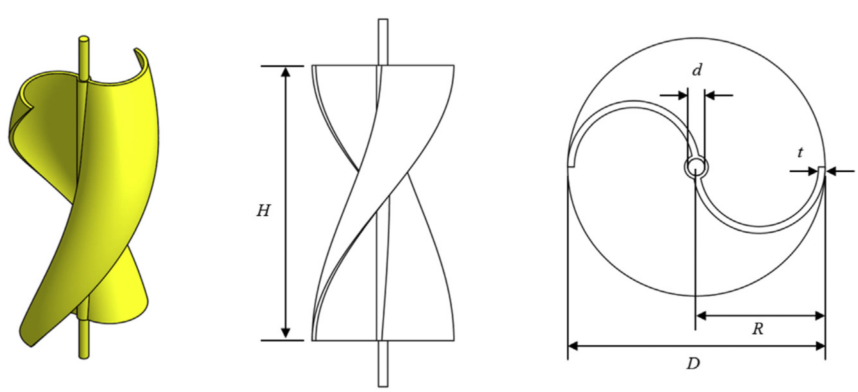

Fig. 1. Schematic views of helical Savonius wind turbine without end plates.