WIND TUNNEL PERFORMANCE DATA OF THE SAVONIUS ROTOR WITH CIRCULAR GUIDE VANES*

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Straight guide vanes are installed axisymmetrically around a Savonius rotor and their effects on the performances of the rotor have been investigated empirically using the wind tunnel. An experiment has been conducted varying the number of guide vanes, the setting angle of the vanes, the relative angle of the guide vanes to the wind direction and the inner radius of the guide vanes. Using the circular guide vanes the starting characteristic of the rotor can be improved considerably, and the values of the parameters when the power of the rotor increases are presented.

Key Words : Fluid Machine, Wind Energy, Savonius Rotor, Guide Vanes

1. Introduction

One of the authors of this study has presented a numerical analysis of a flow around the Savonius rotor using the discrete vortex method⁽¹⁾. As described in his work, the Savonius-type wind turbine has many advantages, that is, simple structure, easiness of self-starting and so on. In spite of such advantages, this type of the wind turbine fails to be developed because of its low efficiency in comparison with the other types like propeller-type and Darrieus wind turbines.

The experimental studies on the Savonius rotor were initiated by Savonius himself in 1931⁽²⁾. Then, several experimental analyses have been made by Bach⁽³⁾, Khan⁽⁴⁾, Sheldahl et al.⁽⁵⁾, Sivasegaram⁽⁶⁾, Nagai⁽⁷⁾ and Ushiyama⁽⁸⁾. In these studies the effects of the rotor bucket shape⁽³⁾⁽⁴⁾⁽⁶⁾⁽⁷⁾, number of buckets⁽³⁾⁽⁵⁾⁽⁶⁾, and the overlap ratio⁽³⁾⁽⁴⁾⁽⁵⁾⁽⁸⁾ on the performances of the rotor have been investigated.

This study is an attempt to enhance the performances of the Savonius-type wind turbine by the wind concentration effect, wind direction deflection effect and diffuser effect of the guide vanes placed around the Savonius rotor. A similar attempt to enhance the rotor performances by using the auxiliary devices has been done by Sivasegaram⁽⁹⁾, too. But the device used by him is an asymmetrical box with funnel-shaped wind inlet, and therefore, one of the advantages of the

Savonius rotor that the rotor performances do not depend upon the wind direction, is lost by using such a device.

Ohara et al.⁽¹⁰⁾ have used a device similar to one used in this work, but the influences of each parameter of the guide vanes on the rotor performances have not been presented in their paper.

In the present study, the effects of the number of the guide vanes, length of the vanes and setting angle of the vanes on the starting torque coefficient and power coefficient have been investigated in detail by using a wind tunnel model. Later in this paper the experimental results are discussed with the data of velocity distributions measured inside the circular guide vanes.

2. Experimental Devices

The construction of the experimental devices is shown in Fig.1. The rotational speed of the rotor is controlled by a DC motor (50 W, 12 V), and the motor shaft is connected to the rotor shaft via a torque pickup. The number of revolutions is measured by using a magnetic pickup and a counter. As shown in Fig.2, the Savonius rotor consists of two buckets with a circular camber (180 deg) and two end plates. The rotor diameter R , rotor height H_r and overlap ratio S/D (S : overlap distance, D : bucket diameter) are 176 mm, 394 mm and 0.2, respectively.

A straight line is chosen as the camber line of the guide vane and the number of guide vanes S_z , inner diameter of guide vanes D_{si} , setting angle of guide vanes θ and the relative angle of guide vanes to the wind direction ϕ_r (Fig.2) are varied. The outer diameter D_{so} , the span of guide vanes H_s and wind velocity U are kept constant as 370 mm, 476 mm and 7 m/s, respectively.

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3. Results of Experiment

As the number of the guide vanes is finite, the rotor performances vary with the angle ϕ_r , which is the angle between a guide vane and the wind direction. Therefore, one pitch of the guide vanes is divided into three points which correspond to three values of ϕ_r , and then at each ϕ_r the rotor performances are measured.

The starting torque coefficient C_t , power coefficient C_p and tip speed ratio μ are defined as

Fig.1 Experimental devices

Fig.2 Rotor and guide vanes

$$\left. \begin{aligned} C_t &= T / \frac{1}{4} \rho U^2 R A_s, \\ C_p &= T \omega / \frac{1}{2} \rho U^3 A_s, \mu = R \omega / 2U \end{aligned} \right\} \dots (1)$$

where T , ρ and ω are the rotor torque, mass density of the air and angular velocity of the rotor, respectively and $A_s = R \cdot H_r$.

3.1 Starting torque coefficient C_t

The effects of ϕ_r on C_t are shown in Fig.3. The effects of ϕ_r are large when S_z is small. When the rotor has no guide vane (• sign in Fig.3), C_t becomes negative for $\phi_s = 20^\circ$. But C_t of the rotor with guide vanes is positive for the whole range of ϕ_s . Hence, it can be concluded that the starting characteristic is improved by using the guide vanes.

The effects of the setting angle of the guide vane θ on the starting torque coefficient are shown in Fig.4. The data presented in the figures are mean values of three values obtained for three ϕ_r . The effects of the guide vanes become large when the setting angle θ is 20° or 30° .

Figure 5 shows the effects of a chord length of the guide vane on C_t . As the chord becomes longer, that is, D_{si}/D_{so} decreases, C_t becomes larger slightly. However, as D_{si} becomes smaller, the guide vanes come nearer to the rotor, and then,

(a) $S_z=4$

(b) $S_z=8$

Fig.3 Effects of ϕ_r on C_t

noise and the fluctuating force which acts on the vanes increase.

3.2 Power coefficient C_p

The effects of ϕ_r on the power coefficient are shown in Figs.6 and 7. The power coefficient for $Sz=4$ varies with ϕ_r remarkably. In case of $\phi_r=30^\circ$, the maximum value of C_p is about 20 % larger than that of the rotor without the guide vanes. But when the wind direction changes to $\phi_r=0^\circ$ or 60° , the output

decreases and becomes smaller than the output of the rotor with no guide vane. Such a tendency does not depend upon the setting angle θ . As shown in Fig.7, the power for $Sz=8$ varies with ϕ_r , but the influences of ϕ_r are not so large as in the case of $Sz=4$. In the case of $Sz=8$, effective value of ϕ_r changes with θ . That is, $\phi_r=15^\circ$ is the best wind direction for $\theta=20^\circ$, but for $\theta=30^\circ$, $\phi_r=15^\circ$ is the worst, and $\phi_r=30^\circ$ gives the largest power coefficient. Considering the change in the wind direction, C_p for three values of ϕ_r are averaged and shown in Fig.8. Parameters, with which the guide vanes used in this work are effective, are $Sz=8$ and $\theta=20^\circ$. But in this case the range of the tip speed ratios μ where a large power coefficient can be obtained becomes

(a) $Sz=4$

(b) $Sz=8$

Fig.4 Effects of θ on C_t

Fig.5 Effects of D_{si}/D_{so} on C_t

(a) $\theta=20^\circ$

(b) $\theta=30^\circ$

Fig.6 Effects of ϕ_r on C_p ($Sz=4$)

narrower than that of the case without the guide vanes.

Figure 9 shows the effects of a chord length of the guide vane on C_p . Similarly to the results of C_t , C_p becomes large as the guide vanes come close to the rotor.

4. Velocity Distributions Inside the Guide Vanes

When the guide vanes are placed axisymmetrically around the rotor, the guide vanes in front of the rotor seem to block a flow to the convex surface of the rotor bucket and to accelerate the flow to the concave surface. However, it can be imagined that the guide vanes in the rear of the rotor work only to increase the

resistance of all guide vanes. For such a reason, an additional experiment has been conducted for $Sz=8$, $\theta=20^\circ$ eliminating the three guide vanes in the rear of the rotor. Results of this measurement are presented in Fig.10 and 11, in which the data are plotted as those for $Sz=8(5)$.

As for C_t , the difference between $Sz=8$ and $8(5)$ is not large, but C_p decreases remarkably with elimination of the three guide vanes. This may occur because of the diffuser effects of the guide vanes located in the rear of the rotor.

The velocity distributions inside the guide vanes have been measured removing the rotor, and the results are presented in Fig.12. In the case of $Sz=4$, $\theta=20^\circ$ and $\phi_r=0^\circ$ (Fig.12(a)), the velocity of the

Fig.7 Effects of ϕ_r on C_p ($Sz=8$)

Fig.8 Effects of Sz and θ on C_p

Fig. 8 Effects of S_z and θ on C_p

flow to the convex surface of the bucket is as large as the velocity of the flow to the concave surface, but in the case of $\phi_r=30^\circ$ (Fig. 12(b)), the velocity to the convex surface is considerably low and the velocity to the concave surface becomes slightly larger than the velocity of a uniform flow. Hence, in this case the power coefficient C_p becomes large as shown in Fig. 6(a).

In Figs. 12(c) and 12(d) the velocity distributions for $S_z=8$ and 8(5) are shown. It does not happen that the resistance of all guide vanes decreases, and then, the wind velocity increases when the three guide vanes located in the rear of the rotor are eliminated. On the contrary, the velocity of the flow through all guide

Fig.12 Velocity distributions at the center of the guide vanes

vanes ($Sz=8$) becomes larger than in the case of $Sz=8(5)$.

In practise the rotor is located at the center of the circular guide vanes, and hence, there is some limit in discussing about the velocity distributions measured after the removal of the rotor.

5. Conclusions

The starting characteristic can be improved by placing the guide vanes axisymmetrically around the Savonius rotor. Power coefficients vary with the angle ϕ_r between the guide vanes and the wind direction. If the wind direction does not change, a power increase of 10~20 % can be expected by selecting an appropriate value of ϕ_r , for example, $\phi_r=30^\circ$ for $Sz=4$, $\theta=20^\circ$ and $\phi_r=15^\circ$ for $Sz=8$, $\theta=20^\circ$. When the wind direction changes much, only a parameter combination of $Sz=8$, $\theta=20^\circ$ gives a larger power than in the case without the guide vanes. The guide vanes have the diffuser effect and serve as a wind concentrator and a wind deflector. When all guide vanes are placed axisymmetrically, their effects becomes large.

In general, the wind turbine requires a protection device from a strong wind or

a rotational speed control device. But such devices are not yet available for the Savonius-type wind turbine. The guide vanes investigated in this study can be used as one of the above-mentioned devices.

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