Aerodynamic Characteristics of Six Bladed Vertical Axis Vane Type Wind Turbine

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Abstract

This paper reports on the experimental investigation on wind loading and aerodynamic effects on the six bladed vertical axis vane type rotor conducted with the help of a subsonic wind tunnel together with the experimental set-up of the vane type rotor and a spring balance. The experiment was performed at different flow velocities varied from 5 m/s to 9 m/s covering the Reynolds number up to 1.2 X 10^5. The vertical axis vane type rotor is a drag based rotor. Drag based vertical axis wind turbines have relatively higher starting torque and less rotational speed compared with their lift based counterparts. Furthermore, their power output to weight ratio is also less. Because of the low speed, these are generally considered unsuitable for producing electricity, although it is possible by selecting proper gear trains. Drag based windmills are useful for other applications such as grinding grain, pumping water and a small output of electricity. A major advantage of drag based vertical axis wind turbines lies in their self–starting capacity, unlike the Darrieus lift–based vertical axis wind turbines.

For the purpose of analyzing the dynamic conditions of rotor, the rpm of the rotor at different loading conditions and the difference in tensions between two ends of the friction belt for different Reynolds number were measured. Finally, from these data, the changes in Tip Speed Ratio, Power coefficient and Torque coefficient with the increase in load were determined at different Reynolds number.

Keywords: Aerodynamic characteristics, Power coefficient, Torque coefficient, Reynolds number, Tip speed ratio, Drag based rotor, Vertical axis wind turbine, Horizontal axis wind turbine.

Introduction

The science of exploitation of wind power is not a new concept but draws on the rediscovery of a long tradition, as the most conventional energy source like oil, coal, gas are not only non renewable but also causing serious threat to the environment; people are rethinking about the environment friendly renewable energy resources in large scale. Replacing the conventional fuels with renewable energy sources include wind energy, solar(photovoaltic) systems, solar thermal systems, biomass energy, geothermal energy, municipal waste etc. the costing of many of these technologies have come down considerably in the recent years. Particularly in wind energy, which is now competitive with conventional power sources in regions of strong winds, however, expected developments have not yet been achieved in wind driven machines. Arising from the increasing practical importance of wind turbine aerodynamics, there have been, over the past few decades, enormous increase in research works concerning laboratory simulations, full-scale

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measurements and more recently, numerical calculations and theoretical predictions of flows over a wide variety of vane type wind turbine.

There are various types of wind turbines. The most common one is the horizontal axis wind turbine – the other one is the vertical axis wind turbine. The primary attraction of the vertical axis wind turbine is the simplicity of its manufacturing comparing to the horizontal axis one. Among different vertical axis wind turbine, the vertical axis vane type wind turbine is a slow running wind machine with relatively lower efficiency. Still it is being used in the developing countries because of its simple design, easy and cheap technology for construction and good starting torque characteristics at low wind speed. It is independent of wind direction for power generation and also works even at a low speed.

Aerodynamics Theory and Performance Characteristics

The aerodynamic analysis of vertical axis wind turbine is complicated due to the orientation in the oncoming wind as its rotational axis is perpendicular to the flow. This accounts a complicated aerodynamics compare to the conventional horizontal axis wind turbine. However, the configuration has an independence of wind direction. The main shortfalls are the high local angle of attack and the wake coming from the blades in the upwind part and axis. Understanding the aerodynamics of the pure drag type vertical axis wind turbine, will give important insight for improving the lift coefficient, and designing this turbine for better and more efficient harnessing of the wind energy.

Lift Force

The lift force, L is one of the major force components exerted on an airfoil section inserted in a moving fluid. It acts normal tyo the direction of fluid flow. This force is the consequence of uneven pressure distribution between the upper and lower blade surface and can be expressed as

$$L = 0.5 C_l \rho V^2 A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

Where ρ is the air density, C_l is the lift coefficient and A is the projected area of airfoil.

Drag Force

The drag force , D acts in the direction of fluid flow. Drag occurs due to the viscous friction forces and unequal pressure on the surfaces of the airfoil. Drag is a function of the relative wind velocity at the rotor surface, which is the difference between the wind speed and the speed of the surface, and can be expressed as

$$D = 0.5 C_d \rho (U - \Omega r)^2 A \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

where Ωr is the speed of the blade surface, C_d is drag coefficient and U is the wind speed.

The lift and drag coefficient values are usually obtained experimentally and correlated against the Reynolds number.

Reynolds Number

The Reynolds number, Re is the ratio of the inertia forces to the viscous forces. It is a non dimensional parameter that defines the charecteristics of the fluid flow conditions and mathematically given as

$$\mathrm{Re} = \frac{UL}{\nu} = \frac{\rho UL}{\mu} = \frac{\rho V_\theta c}{\mu} \quad , \qquad \ldots\ldots(2.3)$$

Where μ is the fluid viscosity, $\upsilon = \frac{\mu}{\rho}$ is the kinematic viscosity, L the characteristic length, c is the blade chord length and V_θ is the blade tip velocity.

Tip Speed Ratio

The tip speed ratio λ, is defined as the velocity at the tip of the blade, to the free stream velocity. It is given by

$$\lambda = \frac{R\Omega}{V} \qquad \ldots\ldots (2.4)$$

Experimental Set up and Procedure

The experiment was carried out in the open circuit subsonic wind tunnel with an outlet test section of (490 mm x 490 mm) cross-section and the rotor was positioned at the exit section of the wind tunnel. Both the ends of the rotor were fitted with end caps. The whole rotor was fixed on an iron frame by using a through shaft that was supported by two ball bearings. A reflected sticker was attached to the shaft. A pulley was attached at one end of shaft. A strip whose one side was tied to a spring balance and other side to a load carrying plate was passed over that pulley. The spring balance was attached to the iron frame. The schematic diagram of the experimental set-up is shown in Figure 1 and the pictorial diagram is shown in Figure 2. The cross sectional views of the rotors which were made of PVC material having diameter, d= 65 mm and height, H= 340 mm are shown in Figure 3. The rotor diameter (D) was 200 mm to maintain the optimum d/D ratio as 1/3.

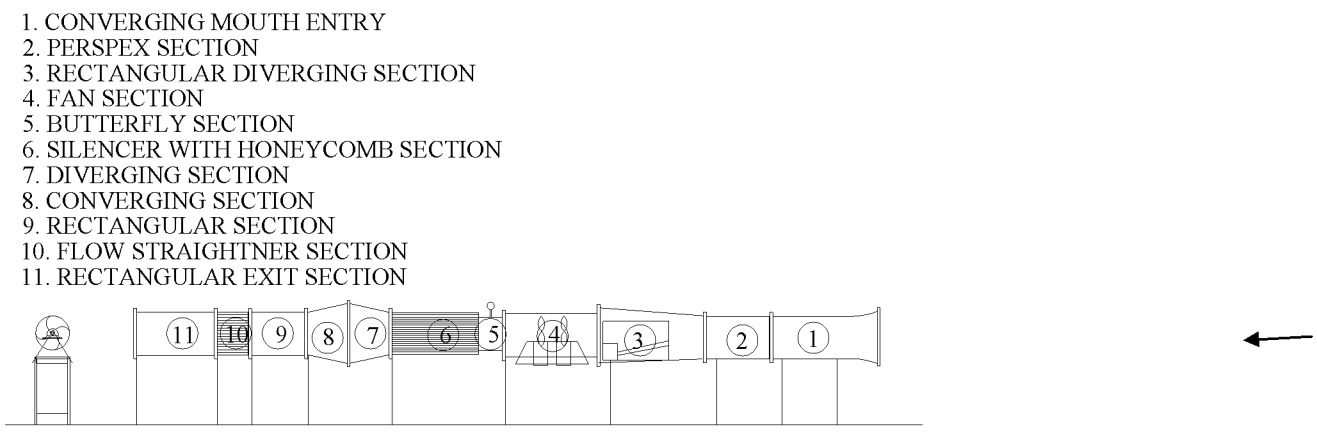

Figure 1: Schematic diagram of the experiment

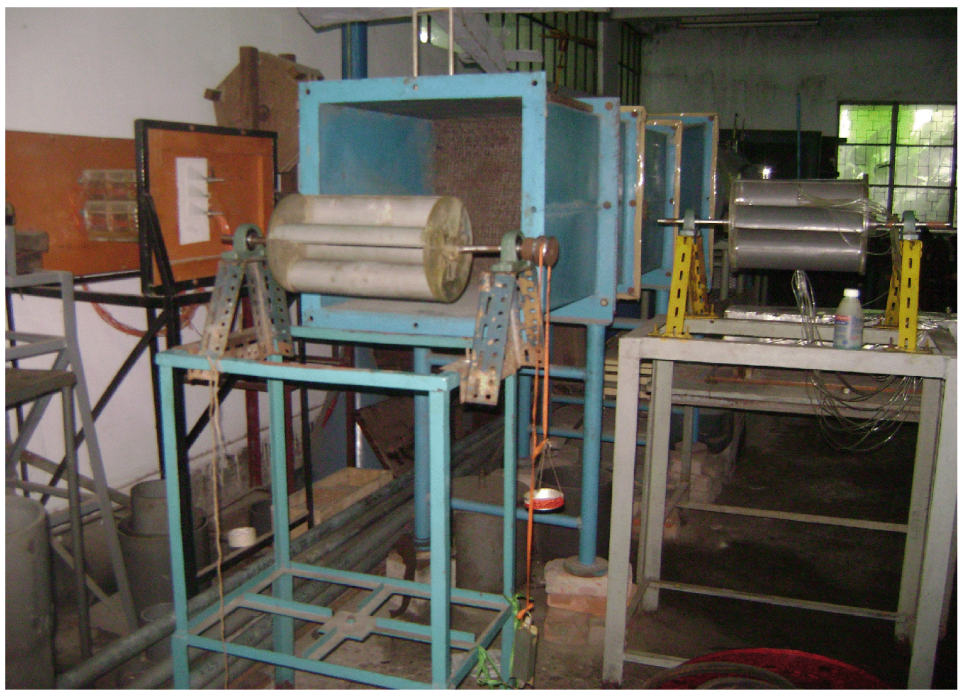

Figure 2: Pictorial diagram of the experiment

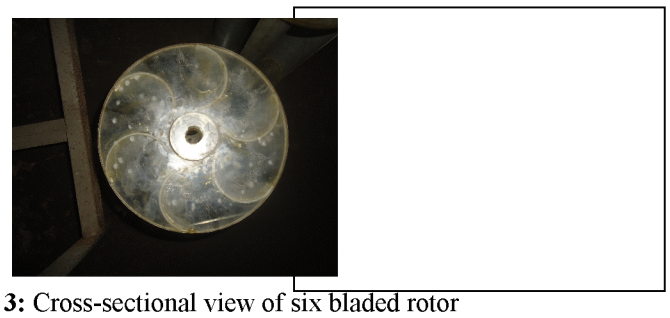

Figure 3: Cross-sectional view of six bladed rotor

In front of the wind tunnel the wind velocity was measured with the help of an anemometer and the velocity was varied from 5 m/s to 9m/s covering the Reynolds numbers up to 1.2 x 10^5 The reading of rpm of the rotor at no load condition and at different loading conditions were measured with the help of a non contact tachometer by reflecting light on the radium sticker and also the reading of weight from spring balance and the applied weight in the load carrying plate were noted down. After taking all the readings up to maximum loading condition, the free stream velocity was further adjusted by 1 m/s. And the same procedures were followed up to reach 9 m/s.

Results and Discussions

The results of six bladed Vertical Axis Vane Type Rotor, in terms of power coefficient versus tip speed ratio at different Reynolds number are shown in Figure 4 to Figure 8.

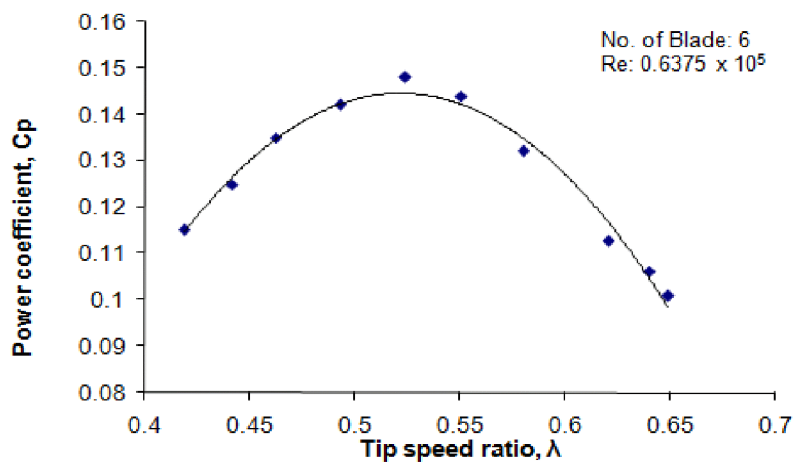

Figure 4: Variation of power coefficient with. tip speed ratio for Six Bladed Rotor at Reynolds number 0.6375 x10^5

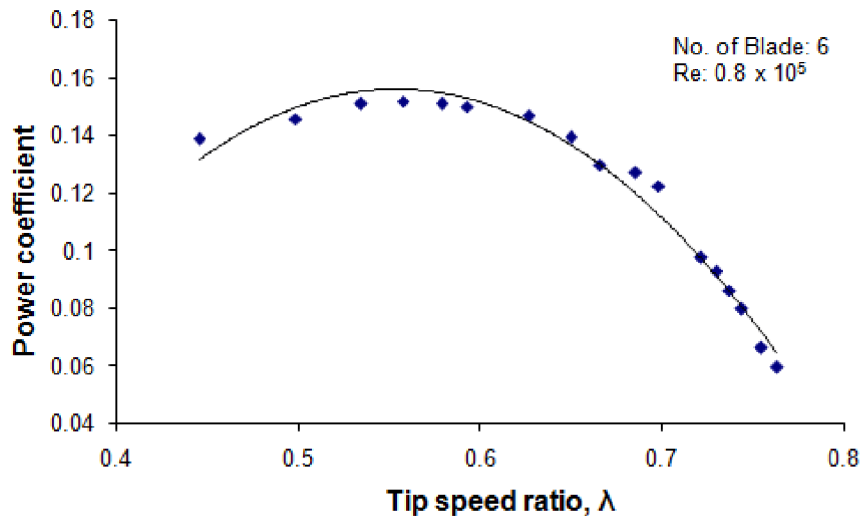

Figure 5: Variation of power coefficient with tip speed ratio for Six Bladed Rotor at Reynolds number 0.8 x10^5

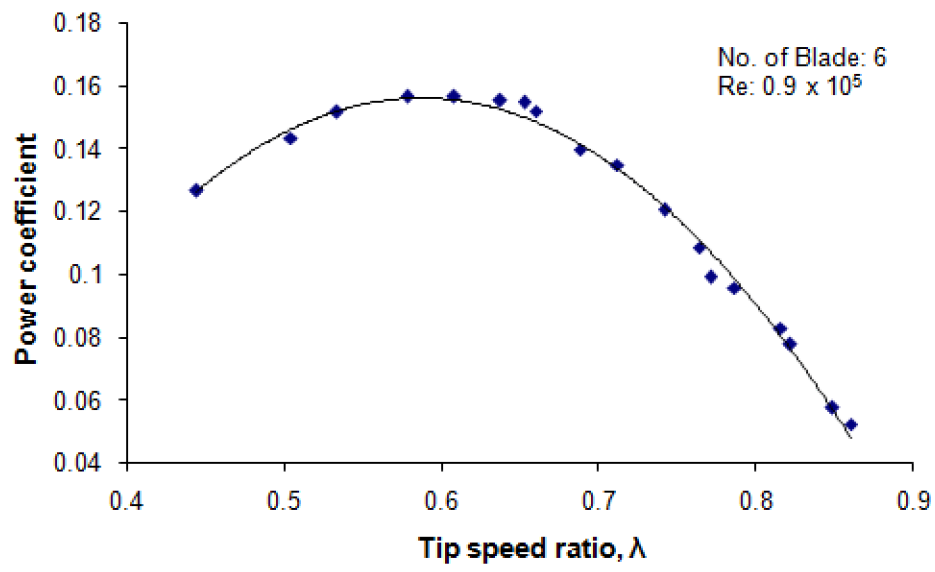

Figure 6: Variation of power coefficient with tip speed ratio at Reynolds number 0.9 x 10^5

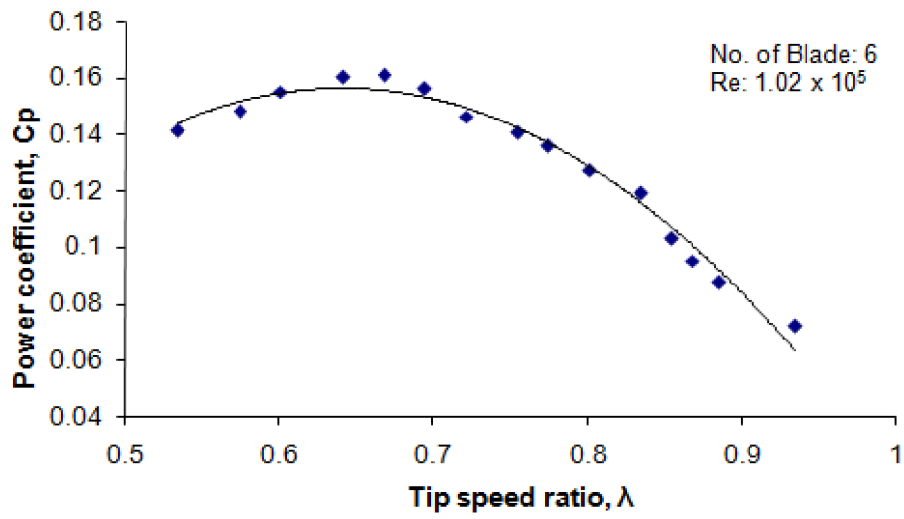

Figure 7: Power coefficient versus tip speed ratio at Reynolds number at 1.02 x 10^5

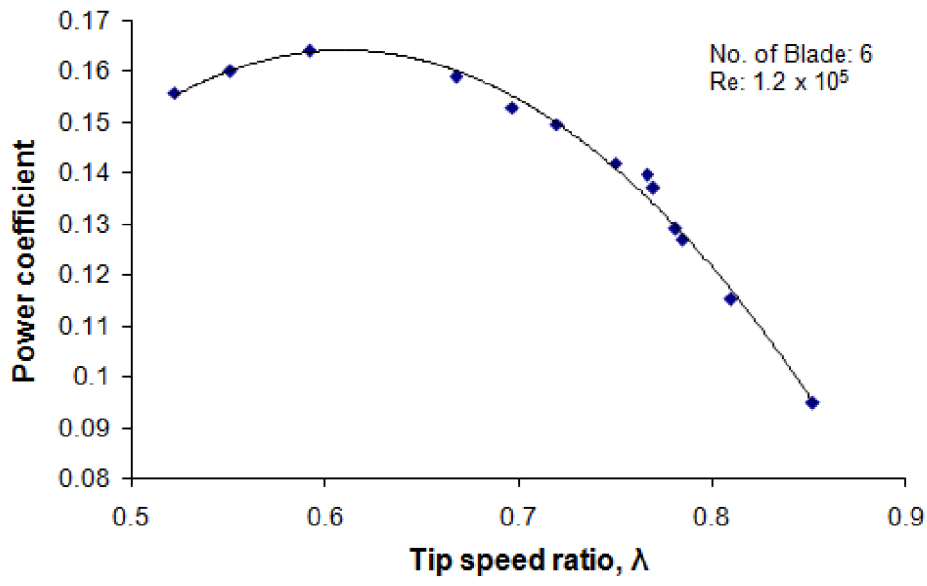

Figure 8: Power coefficient versus tip speed ratio at Reynolds number of 1.2 x 10^5

Here in Figure 9 to Figure 12 the results of torque coefficient versus tip speed ratio at different Reynolds number are shown.

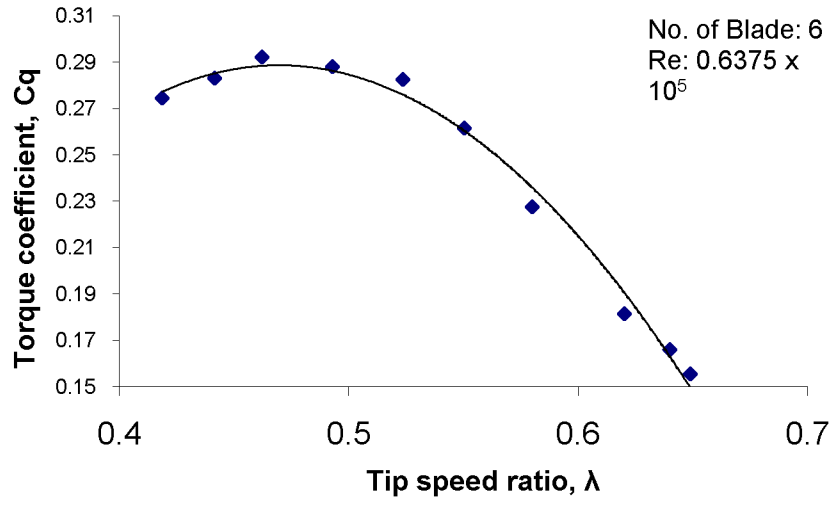

Figure 9: Torque coefficient versus tip speed ratio at Reynolds number of 0.6375 x 10^5

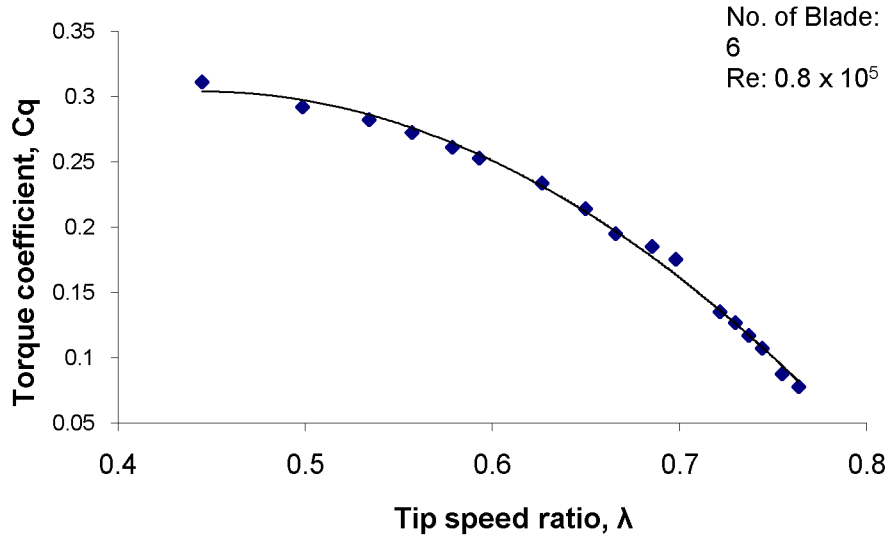

Figure 10: Torque coefficient versus tip speed ratio at Reynolds number of 0.8x 10^5

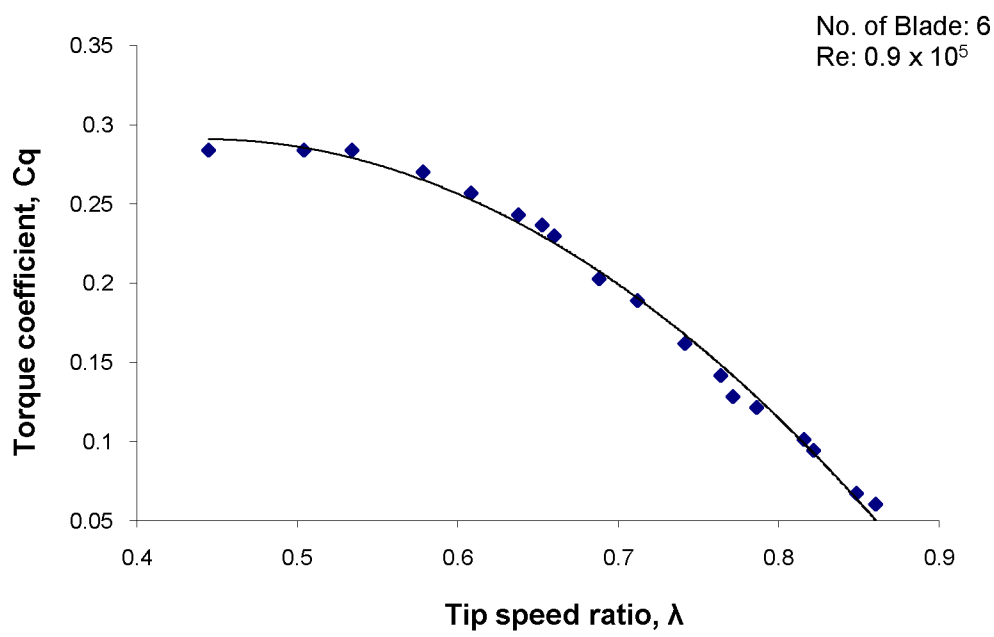

Figure 11: Torque coefficient versus tip speed ratio at Reynolds number of 0.9x 10^5

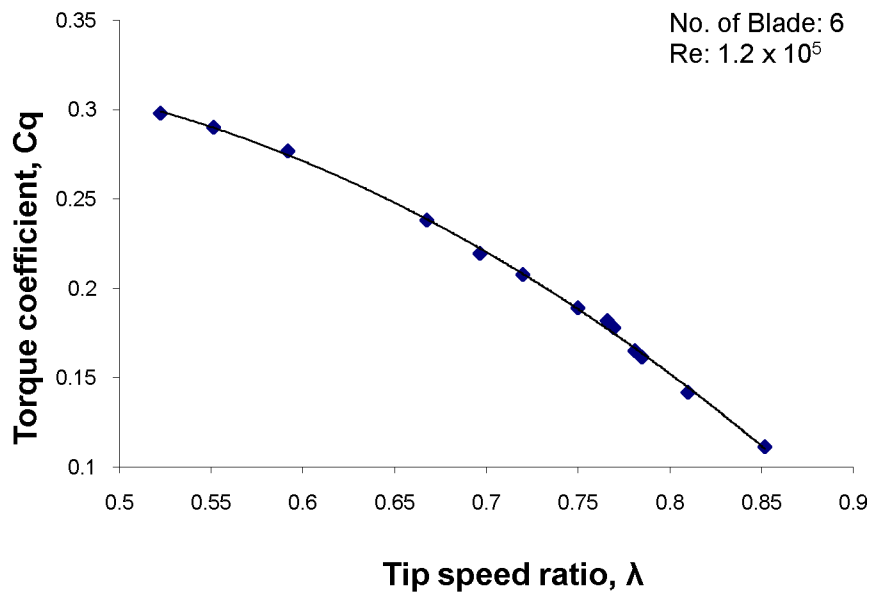

Figure 12: Torque coefficient versus tip speed ratio at Reynolds number of 1.2x 10^5

From Figure 4, it is seen that the value of maximum power coefficient is 0.148 and is obtained at tip speed ratio 0.52 at Reynolds number 0.6375 x 10^5. For further loading step by step the power coefficient decreases with decreasing the value of tip speed ratio. From Figure 5 to Figure 8, the value of maximum power coefficient is found as 0.152, 0.157, 0.161 and 0.163 available at tip speed ratio of 0.56, 0.579, 0.67 and 0.69, for Reynolds number 0.8 x 10^5, 0.9 x 10^5, 1.02 x 10^5 and 1.2 x 10^5 respectively. From this data, it is observed that the value of maximum power coefficient increases with increasing the Reynolds number and these higher values of power coefficient move to the region of larger values of tip speed ratios.

The variations of results for increasing Reynolds number in terms of torque coefficient vs. tip speed ratio are presented in Figures 9 to 12. From Figure 9, it is found that the value of maximum torque coefficient is found as 0.3 at tip speed ratio 0.4. The value of maximum torque coefficient is observed as 0.295 at tip speed ratio 0.445(Figure 10), 0.284 and 0.255 at tip speed ratio 0.5 and 0.54 respectively (Figure 11 and Figure12). By analyzing these figures it can be said that the torque coefficient decreases with increasing the tip speed ratio as the Reynolds number increases. Figure 13 shows a comparison of power coefficient vs. tip speed ratio at different Reynolds number. From this graph it is apparent that the maximum value of power coefficient increases with increase in Reynolds number and it is shifted towards the higher values of tip speed ratios. Here it is calculated that the value of maximum power coefficient increases by 10.5% as the Reynolds number changes from 0.637 x 10^5, to 1.2 x 10^5. So a conclusion can be drawn that the increase in Reynolds number make the nature of power coefficient vs. tip speed ratio curve slightly sharper.

In Figure 14 a comparison of torque coefficient vs. tip speed ratio at different Reynolds number is shown. This graph depicts that for comparatively higher values of Reynolds number the maximum value of torque coefficient is lower and it is shifted towards the higher values of tip speed ratio. Here the value of torque coefficient is decreased by 17.65% as the Reynolds number increases from 0.637 x 10^5 to 1.2 x 10^5.

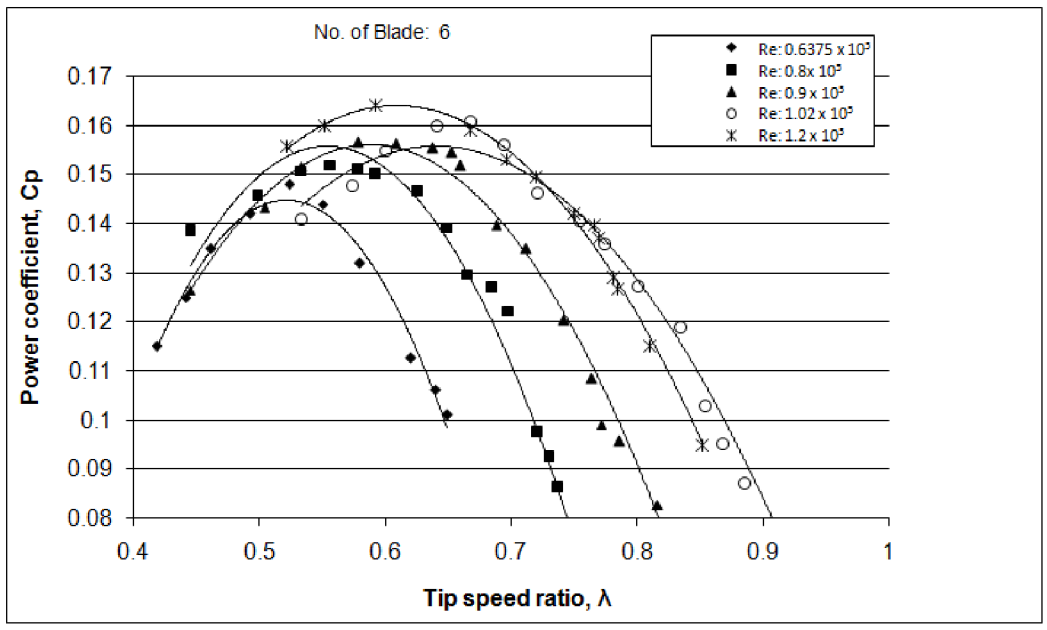

Figure 13: Power coefficient versus tip speed ratio at different Reynolds number

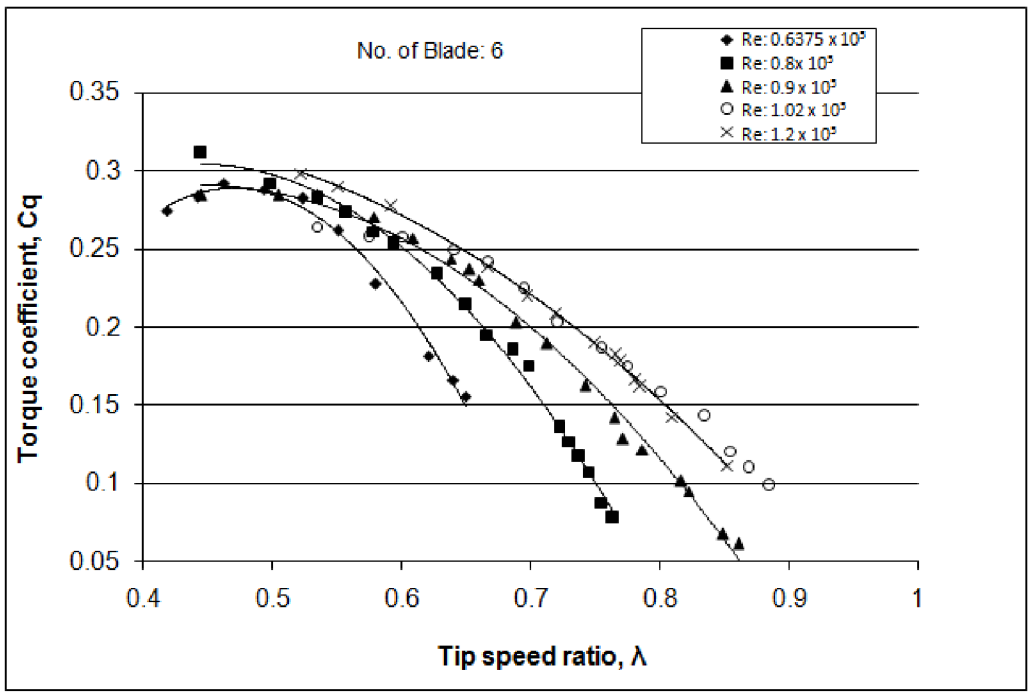

Figure 14: Torque coefficient versus tip speed ratio at different Reynolds number

Conclusion

To obtain the aerodynamic characteristics in dynamic condition the rpm of the rotor at different loading conditions and the difference in tensions between two ends of the friction belt for different Reynolds number were measured. From these data, the changes in tip speed ratio, power coefficient and torque coefficient with the increase in load in the load carrying plate were determined at different Reynolds number. By varying the free stream velocity at different loading conditions, a Reynolds number independent approach was made. From the experimental analysis the following conclusion can be drawn:

i) The value of maximum power coefficient is higher for higher Reynolds number.
ii) As the Reynolds number increases, the value of maximum power coefficient is shifted towards the higher tip speed ratio.
iii) The value of maximum torque coefficient is lower at higher Reynolds number.
iv) The increase in Reynolds number make the nature of the torque coefficient vs. tip speed ratio curve slightly blunt.

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