Res. Rep. *Nagaoka National Coll. Tech.* *39*,*No.2* (2003)

Paper

Wake-Assisted Windmill System with Parallel Vertical-Axis

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Abstract

For the improvement of the performance of drag-type windmills with vertical-axis, the experimental study proposed the windmill system using the wake behind a bluff body. The model windmill has two Savonius rotors that were set in parallel behind the circular cylinder. Through the wind tunnel experiment the revolution of the rotor of the windmill system was compared with that of the single rotor. The revolution of the windmill system was found higher than that of the single rotor. Also the optimal configuration of the Savonius rotors was found. From the experiment for three types of the devices for power augmentation; guide-vane, circular arc plate and splitter plate, the power augmentation system was found to decrease the revolution of rotor in all conditions.

INTRODUCTION

As an electronic power generation, the windmills with vertical-axis have, in general, lower efficiency than that of the wind turbines with horizontal-axis owing to the lower revolution than that of the wind turbines. Windmills with vertical-axis are nevertheless much superior to the wind turbines owing to the characteristics of silence, smooth self-starting and the good torque performance. A Savonius rotor, which is one of the drag-type windmills with vertical-axis, has two convex faced buckets around the rotating axis. The difference in the drag forces between these two buckets brings the rotation force around the axis, which leads to the upstream movement of the convex faced bucket. If the approaching flow toward the convex faced bucket could be blocked in part, drag force in rotation by this convex bucket would be decreased, and thereby the performance of the rotor would increase dynamically. Owing to the effect of blockage of the approaching flow, setting the guide vanes around the Savonius rotor will thus be one of the promising ways to improve the performance.

Aiming to the improvement of the performance of drag-type windmills with vertical-axis, this study proposes a wake-assisted windmill system using a bluff body [1]. Owing to the wake region formed behind the bluff body the difference in velocities between the mean-flow and a wake flow develops. **Figure 1** shows the present windmill system. In the wake region behind the bluff body, two Savonius rotors were set in

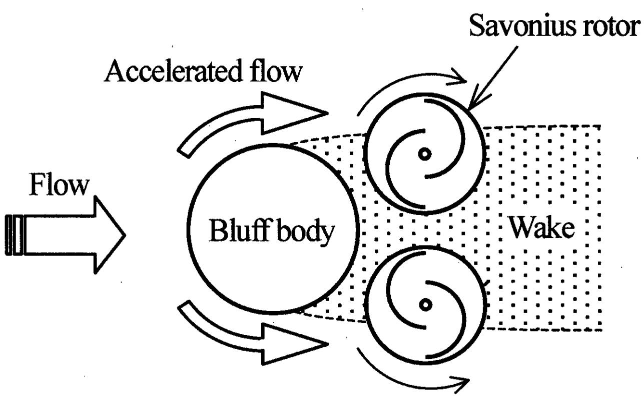

Fig. 1 Concept of the windmill system

Accepted 2003. 9 . 2
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parallel aiming to produce the difference in velocities of the flow approaching the reversing buckets. The flow accelerated along the bluff body approaches the advancing buckets of rotors. Thus, the rotors in the present windmill system will rotate faster than single rotor. Although the windmills with vertical-axis can, in general, start rotation in all wind directions, the present windmill system needs the flow on the front face of the bluff body. Facing automatically to the optimal direction, the present windmill system can follow any direction of wind. We can use the power augmentation devices [2] which are only used for normal windmill facing to the constant flow direction. To form the considerable wake region in this windmill system, two-dimensional bluff body of pillar-shape (ex. such as a streetlight) is needed. Owing to the windmills with vertical-axis we can expect that this windmill system can be used even in urban area.

To clarify the advantage of the present windmill system, we compared the first the revolution of rotors with that of the single rotor. Various configurations of rotors were tested the second to determine the optimal rotor position, and three kinds of power augmentation devices; guide-vane, circular arc plate and splitter plate were tested finally.

EXPERIMENTAL APPARATUS AND PROCEDURE

Experiment was conducted using the wind tunnel of open suction type; 400 mm × 400 mm in cross section. **Figure 2** shows the schematic illustration of the model of the windmill system for wind tunnel experiment. The free-stream velocity was 5 m/s through the experiment. The Savonius rotors used in this study have the over-lap between two buckets, of which the ratio is 0.5. To avoid the deviation of the centers of axes on both ends of rotor, the single axis rod was set through the rotor. As the two-dimensional bluff body the circular cylinder is used. The output signal of the synchronized pulse from the photo sensor mounted on the upper side of the rotating axis rod indicates the rotation of rotor, and thereby the data of revolution of rotor was acquired by the pulse counter. The indicated results of the revolution are the mean values through the data acquisitions of ten times.

Three experiments were conducted aiming to clarify the characteristics of the windmill system. The revolution of rotors in the windmill system was compared the first with that of single rotor. To distinguish the efficiency due to the parallel setting of rotors from that due to setting rotors in a wake, the experiment without the circular cylinder was also conducted. The experiments at several configurations of rotors were conducted the second aiming to find the optimal position of the rotors near the circular cylinder. Twenty-five points, as shown in **Figure 3,** were selected as the position of setting the rotors. Two rotors were set symmetrically to the mean flow. Three power augmentation devices were tested finally aiming to the improvement of the revolution of rotors. Guide vane, circular arc plate and splitter plate were tested as the power augmentation devices. The guide vane concentrates the approaching flow and guides it to the rotor. The quarter angular circular arc plate is set behind the rotor. It acts as the casing cover of the

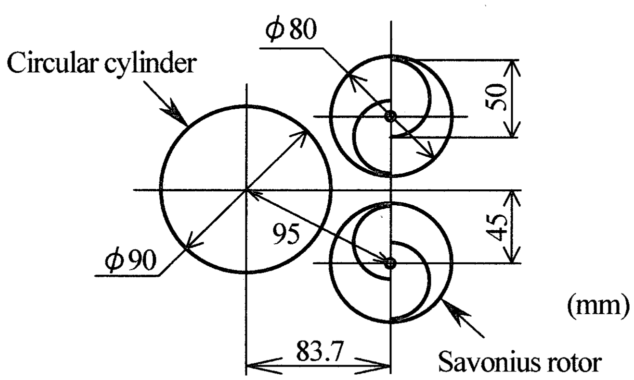

Fig. 2 Detail of experimental apparatus

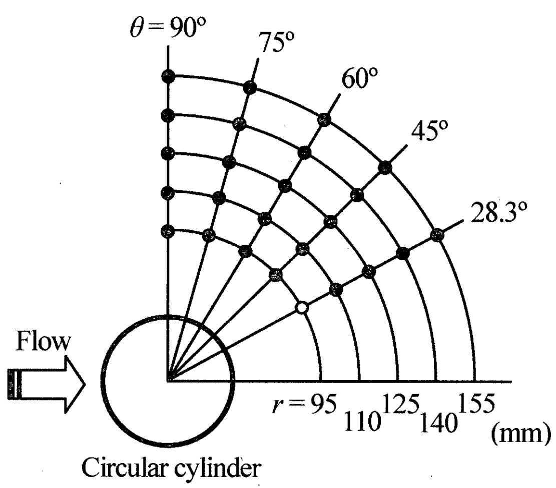

Fig. 3 Configuration of the axis of the rotor (●:axis position, ○:standard axis position)

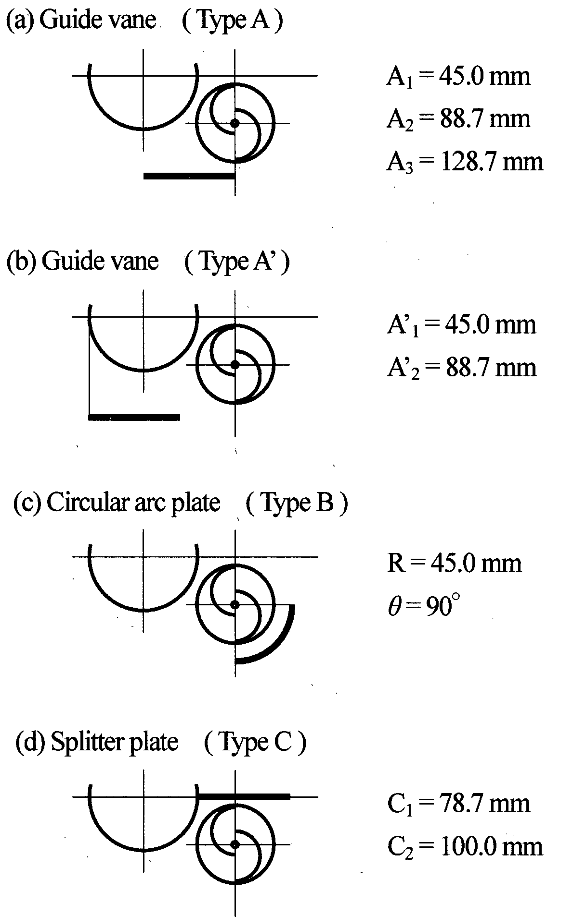

Fig. 4 Condition of power augmentation devices

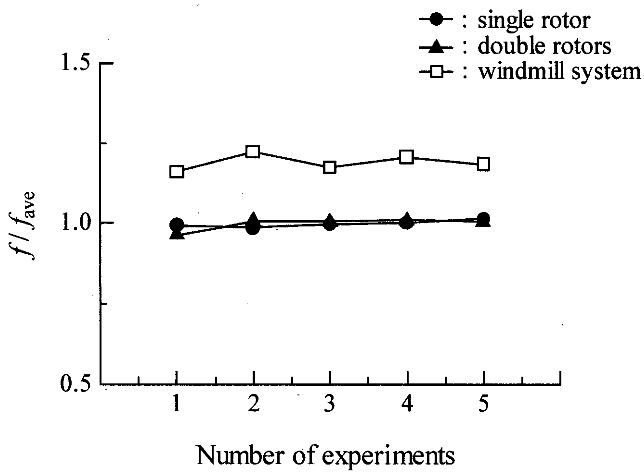

Fig. 5 Comparison of revolutions of rotor

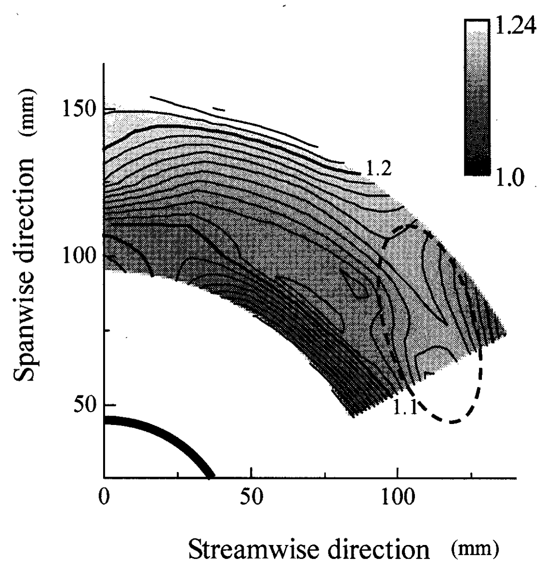

Fig. 6 Revolutions of rotor at various positions

rotor such as the pump and/or the blower. The splitter plate is used to prevent the flow caused by one side rotor affecting the other side rotor. The conditions of these power augmentation devices are shown in **Figure 4.**

RESULTS AND DISCUSSION

Figure 5 shows the revolutions of rotor at three conditions; single rotor, double rotor in parallel and the windmill system. To confirm the repeatability of the results, the measurements for data acquisition are conducted five times in the same condition. The revolutions are normalized by that of single rotor; f_{ave}. As shown in **Fig. 5,** the revolution of double rotors has the same value of that of single rotor with good repeatability. On the other hand, the revolution of the windmill system is 1.2 times higher than those of other two conditions. The revolution of rotor seems to become high owing to the rotors in the wake behind a bluff body. In the case of the windmill system, the revolution varied in five experiments. The variation of the revolution can be attributed to the rotor in the unsteady flow in the wake, and is negligibly small. **Figure 6** shows the variation of the revolutions of rotor which are normalized by that at the standard position, where $r \doteq 95$ mm and $\theta = 28.3°$; f_0. We can see that the revolution at the standard position is the lowest in all position. As the position of rotor becomes far from the circular cylinder, the revolution of rotor increases. In the experiment the flow between the rotor and wind tunnel wall will be accelerated as the position of rotor becomes close to the wall, and thereby the revolution of rotor increases. At the position $\theta = 90°$ where the rotor is in the side of the circular cylinder, two rotors and circular cylinder line up in a straight line perpendicular to the mean flow, and the revolution is

Tab. 1 Revolutions of rotor with power augmentation devices

Without devices
1.000

Type A,B,C

A_1	A_2	A_3	A_1'	A_2'
0.873	0.744	0.817	0.981	0.860

B
0.622

C_1	C_2
0.965	0.977

Type AB

A_1B	A_2B	A_3B
0.666	0.451	0.410

Type BC

BC_1	BC_2
0.683	0.680

Type ABC

A_1BC_1	A_2BC_1	A_3BC_1
0.634	0.411	0.425

A_1BC_2	A_2BC_2	A_3BC_2
0.592	0.468	0.433

high. The flow around the rotor is accelerated owing to the narrowed flow path. We can not determine the optimal position of rotor only from these results. Except for this region affected by the accelerated flow, however, the optimal position will be in the region surrounded by dashed line in **Fig. 6.** To examine the characteristics in detail, however, the wind tunnel of open jet type should be used. **Table 1** shows the revolution of rotor with the power augmentation devices, where we can see the decreased revolutions in all condition. By setting the circular arc plate, in particular, the revolution extremely decreases. When the guide vane was set, because of the blockage effect the approaching flow is decelerated. The circular arc plate retards the flow passing through the rotor to downstream. Sato et al. suggested that the circular arc plate will decrease the revolution of Savonius rotor [3] . The splitter plate, which was set to prevent the effect of the flow between two rotors, has only small effect on the stabilization of rotation. The revolutions of rotor decrease at the condition in combination of devices. When the combined devices include circular arc plate, the revolution extremely decreases.

CONCLUDING REMARKS

The windmill system with parallel vertical-axis using the flow around the bluff body was studied experimentally. It was aimed to estimate the advantage of this system and the running characteristics. The revolution of rotor, which depends on the position, in the present system was higher than that of the single rotor. In the present stage of this study could not determine the optimal position of rotor. The power augmentation devices had no effect on the increase of the revolution of rotor. In addition to the present discussion on the revolution characteristics of the rotor, the coefficient of torque and power also should be discussed later. For the improvement on the windmill system, the shape of the bluff body is, of course, the important factor.

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