

## Research Article

### A PIV Visualization Study on Static Flow Field Characteristics of Savonius Rotor in Food Production Bases with Different Overlap Ratios

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**Abstract:** In this study, the PIV sensor visualization experiments are carried out on Savonius rotor in food production with two kinds of overlap ratios of 0 and 0.2 to study the mechanism of the effects of overlap ratio on static flow field. The static velocity fields in and around Savonius rotor in food production were obtained in the test at four typical azimuth angles of 0°, 35°, 90° and 165°. The test results show that the existence of overlap ratio has large effects on the static flow fields of the rotor in food productions with and without overlap ratio at different azimuth angles.

**Keywords:** Flow field, overlap ratio, PIV sensor visualization, savonius rotor in food production

## INTRODUCTION

The concept of Savonius wind turbine was proposed in the 1930s by Savonius (1931), which is a drag-type wind turbine named after the inventor. The simple structure, low cost and higher rotational torque are the main advantages. In the past, most researches on such wind turbine were concentrated on wind tunnel experiments to find out the structure parameters effects on the torque characteristics and numerical simulation to analyze flow characteristics. The overlap ratio is an important factor which affects the torque performance of Savonius rotor in food production according to the past researches. Yan *et al.* (2009) carried out a wind tunnel experimental study on the overlap ratio of Savonius rotor in food productions. Zhenzhou and Yuan (2010) used numerical simulation methods to optimize the Savonius rotor in food production. Wenqiang *et al.* (2013) analyzed the torque characteristics of Savonius rotor in food production by numerical simulation methods and wind tunnel tests.

According to results of previous studies, the torque characteristics of Savonius rotor in food production have great relationship with its overlap ratios. However, the effect mechanism should be revealed from flow field. It is an effective way that using visualization methods to study flow field around the wind turbine. With development of measurement technology, PIV (particle image velocimetry) visualization experimental methods were used to research the flow field characteristics, which has become a cutting-edge visual method of quantificational measuring flow field distribution and it has been widely used in the research of wind turbine (Danmei *et al.*, 2007; Zhi-Ying *et al.*, 2013, 2009).

In this study, two kinds of Savonius rotor in food productions with and without overlap ratio were designed and made. The overlap ratios were decided as 0 and 0.2. PIV Visualization tests were conducted on the two types of Savonius rotor in food productions at different azimuth angles. The static flow field in and around Savonius rotor in food production were measured at the wind speed of 2 m/s and the effects of overlap ratio on the flow field characteristics were analyzed.

## EXPERIMENTAL DETAILS

**Savonius rotor in food production:** Figure 1 shows the geometry of test Savonius rotor in food production and photographs. The rotor in food production was composed by two semi-circular buckets relatively and the overlap zone exists in central part. Optical glass (SiO<sub>2</sub>) was selected as model material owing to its light transmission rate of 92% based on the requirements of laser light transmittance. The diameter of bucket is 0.047 m and the height of rotor in food production is 0.16 m. The overlap ratio (OL) was defined as ratio of the overlap and the diameter of bucket, as shown in Eq. (1). The OL was selected as 0 and 0.2 to compare the effects of OL on static flow field characteristics based on past research (2).

where,

$U$  = Wind velocity, m/s

$\alpha$  = Installation angle

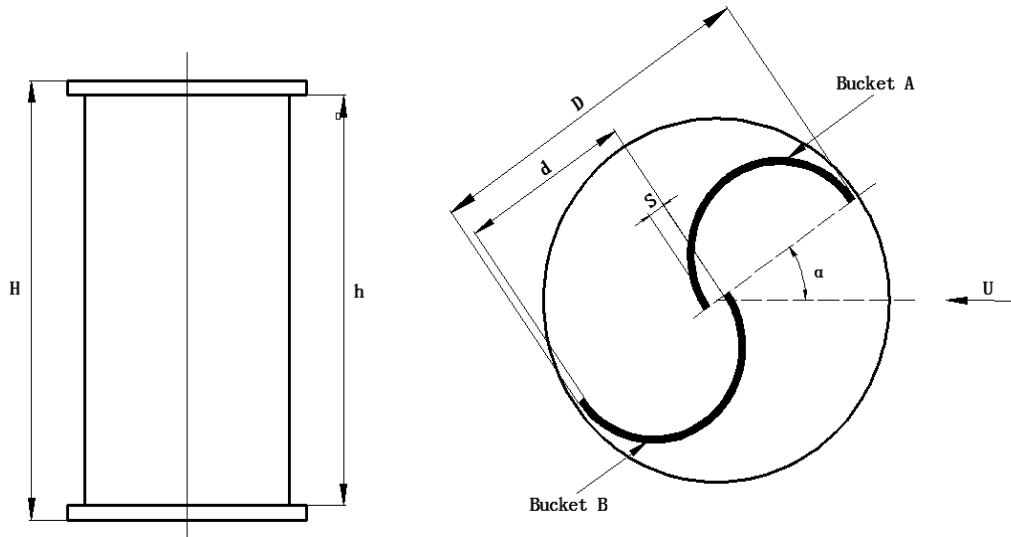
$D$  = Diameter of rotor in food production, m

$d$  = Diameter of blade, m

$S$  = Overlap

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(a) Geometry of test rotor in food production



(b) Photographs

Fig. 1: The test rotor in food production models

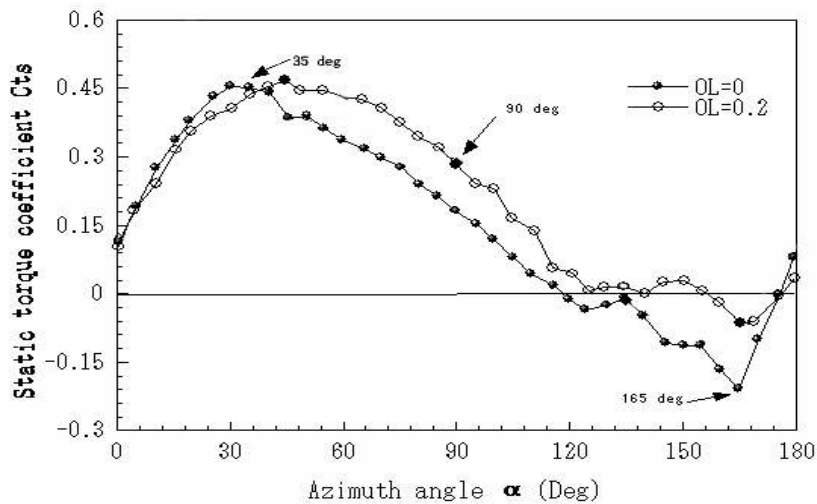


Fig. 2: Static torque coefficients of the test rotor in food productions with OL = 0 and 0.2

H = Height of rotor in food production, m  
 h = Height of blade, m

$$OL = \frac{s}{d} \quad (1)$$

**Experimental system and methods:** Figure 2 shows the PIV experimental system. The wind tunnel used in

test is an open type small scale one with the test section size of 1 m×1 m. The Savonius rotor in food production was placed in the test section of wind tunnel. The PIV system used in the experimental test is a two-dimensional particle image velocimetry system provided by TSI company of USA, which mainly includes Laser (120Mj/pulse, frequency: 15 Hz/sec), LaserPulse Synchronizer, CCD Camera (16 frame/sec,

Table 1: Experimental conditions

No.	Test conditions	Figures
1	Blade Material	Optical glass (SiO <sub>2</sub> )
2	Overlap ratio (OL)	0, 0.2
3	Azimuth angle ( $\alpha$ )	0°, 35°, 90°, 165°
4	Wind velocity (U)	2 m/s
5	Reynolds (Re)	16000

Lens: 55 mm/F1.8), Smoke Generator (Particle size: 1-2  $\mu\text{m}$ ). The laser emitted sheet light and the test section was shot by camera. Images were shot to analyze flow field characteristics accurately in order to catch 10 pairs of cross-correlation PIV group in each section.

Four typical angles azimuth angle were selected as 0°, 35°, 90° and 165° according to the past research results which is shown in Fig. 3 (Yan *et al.*, 2009). The static torque of the Savonius rotor in food production with no overlap ratio had the maximum plus value at near 35° and the minimum minus value at near 165°. The 0° and 90° were the typical azimuth angles. The experimental conditions were shown in Table 1.

## RESULTS AND ANALYSIS

Figure 4 and 5 show the velocity fields while OL are 0 and 0.2 at difference of azimuth angles.

According to Fig. 4a and 5a, when fluid flows through bucket A and B, majority fluid flows from outside, however, less flows into the interior of rotor in food production while azimuth angle is 0°, because bucket A was not installed up the windward side. Hence, the effect of driving force of fluid has minor difference to Savonius rotor in food production with and without overlap ratio from analysis of flow field characteristic. However, it is obvious that countercurrent exists in back of bucket A by observing flow field characteristics of two kinds of overlap ratios and which hinders the whirling of bucket A to a small extent.

By observing (b), majority fluid flows into the internal of rotor in food production while the azimuth angle is 35°, because bucket A was installed up the windward side. Overall, Flow field has been obviously improved compared with it at 0°. Vortex

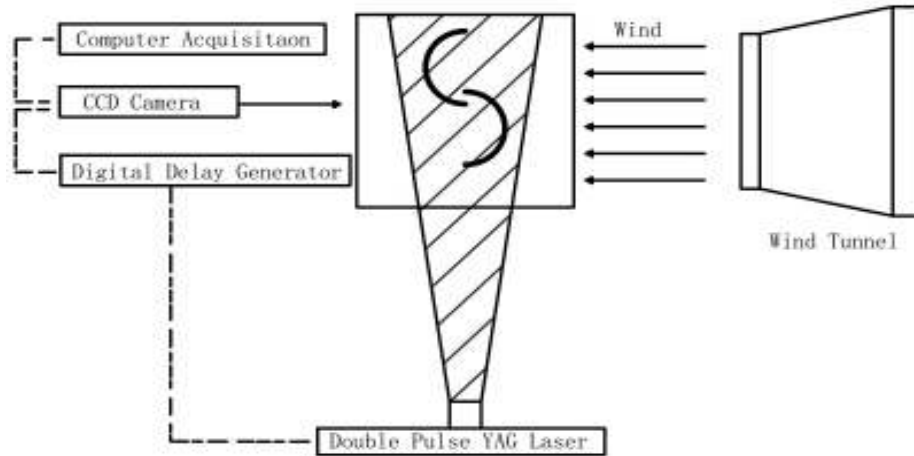
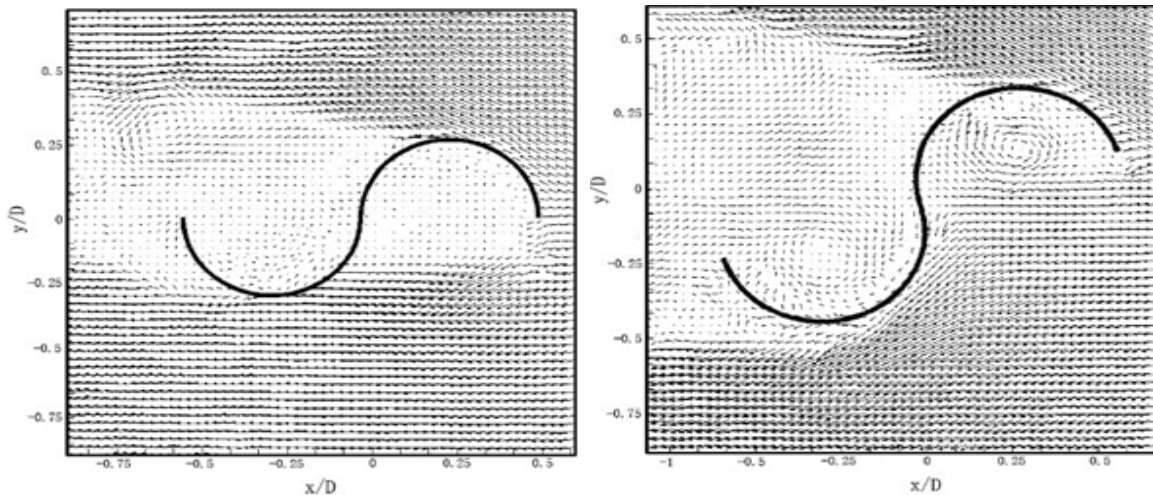


Fig. 3: Schematic diagram of the experimental apparatus



(a)  $\alpha = 0^\circ$ , OL = 0

(b)  $\alpha = 35^\circ$ , OL = 0

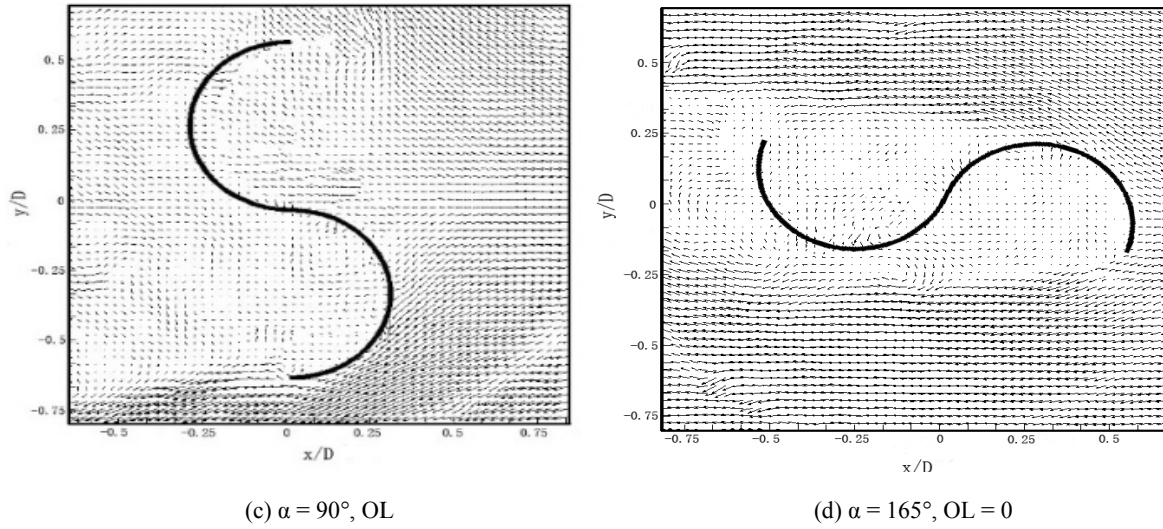


Fig. 4: Velocity field distributions around the rotor in food production with OL = 0

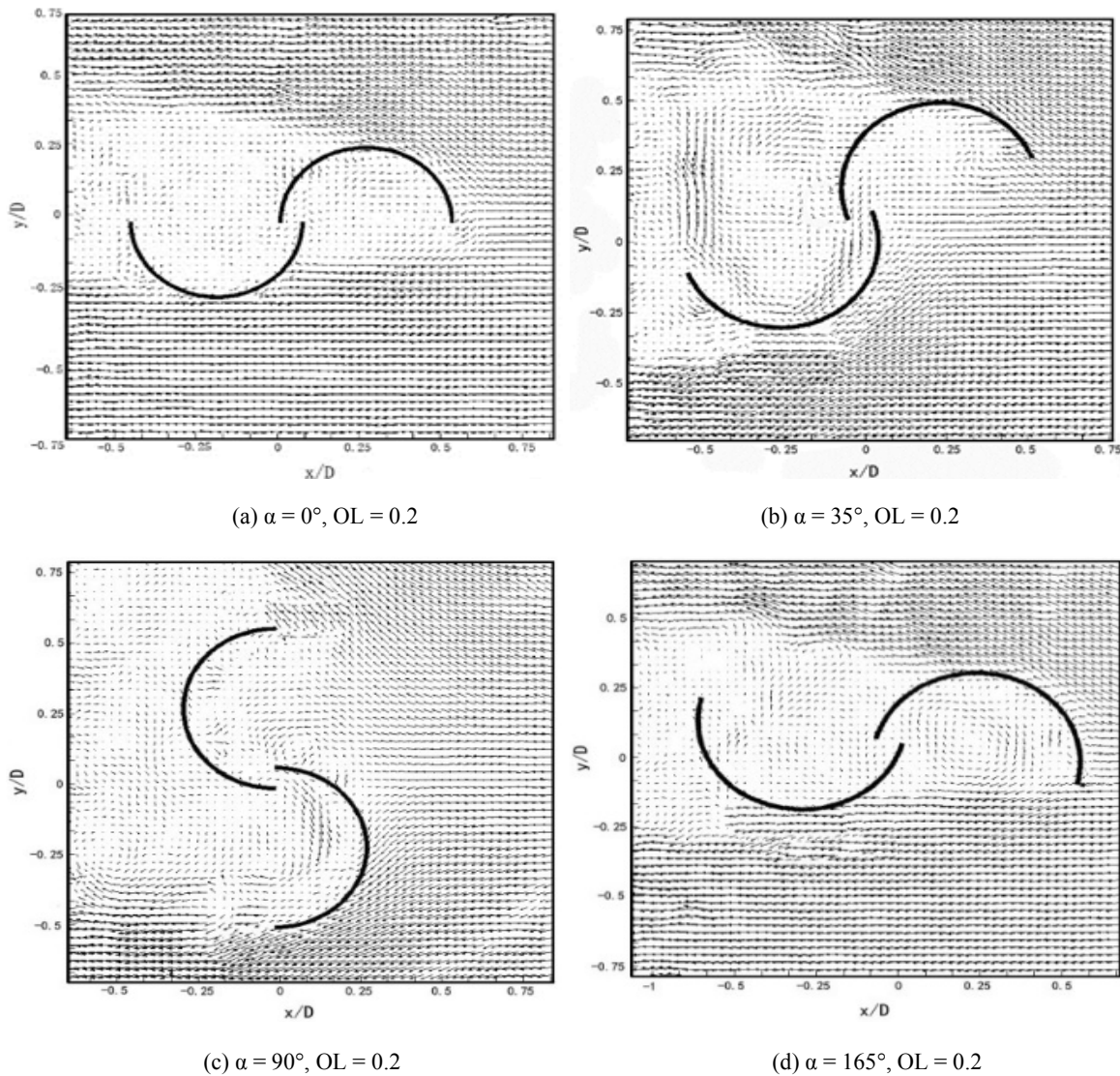


Fig. 5: Velocity field distributions around the rotor in food production with OL = 0.2

appears at interior of bucket A due to the counterclockwise rotation of bucket B and a portion of the fluid flows along the convex side of bucket B, then countercurrent exists in interior of bucket B, which also thinly contributes to the counterclockwise rotation of bucket B. However, flow field is completely different while overlap ratio is 0.2. The flow field, which is in the interior of bucket A, flows along concave side, then pushes forward rotation of bucket B, but the countercurrent being back of bucket A hinders whirling of bucket A. Therefore, the effect of overlap ratio to static torque of Savonius rotor in food production is minor at 35°, but the static torque has been enhanced compared with that at 0°.

No visible countercurrent exists while the azimuth angle is 90° by observing (c). The fluid is hindered by the Savonius rotor in food production installed vertically and it is obvious that speed of fluid flowing by is decreased. But at the same angle, the flow field is improved to a great extent with overlap ratio of 0.2. Because fluid flows into the overlap area, which leads to speed increased and pushes the rotation of bucket B. Therefore, the static torque of Savonius rotor in food production with overlap ratio is larger than that without overlap ratios.

According to (d), most fluid flows away from the external of rotor in food production, which is similar with that of 0°. The fluid hinders the rotation counterclockwise because the Savonius rotor in food production is placed leeward, which will lead to negative moment generated. However, the phenomenon has been ameliorated while overlap ratio is 0.2, what has been found is that vortex appears. The fluid flowing into bucket A has pushed its rotation, which will make the static torque increased.

### CONCLUSION

Under the experimental condition of this study, the conclusions can be summarized as below:

- The existence of overlap ratio has large effects on the static flow fields of the rotor in food production with overlap ratio and the rotor in food production

without overlap ratio at different azimuth angles.

- The existence of internal flow from advancing bucket to returning bucket through overlap area at some azimuth angles improves the flow characteristics of the rotor in food production without overlap ratio which is the main reason for the large difference of torque performance of the two type rotor in food productions.

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