PRESSURE DISTRIBUTION OF SMALL WIND TURBINE BLADE WITH WINGLETS ON ROTATING CONDITION USING WIND TUNNEL

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ABSTRACT

Investigation of pressure distribution over an envelope of the blade with and without winglets for a small wind turbine was carried out in boundary layer wind tunnel. In this paper the various winglet configurations taken for improving the aerodynamic performance of a small wind turbine were investigated. The winglets are considered as small fences placed downward at the tip of the blade to improve blade performance by decreasing the induced drag. The different winglet configurations had been tried based on the winglet height and curvature radius. The pressure measurements were made with different chord wise and span wise locations on the blade with and without winglets nearby tip region. The results show that the winglet improves the overall pressure difference between pressure surface and suction surface. The presence of winglet seemed to have the pressure increased at 0.3c and the maximum pressure difference was observed at a span of 0.95R for all winglet configurations. In the suction surface pressure decrease was around 10% for all winglet configurations. Furthermore, the overall pressure distribution was compared with all the winglet configurations and without winglet.

KEYWORDS: Wind turbine rotor, Winglets, pressure distribution, blade surfaces

INTRODUCTION

Wind energy plays a vital role in renewable energy resources. In this form of energy, the small wind turbine system is more affordable for household, hill areas and agricultural farms purposes. At present small wind turbine users are very small in numbers because of low efficiency and wind conditions. Performance enhancement of small wind turbine rotor is necessary to increase the users. In general, any design modification in wind turbine blade is analyzed by a numerical calculation, and also verified by wind tunnel experiment. Many studies have been carried out on wind turbines in order to increase the power output. One way of improving the wind turbine performance is adding a winglet on the blade tip.

In 1990’s Van Bussel proposed momentum theory for winglets on horizontal axis wind turbine rotors to obtain performance improvement [1]. Riso laboratory is currently carrying out research work on winglets for wind turbine rotor blades numerically. The power augmentation of the wind turbine with the various tip vanes were investigated numerically [2]. The pressure distribution of wind turbine blade with tip vane was reported by Wang [3]. The numerical investigation of the aerodynamic study around the wind turbine rotor with winglets has been carried out [4]. Different blade tip geometries were tested with the design code and found that tip modification enhances the aerodynamic performance [5]. The winglet added wind turbine rotor blades were tested dynamically and reported 6.42% power increase [6]. Very
few researchers have studied the effect of geometrical modification on blades using winglet experimentally compared to numerical studies.

The paper presents the pressure distribution along span wise and chord wise of the small wind turbine blade with winglets experimentally to improve its performance.

**EXPERIMENTAL STUDIES**

**Boundary Layer Wind Tunnel**

The pressure measurements are carried out in a turbulence level of 1% using wind tunnel facility at SERC CSIR, Chennai. An open circuit blower type wind tunnel with a maximum test section velocity of 55 m/s and the test section dimensions are 18 m long, 2.5 m wide and 1.8 m high. The ceiling of the test section can be adjusted in order to obtain a zero pressure gradient.

**Wind Turbine rotor models**

Four rotor models of 340 mm diameter with 20 mm hub diameter and 140mm as the length of the blade was fabricated using aluminium. NACA 4412 profile was used from the blade root to tip and the same profile was maintained for different winglet configurations. The effect of winglet curvature radius and winglet height was more compared to the other winglet parameters like sweep angle, cant angle, toe angle and twist angle reported in [4]. Four winglet models were fabricated with two different winglet parameters. Table 1. provides the geometric parameters of winglet configurations used in this study. The winglets bended towards the suction side and the airfoil shape were maintained same as the wind turbine blade. The taper of the winglets were used same as blade taper. This study focused on variation of winglet height and curvature radius of the winglet configuration by keeping the constant cant angle at 75° for all models.

<table>
<thead>
<tr>
<th>Rotor with Winglet</th>
<th>Winglet height (% rotor radius)</th>
<th>Curvature radius (% winglet height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W1</td>
<td>2%</td>
<td>12.5%</td>
</tr>
<tr>
<td>W2</td>
<td>2%</td>
<td>25%</td>
</tr>
<tr>
<td>W3</td>
<td>4%</td>
<td>12.5%</td>
</tr>
<tr>
<td>W4</td>
<td>4%</td>
<td>25%</td>
</tr>
</tbody>
</table>

**INSTRUMENTATION**

The rotor model blades were attached to hub in the horizontal shaft. The rotor shaft was mounted on two support arm with each holding a low friction roller bearing to ensure rotor shaft rotational freedom. The rotor shaft was mounted on a vertical tower of height of 300mm and a digital laser tachometer of
accuracy 0.02% was located inside the tower to measure the rotational speed of the rotor models. The small wind turbine rotor model mounted in wind tunnel was shown in fig.1. The ratio of model area to wind tunnel test section area was less than 1% justifying the neglect of blockage effects.

Fig. 1 : The wind turbine model in the test section of the wind tunnel

Fig. 2 : Pressure Locations on the rotor blade
Fig. 2 shows the rotor blade pressure taps arrangement. The pressure taps were connected via metal tubes to pressure transducers set inside of the tower nacelle. The pressure measurements were made at three radial locations near to the blade tip to study the various winglet effects. Each radial locations six pressure taps were taken for measurements. The sampling frequency was about 60Hz. The pressure transducers were connected to the transmitter. These pressure transducers calibrated themselves and require no additional amplification. The pressure data were transmitted through transmitter. Transmitted pressure data was acquired using data receiver. This data was stored in PC through AD/DA card. The Fig 3 shows measurement system used for this study. The tachometer sensor was mounted near the rotating shaft positioned vertical axis of the tower and connected to the AD/DA card. It was used to measure the rotational speed of the wind turbine rotor models.

![Measurement System](image)

**Fig. 3 : Measurement System**

**Validation**

In this study the pressure coefficient values of without winglet rotor model are very close to the Ronsten [7] prediction shown in Fig. 4.
RESULTS AND DISCUSSION

All the measurements presented in this paper are conducted at a turbulence level of about 1%, using four different configuration of winglet at constant wind speed of 5 m/s. Static surface pressure data, both chordwise and spanwise for all winglets were measured. The data is further analyzed for pressure coefficients using the following relationship

\[
C_p = \frac{p - p_w}{\frac{1}{2} \rho [U_w^2 + (\omega r)^2]}
\]  

(1)
Fig. 5(b) : Comparison of pressure coefficient at 90% radial

Fig. 5(c) : Comparison of pressure coefficient at 85% radial

Fig. 6 (a) : Comparison of pressure coefficient at 30% chord
Spanwise pressure distribution

Fig. 5(a) shows the pressure distribution of all wind turbine rotor blades at 95% span. At x/c =0.3 rotor models with winglet had high value of pressure coefficients compared to rotor without winglet. The remarkable difference in pressure distribution between winglet and without winglet is increased in suction surface for all rotor models. Even though, pressure difference increases as winglet height increase more in suction surface and less in pressure surface. As well as higher curvature radius winglets pressure difference is less compared to the lesser curvature radius. At x/c=0.6 the pressure difference between surfaces is more only in higher winglet height rotors and remaining rotors shown the same as without winglet rotor. At x/c=0.9 for all rotor models pressure coefficients are seems to be same as without winglet rotor.

On the other hand pressure coefficients of pressure surface of winglet rotor model blades are almost same as without winglet rotor in all the chordwise locations. The curve of pressure coefficients of pressure surface for all rotor models are seems to be smooth in shape. Moreover, it is obvious that the difference in increment by the winglet on the leading edge is larger than that on the trailing edge. The pressure difference is seen maximum where the thickness of airfoil is maximum along the span. After
comparing these results, the smaller curvature and higher height winglets can increase pressure difference more.

Fig. 5(b) shows the pressure coefficient of all rotor model blades at 90% span. The pressure coefficient values of all winglet rotor models are higher than without winglet rotor model. On the suction surface, the lesser curvature winglet rotor models pressure coefficient values are higher than the higher curvature rotor models at x/c=0.3. The pressure coefficient value of W2 rotor model is higher than other winglet rotor models at x/c=0.6. At the trailing edge all rotor model pressure coefficients are same. On the pressure surface winglet rotor models pressure difference slightly decreases compared to the without winglet rotor model. As the result with decrement of the radial position, the influence of the winglet gradually decreases.

Fig. 5(c) compares the pressure coefficient of all rotor model blades in chordwise locations at 85% span. At x/c 0.6 and 0.9 locations pressure coefficients for all rotor model blades are almost same, but only the pressure difference is seen at x/c=0.3. The influence of winglet is very less compared to the other (95% & 90%) radial locations. It is found that from fig. 5(a) to 5(c) that pressure difference between pressure surface and suction surface decreases from root to tip and also the pressure difference are seen more at a location nearby leading edge of the blade section. As the result, the effects of the winglets are obvious at the blade tip.

**Chordwise pressure distribution**

Fig. 6(a) shows the spanwise pressure distribution of all the rotor model blades at 30% chord. The pressure difference is more in r/R=0.95 for all the rotor models. In particular, the pressure difference increases as winglet height increases or curvature radius of winglet decreases. At r/R=0.9 the pressure difference of all the rotor models are identical with r/R=0.95. On the other hand, pressure surface values are all most identical, but only slight difference is seen.

Fig. 6(b) shows the comparison of pressure distribution at 60% chordwise location of all the rotor model blades. A pressure difference for all rotor model decreases as chord increase. Maximum pressure is seen in W1 and W2 in r/R=0.95 and remaining rotor model blade pressure coefficient are almost identical. At r/R=0.9 W1 and W2 experiences the pressure decrease as the chord increases. But the W3 and W4 gives same pressure throughout the chord length of the blade. On the suction surface pressure coefficient for all rotor models are same and also seen very smaller deviations in its values. At r/R =0.85 W2 and W4 gives more pressure difference than other winglet rotor models. As a result, the decrement in radial position corresponds to decrease in pressure from root to tip of the blade.

Fig. 6(c) compares the pressure coefficient of all rotor model blades at 90% chord. The pressure difference for all the radial positions are identical on both suction and pressure surfaces, but only small deviation is seen. The pressure difference is slightly more for W2. It is found that fig. 6(a) to 6(c) that pressure difference decreases from leading edge to trailing edge. From the above results, the tip effects of the blades are more at x/c=0.3, near by the blade tip.
CONCLUSIONS

The effect of the winglets at the blade tip of wind turbine is dominant. The winglet increases the pressure difference by increasing the pressure on the pressure surface and decreasing the pressure on the suction surface. At the location of maximum thickness of the airfoil, the pressure difference is maximum and pressure difference decreases as the chord length increases.

The pressure difference increases as winglet height increases or curvature radius of winglet decreases. The winglet W2 gives more pressure difference at the tip region of the blade. As the pressure difference of the blade increases, the momentum transfer increases hence the blade can absorb more energy from the wind. The W2 winglet configuration can improve the power output of the wind turbine.

NOMENCLATURE

$U_\infty$ - wind speed
$p$ - Local pressure
$p_\infty$ - Free stream pressure
$\rho$ - Density of air
$\omega$ - Rotational angular velocity
$r$ - Local radius for the spanwise location
$x$ - Distance between leading edge to chordwise location
$c$ - Chord of blade

REFERENCES


7. Goran Ronsten, Static pressure measurements on a rotating and a non-rotating 2.375 m wind turbine blade, Comparison with 2D calculations, J Wind Eng Ind Aerod, 39 (1992) 105-118.

Table Legends

Table 1. Winglet Parameters.

Figure Legends

Fig.1 The wind turbine model in the test section of the wind tunnel

Fig. 2 Pressure Locations on the rotor blade

Fig. 3 Measurement System

Fig. 4 Comparison of pressure coefficient

Fig. 5(a) Comparison of pressure coefficient at 95% radial

Fig. 5(b) Comparison of pressure coefficient at 90% radial

Fig. 5(c) Comparison of pressure coefficient at 85% radial

Fig. 6(a) Comparison of pressure coefficient at 30% chord

Fig. 6(b) Comparison of pressure coefficient at 60% chord

Fig. 6(c) Comparison of pressure coefficient at 90% chord