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Performance Study of a Vane Type Rotor – Static and Dynamic Method

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Abstract

This paper reports on the study of comparative analysis of aerodynamic characteristics of a vertical axis vane type rotor. The aerodynamic characteristics were investigated experimentally by both static and dynamic approach. In static approach, the dynamic characteristic of the rotor was predicted by calculating the static torque coefficient produced in the rotor by measuring the pressure distribution over both the concave and convex surfaces of the blades. While in dynamic approach the power coefficient was calculated by measuring the rpm of the rotor at the different loading conditions and the difference in tensions between the two ends of the friction belt. A good correlation is observed between the predicted and calculated power coefficient of the blades.

Keywords: *VAWT, HAWT, Tip Speed Ratio, Reynold's Number, Drag Coefficient, Torque Coefficient, Power Coefficient.*

I. Introduction

Now a day, renewable energy becomes a burning issue, not only due to the crisis of traditional energy sources but environment is a great concern as well. Wind energy is a promising sector of green renewable energy. Over the past few decades, enormous increases in research works concerning laboratory simulations, full-scale measurements and more recently, numerical calculations and theoretical predictions of flows over a wide variety of rotor. Major part of the research work contributed greatly to the knowledge of analytical prediction method of wind turbine, mainly the horizontal axis one because of its significant power output ratio. Later on, vertical axis rotor of different types and shapes are developed throughout the world, among them Darries rotor, two semi cylindrical bladed Savonous rotor, S shaped rotor draw additional attention of the researchers as vertical axis wind turbine is a drag based, slow running wind machine having lower efficiency. But still popular in developing countries because of its easy and simple construction technology and good starting torque characteristics even at low wind speed, furthermore, it is independent on wind direction. G. J. Bowden and S. A. McAleese (1984) made some measurements on the Queensland optimum S-shaped rotor to examine the properties of isolated and coupled S-shaped rotor. G. F. Homicz (1991) worked on blade fatigue life and simulate the random loads of VAWT Stochastic Aerodynamic Loads produced by Atmospheric turbulences. M. D. Huda *et al.* (1992) analyzed the performance of S-shaped rotor by placing a flat plate in front of the returning blade. A. K. M. S. Islam *et al.* (1995) investigated the aerodynamic forces acting on a stationary S-shaped rotor and made an attempt to predict the dynamic performance from these forces. U. K. D. Saha and D. Maity (2008) conducted experiment with wind tunnel for having the optimum design configuration for Savonious type rotor. F. M. Kamal (2008) worked with vane type vertical axis rotor and analyzed the aerodynamic characteristics at static condition by measuring the pressure difference at different rotor angle and predicts the dynamic characteristic i.e. the power coefficient of the rotor. Later on Z. Ferdous (2011) worked with the same rotor and carried the experiment to find the dynamic aerodynamic characteristics i.e. power coefficient by calculating the speed of the rotor at different loading condition. The present paper reports a comparison of the dynamic characteristics predicted by F. M. Kamal (2008) with the experimental result obtained by Z. Ferdous (2011).

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II. Construction Detail of the Rotor

The rotor was made up of five half cylinders (blade) of diameter d = 65 mm and height, H = 340 mm. The rotor was made of PVC material. The center to center distance between the blades were 137.5 mm. Rotor diameter, D is 200 mm, optimum value of d/D is taken 3.The whole rotor was fixed on an iron frame by using two side shafts and two ball bearings.

Figure 1: Five Bladed Rotor

III. Experimental Setup:

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 5.93 m long with a test section of (490 mm×490 mm) 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 18.16 m³/s at a head of 152.4 mm of water and 1475 rpm with each of the fans connected to a motor of 2.25kW capacity and 2900 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 460 mm long and made of 16 SWG black sheets. The angle of divergence and convergence was 7°, 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.

IV. Experimental Procedure

In static approach, the mean velocity of air was measured in a vertical plane 100 cm downstream from the outlet of the wind tunnel (without placing the rotor) by a pitot static tube connected to an inclined manometer with kerosene as the manometric fluid. The pressure distribution over the blade surfaces (concave and convex) was measured step by step by using the multi-manometer. At first, the vane rotor with the frame was placed 100 cm downstream in front of the exit section of the tunnel on a table. One blade of the rotor was fixed parallel to the free stream velocity i.e. parallel to the horizontal, which was the reference plane and from this plane angle of rotation was also measured. The pressure measurements were made at 8 pressure tappings on each blade. The tappings were made with copper tubes of 1.5 mm outer diameter and 10 mm length that were press fitted to the tapping holes. The tappings were located at the mid-plane of one side of each blade, so that pressure distribution at every 10° on the blade surface could be measured. The pressure tappings were connected to an inclined multi-manometer (manometric fluid was water and had an accuracy of ± 0.1 mm of water column) through 2 mm PVC tubes. The pressures were measured at every 10° interval of rotor angle. At a particular rotor angle, α the rotor blades experience forces (per unit span length) due to the pressure difference between the concave surface and convex surface and these forces can be resolved into two components F_n and F_t. Finally static torque coefficient was measured by calculating normal and tangential drag coefficient from the forces F_n and F_t. Based on the static torque the dynamic power coefficient was predicted, whereas in dynamic approach, 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 Fig. 2. Non-contact electrical tachometer was used to measure the speed of the model wind turbine at different loading conditions. Wind speed behind the rotor was measured by a digital anemometer and the speed of the model rotor at different Reynolds number was determined using a non-contact digital tachometer at different loading conditions.

Figure 2: Pictorial diagram of the experiment in static approach

Figure 3: Pictorial diagram of the experiment in dynamic approach

V. Results and Discussions

This paper reports the comparative analysis of the aerodynamic characteristics of vertical axis vane type five bladed rotor, both static and dynamic method. In static approach, the analysis was basically concern study of pressure distribution over the concave and convex surfaces of the blade at different angles of rotation. The forces experienced by the rotor blades were calculated from this pressure difference and finally the drag coefficient and torque coefficient were calculated by using raw data. The Normal Drag coefficient, Tangential Drag coefficient and Total static Torque coefficient at different rotor angle are shown in Fig.5, Fig. 6 and Fig. 7 respectively. The dynamic characteristic, power coefficient was predicted by calculating the relative velocity of the rotor, free stream velocity and the static drag coefficient for different tip speed ratio. The predicted power coefficient against different tip speed ratio is shown in Fig. 8. It is found that the nature of the torque coefficient is opposite to that of the drag coefficient which contributes significantly for producing torque.

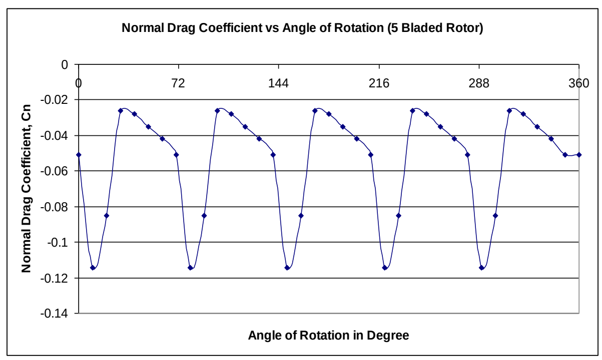

Figure 5: Normal Drag coefficient at different angle of rotation

1. CONVERGING MOUTH ENTRY
2. PERSPEX SECTION
3. RECTANGULAR DIVERGING SECTION
4. FAN SECTION
5. BUTTERFLY SECTION
6. SILENCER WITH HONEYCOMB SECTION
7. DIVERGING SECTION
8. CONVERGING SECTION
9. RECTANGULAR SECTION
10. FLOW STRAIGHTNER SECTION
11. RECTANGULAR EXIT SECTION

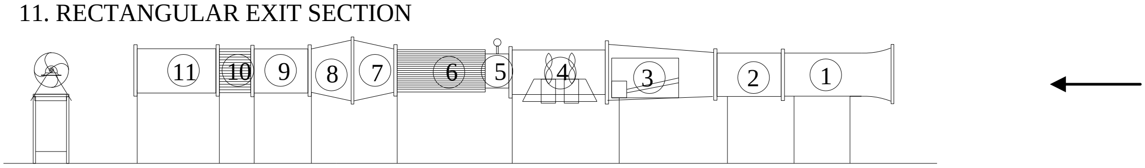

Figure 4: Schematic diagram of the set up

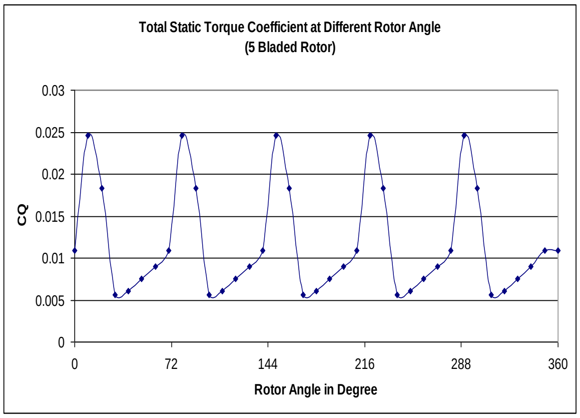

Figure 6: Tangential Drag coefficient at different angle of rotation.

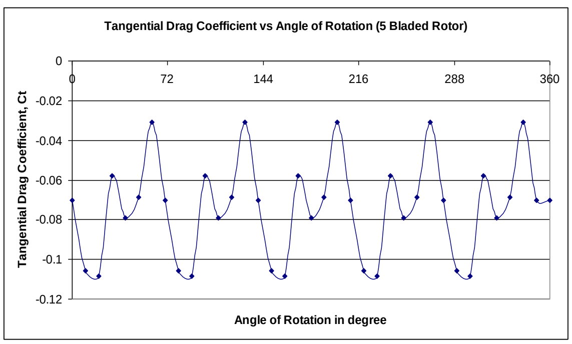

Figure 7: Total static Torque coefficient at different angle of rotation

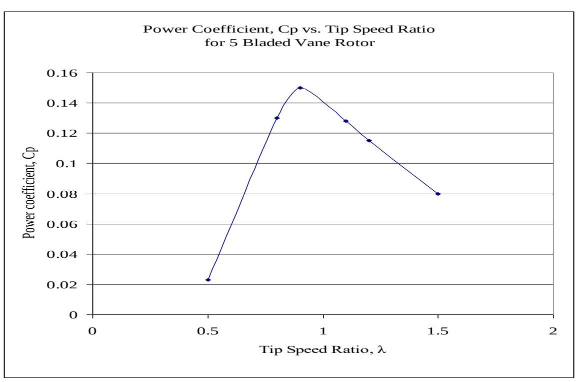

Figure 8: Power coefficient at different tip speed ratio

In dynamic approach, the power coefficient and torque coefficient was directly calculated at different tip speed ratio for different Reynolds number. In Figs. 9 and 10 the power coefficient vs. tip speed ratio at Reynold;s number 0.8×10^5 and 1.02×10^5 are shown and the torque coefficient vs. tip speed ratio for the same Reynold's number are shown in Figs. 11 and 12.

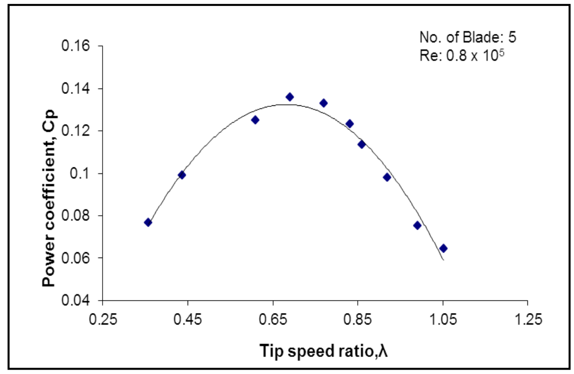

Figure 9: Power coefficient vs. tip speed ratio at Reynold's no 0.8×10^5

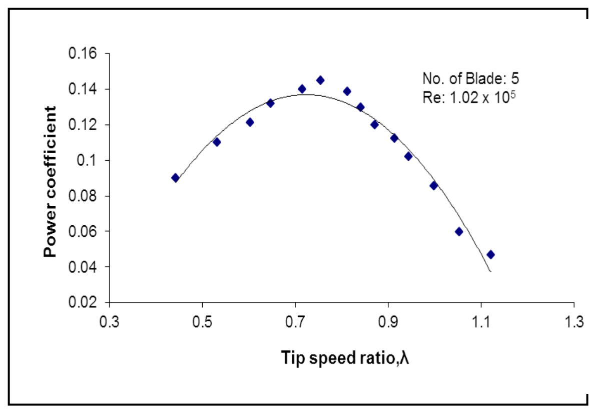

Figure 10: Power coefficient vs Tip speed ratio at Reynold's no 1.02×10^5

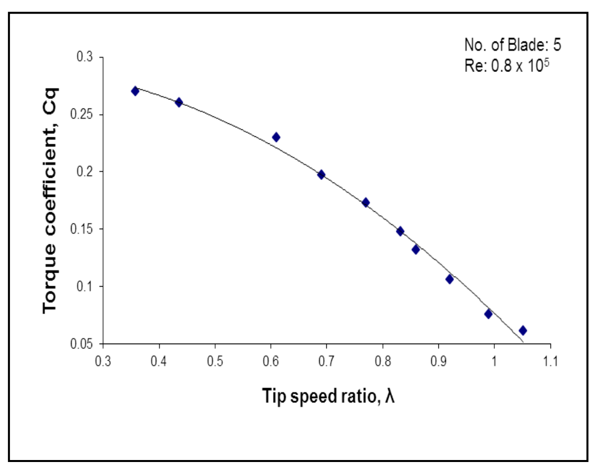

Figure 11: Torque coefficient vs Tip speed ratio at Reynold's no 0.8×10^5

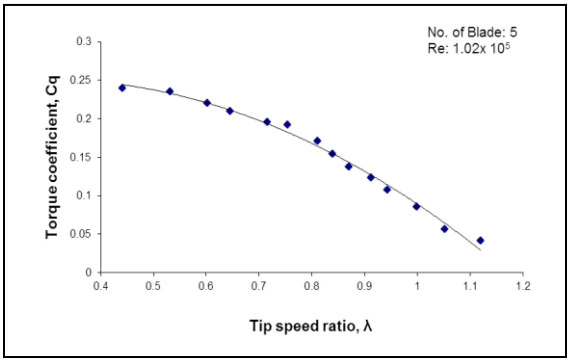

Figure 12: Torque coefficient vs Tip speed ratio at Reynold's no $1.02{\times}10^5$

The comparison of power coefficient vs. tip speed ratio as predicted in static approach by F. M. Kamal (2008) and calculated from the data in dynamic approach by Z. Ferdous (2011) is shown in Fig. 13 and that of the torque coefficient vs. tip speed ratio is shown in Fig. 14.

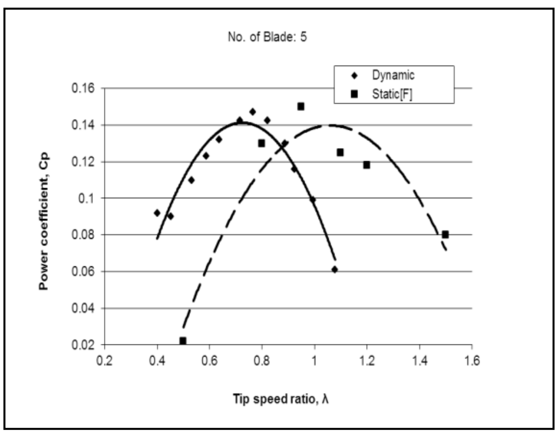

Figure 13: Power coefficient vs. Tip speed ratio in static and dynamic method.

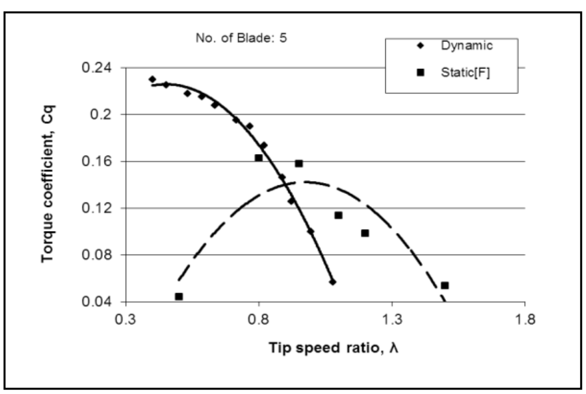

Figure 14: Torque coefficient vs. Tip speed ratio in static and dynamic method.

VI. Conclusions

By analyzing the curve in Fig. 13 and 14, it is seen that the pattern of curve in both experimental and predicted one is identical. It can be concluded that the nature of curve of Power coefficient vs Tip speed ratio matches qualitatively for both static and dynamic method, though a greater deviation is observed. Both the static and dynamic methods are important from their subject point of view, static method gives more detailed information regarding flow separation, torque analysis and corresponding drag analysis. On the other side, dynamic method is able to give the dynamic properties i.e., power coefficient, torque coefficient more accurately and in a straight forward manner.

Acknowledgment

I like to extend my sincere gratitude to F.M. Kamal, who works with the same rotor in static method and analysis all the required properties and write down a program to predict the dynamic property, i.e. power coefficient by using the raw data. This paper reports the comparison between that predicted power coefficient against the experimental power coefficient at different loading conditions.

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