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PERFORMANCE OF A CIRCULAR ARC HORIZONTAL AXIS WIND TURBINE

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ABSTRACT

An experimental investigation and design analysis of a Horizontal Axis Wind Turbine with arched steel plate section has been performed. Wind characteristics of different regions of Bangladesh have been analyzed and hence, a compatible design of Horizontal Axis Wind Turbine applicable to the pump has been carried out. Performance of the wind turbine models with circular arc blade section for different number of identical blades have been studied at constant wind velocity. The theoretical analysis has been done using momentum theory and Blade element theory. It is observed that the calculated results of the wind turbine with circular arc blade profile are comparable with those of the turbine with airfoil blade section. An extensive experimental investigation of the performance of the designed wind turbine model has been conducted in the wind tunnel. The wind turbines with 2, 3, 4, 5 and 6 blades for linearized chord and twist angle have been considered. The experimental investigation was performed for each turbine at various blade pitching and at different wind velocities. Finally, the calculated results of the wind turbine have been compared with the existing experimental results. It is observed that there are good agreements between the present experimental result and the existing other experimental results.

Keywords: Horizontal Axis Wind Turbine, Circular Arc Blade, Power Coefficient, Pitching Angle.

1. INTRODUCTION

For exploitation of energy in the field of wind, there have been reasonable developments. Still people are doing further research and development in this sector to find more efficient and cost effective machinery. Now-a-days both horizontal and vertical axis wind machines of different kinds have been developed in different parts of the world. For the present study attention has been focused on horizontal axis wind machines only. A horizontal axis wind machine with circular arc blade section has been chosen for the present theoretical and experimental investigation. This machine can be constructed with semi-skilled technicians and also the cost of production is not high. Most horizontal axis turbines built today are two or three-bladed, although some have fewer or more blades.

A prime objective in wind turbine design is for the blade to have a relatively high lift–to-drag ratio. This ratio can be varied along the length of the blade to optimize the turbine's energy output at various wind speeds [2,3,5]. Energy that comes from converting kinetic energy that is present in the wind into more useful forms of energy such as, mechanical energy or electricity.

2. EXPERIMENTAL SET-UP AND PROCEDURE

The schematic diagram of the experimental set-up of the present investigation is shown in Figure: 1. An open circuit subsonic type wind tunnel was used to develop the required flow and the rotor was positioned at the exit section of the wind tunnel. The tunnel was 6.55 m long with a test section of (490mm × 490mm) cross-section.

The central longitudinal axis of the wind tunnel was maintained at a constant height from the floor. The converging mouth entry was incorporated into the system for easy entry of air into the tunnel and maintains uniform flow into the duct free from outside disturbances. The induced flow through the wind tunnel was produced by two-stage rotating axial flow fan of capacity 30,000 cfm at the head of 152.4 mm of water and 1475 rpm. A butterfly valve, actuated by a screw thread mechanism was placed behind the fan and was used to control the flow. A silencer was fitted at the end of the flow controlling section in order to reduce the noise of the system. The diverging and converging section of the wind tunnel was

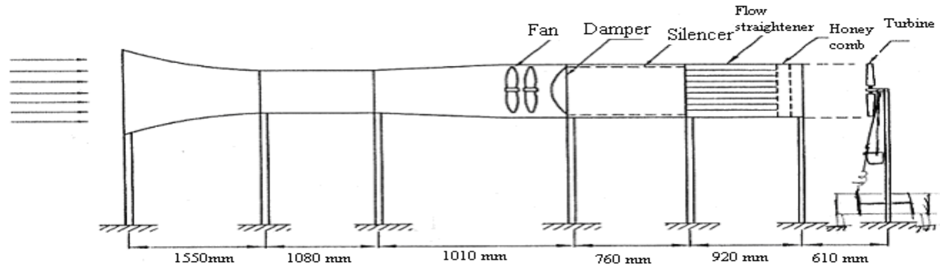

Fig 1. Schematic Diagram of Wind Tunnel

460 mm long and made of 16 SWG black sheets. The angle of divergence and convergence was 7^0, which was done with a view to minimizing expansion and contraction loss and to reduce the possibility of flow separation. Other three outlet square (610 mm each) sections were used to make the flow straight and uniform. The flow velocity in the test section was adjusted within 15 m/s covering Reynolds no up to 2×10^5.

Al-blades were used with camberness ratio 0.07. For camberness ratio 0.07: rotor radius 250 mm, root chord length 37.50 mm, Tip Chord length 12.00 mm, Root twist angle 13^0, Tip Twist angle 2^0. For this type of blade 2, 3, 4, 5 and 6 number of blades was used.

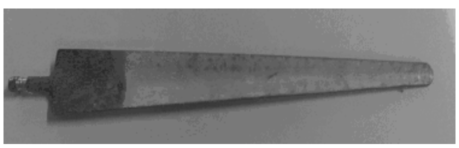

Fig 2. Blade Profile with f=0.07c

Fig 3. Experimental Set-up with B = 4

At first, the velocity was measured without the model turbine at the sections which was placed in front of the rotor at different locations and average velocity was measured directly. The experimental set-up is shown in Figure 3. The model turbine was placed at 0.5 - rotor diameter downstream from the wind tunnel exit end. This velocity distribution was along the vertical direction passing through the axis of the wind tunnel. It can be seen that the velocity is more or less uniform throughout. Similar velocity distribution had been observed in the horizontal direction as well. Non-contact electrical tachometer was used to measure the speed of the model wind turbine at different loadings.

Wind speed behind the rotor was measured by a digital anemometer and the speed of the model wind turbine shaft having 2, 3, 4, 5 and 6 blades with different pitching were determined using a non-contact digital tachometer at different loading.

3. RESULT AND DISCUSSION

Effect of number of blades or solidity and pitching are taken into consideration in the study. The blade pitching angles are chosen as 2°, 4°, 6° and 8° for each set of rotor consisting of fixed number of blades. Blade pitch angle of 0^0 is seemed to be less convenient.

A wind rotor can only extract power from the wind, because it slows down the wind: The maximum power extraction is reached when the wind velocity in the wake of the rotor is 1/3 of the undisturbed wind velocity. If the wind speed increase, power increase. Multi-bladed rotors operate at low tip speed ratios and two or three-bladed rotors operate at high tip speed ratios.

3.1 Comparison of the Results with Earlier Experimental Data

Comparison of the experimental results of power coefficients of wind turbines having circular arc blade section with camberness ratio f = 0.07c are made with those having the conventional NACA 4418 [1] blade section and CABS [4] blade section. It can be observed from these figures that as the number of blade increase, the maximum power shifted towards the lower tip speed ratio. The experimental results are good at tip speed ratio around 5. The experimental results turbine having NACA 4418 [1] blades section is good at tip speed ratio around 6 and CABS [4] at tip speed ratio around 5. It can also observe from these figures that the experimental results of the peak power coefficients of the turbine with NACA 4418 [1] blade section is higher. At low tip speed ratio, the power coefficient of the turbine CABS [4] are significantly higher than those with conventional NACA 4418 [1] and circular arc blade section with camberness ratio f = 0.07c. It is indicating that at relatively low tip speed ratio wind turbine with circular arc section is better.

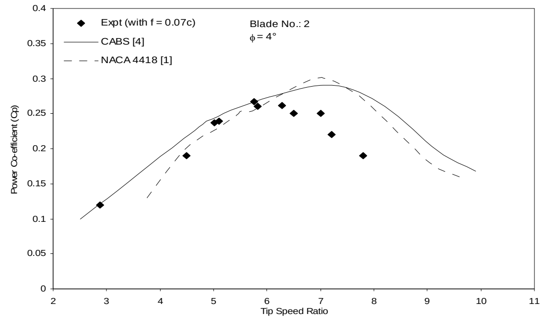

Fig 4. Power Coefficient vs Tip Speed Ratio for B = 2 and ϕ = 4° with f = 0.07

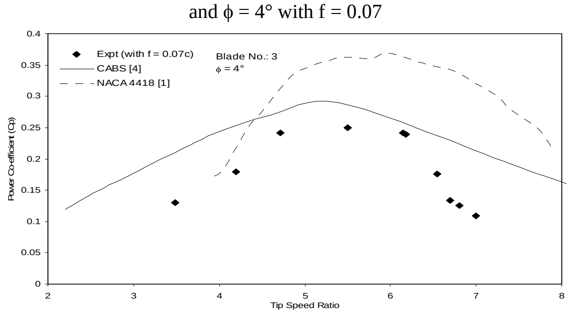

Fig 5. Power Coefficient vs Tip Speed Ratio for B = 3 and ϕ = 4° with f = 0.07

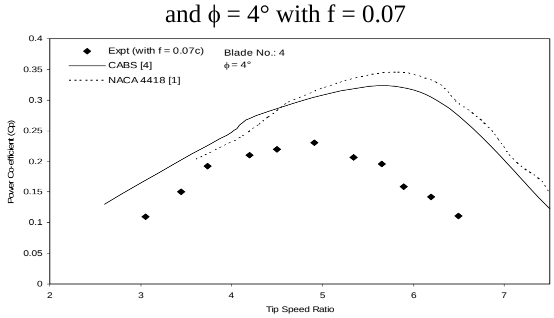

Fig 6. Power Coefficient vs Tip Speed Ratio for B = 4 and ϕ = 4° with f = 0.07c

Experimental results showing the effect of blade pitching on the performance characteristics of HAWT having circular arc blade section are presented in Figure 7 with camberness ratio f = 0.07c

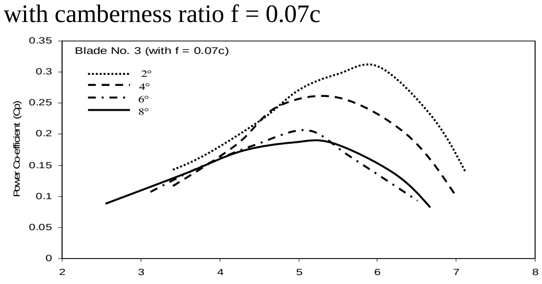

Fig 7. Power Coefficient vs Tip Speed Ratio for B = 3 (f = 0.07c) with different pitching

As the blade pitching angle increases the power coefficient values drops and shifting of maximum power coefficient to the smaller values of tip speed ratio.

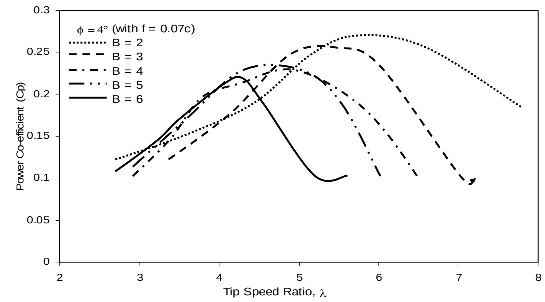

Fig 8. Power Coefficient vs Tip Speed Ratio for ϕ = 4° (f = 0.07c) with different Number of Blades

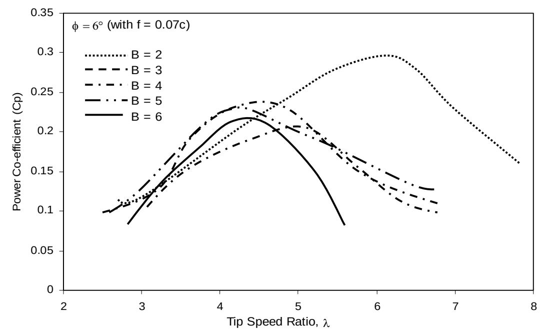

Fig 9. Power Coefficient vs Tip Speed Ratio for ϕ = 6° (f = 0.07c) with different Number of Blades

The variations of result for changing number of blades in terms of C_p versus λ are shown in Figures 8 to 9 for camberness ratio 0.07. However, the maximum power coefficient is affected by changing the number of blades. It can be observed from these figures that increase of number of blades, higher power coefficients move to the region of smaller values of tip speed ratios.

4. CONCLUSION

In regards to the present experimental investigation and design analysis of the horizontal axis wind turbines the following conclusions can be drawn:

1. For horizontal axis wind turbines, classical Strip theory have been found to give adequate results under normal operating conditions near the design tip speed ratio are comparable to those with conventional blade section.
2. The power coefficient values of the horizontal axis wind turbine with circular arc blade profile are comparable to those with conventional blade section. As the solidity (or number of blade) increases, the peak power co-efficient is shifted towards the lower tip speed ratio value.
3. With the increase of the pitch angle, the power co-efficient decrease in general expect of blade pitching angle of 2^0, for which the power co-efficient value improves a little at high tip speed ratio range.
4. To produce the same power, it will be wise to choose small number of blades (say 2) in place of large number of blades.

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6. NOMENCLATURE

Symbol	Meaning	Unit
A	Turbine disc cross-sectional area	mm^2
B	Number of blades in the rotor	No.
C	Chord of the Blade	mm
D	Diameter of the Rotor	mm
C_D	Blade drag coefficient	
C_L	Blade lift coefficient	
C_P	Power coefficient	
λ	Tip speed ratio	
ρ	Air density	Kg/m^3
φ	Angle of relative wind velocity	^{0}

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