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Web innovation in horizontal wind pipe turbine propeler

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Abstract. The efficiency limitations of wind turbines provided by Betz's Theorem prompted researchers to develop new geometric shapes of wind turbines propeller that split pipe spiral slice by placing the web between turbine blades. The idea of developing the shape of the turbine was inspired by the shape of a duck's or swan's leg which has a web between its fingers that functions to obtain the thrust when swimming in water. The purpose of this study is to obtain the strength of material with optimal geometry and aerodynamic parameters in producing wind turbine efficiency. The method of obtaining research data is using solid work software for design, Ansys software for CFD simulations and Wind Tunnel laboratory equipment for experiments and also using Minitab 19 software for data processing. The results of the CFD simulation and experiment based research show that the turbine propeller turbine with using the web has higher efficiency than without the web.

1. Introduction

The current problem is designing wind turbines from materials that are easily found in the market, one of which is pipes. The actual function of the pipe is to drain a fluid. Thus it is necessary to analyze the working stress that occurs in the construction and simulation of CFD, so that this designed pipe propeller wind turbine can be applied in the community.

Unlike natural resources that come from fossils such as oil and gas, wind is a natural resource that will never run out. Indonesia is a tropical country that has a lot of wind potential, but until now wind power is still rarely used as an energy source [1]. The potential for wind flow in Indonesia with an average speed of between 9 m / s to 12 m / s is an opportunity to be developed as a wind power plant [2].

A very influential factor in the performance of wind turbines is wind speed, but a very large wind speed will make the wind turbine damaged and not work efficiently. Therefore, before designing and building a wind turbine, we must first consider the potential wind speed in the area [3]. Similar research has been conducted by Monteiro et al. [4], Murugan et al. [5], and Abdelwaly et al. [6], entitled the effect of wind speed to obtain the maximum electrical power efficiency in wind turbines.

Aerodynamic design principles for wind turbine blades must take into account the careful blade design, airfoil selection, and optimal angle of attack [7]. The aerodynamic performance of horizontal axis wind turbines is highly dependent on many parameters, including airfoil type and blade geometry [8]. The method used to optimize the geometry of small wind turbine blades is obtained from a spiral split circular pipe with an optimal distribution and airfoil sweep can be obtained with the right cutting path. The geometry of the blade is obtained by folding the shape of the blade surface into the pipe, it is very difficult to describe the shape of the blade in the pipe. Moreover, the surface is located in three-



dimensional space. In Figure 1 there are three sections of the blade (tip, root, and intermediate) and their relative positions on the longitudinal axis of the blade [9].

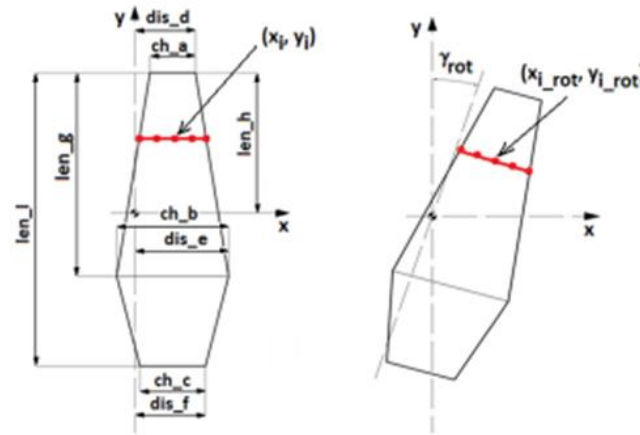


Figure 1. Blade shape geometric parameters [9].

The geometry of the blade is obtained by folding the shape of the blade surface into the pipe, it is very difficult to describe the shape of the blade in the pipe. Moreover, the surface is located in three-dimensional space. The shape of the surface parameters shown in Figure 1. are the three sections of the blade (tip, root, and intermediate) and their relative positions on the longitudinal axis of the blade. The shape of the blade surface can also be rotated with respect to the origin of the axis (x, y, z) from the angle γ_{rot} , can be seen in Figure 1.

Although the measurement data (experiment-based) is able to provide precise information on the proper wind turbine performance parameters of the flow around the blade, the development of more effective designs is still going to be a slow process based on trial and error. Various Computational Fluid Dynamic (CFD) techniques have been used to predict the field flow around wind turbine blades and their efficiency [10]. Hence to overcome the limitations of the experimental methodology, this study used CFD simulations to investigate the aerodynamics of the flow field around the blade.

1.1. Problem and basic principle

The wind kinetic energy of an object with mass m and velocity v is $E = 0.5 \times m \times v^2$, assuming that the velocity v does not approach the speed of light. Since mass can be replaced by air density ρ , area A , and velocity v , it can be written: $m = \rho \cdot A \cdot v$.

The formulation of kinetic energy in a wind turbine is

$$EK = \frac{1}{2}mv^2 \quad (1)$$

The mass flow rate equation is:

$$m = \rho Av \quad (2)$$

By changing the air mass at eq (1) with eq (2), the formulation of the potential power calculated from the wind velocity is:

$$Pa = \frac{1}{2}\rho Av^3 \quad (3)$$

Coefficient of power is ratio output and input

$$C_p = \frac{P_m}{P_a} \quad (4)$$

The mechanical power of wind turbine

$$P_m = \frac{1}{2} \rho A v^3 C_p \quad (5)$$

The tip speed ratio is the ratio of the blade tip tangential speed to the free wind speed. For certain wind speeds, the tip speed ratio will affect the rotation of the rotor. The lift type wind turbine will have a relatively larger tip speed ratio compared to the drag wind turbine [11-13].

$$\lambda = \frac{2 \cdot \pi \cdot n \cdot r}{60 \times v} \quad (6)$$

The maximum power coefficient that can be achieved by the wind turbine according to the Betz limit is 59.26%. However, in practice the value obtained from the center of the power coefficient is around 45%. Figure 2 is a graph depicting the Betz ideal constant and the actual turbine power coefficient as a function of TSR.

Based on the empirical approach, when practitioners build a horizontal wind turbine, it is usually only guided by the relationship between the parameters of the turbine power, diameter and TSR as shown in figure 3.

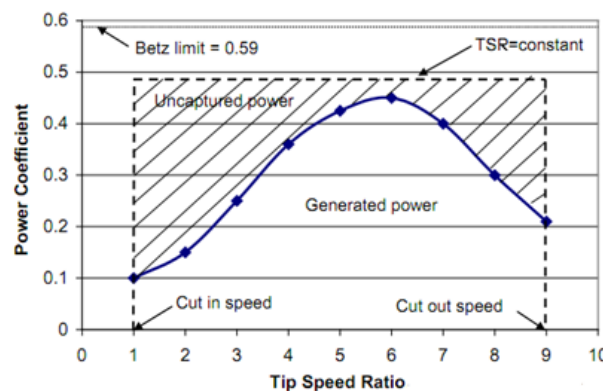


Figure 2. Wind turbine performance diagram.

Power (watts)	Diameter (metres)	TSR=4	TSR=6	TSR=8	TSR=10
10	0.4	2032	3047	4063	5079
50	0.8	909	1363	1817	2271
100	1.2	642	964	1285	1606
250	1.9	406	609	813	1016
500	2.7	287	431	575	718
1000	3.8	203	305	406	508
2000	5.3	144	215	287	359
5000	8.4	91	136	182	227

Figure 3. Design parameter relationship between Power, Diameter and TSR [4].

2. Methodology

This research was conducted using two methods, namely experimental tests on the wind tunnel and CFD simulation, from the two methods obtained data and the value of the effect (P-value) of wind speed and angle of attack on wind turbine shaft torque. Tests conducted on the web-less pipe propeller wind turbine model and the pipe propeller wind turbine model using the web.

The idea of developing the shape of the pipe propeller wind turbine using the web was inspired by the shape of a duck's or swan's leg which has a web between its fingers that functions to obtain the thrust when swimming in water. The web as shown in Figure 4 is made of plates that are assembled on the corner hub between two pipe blades made of the same material and thickness as the pipe material. The web plane is also set to have a certain slope to function as a guide for the flow of wind to enter the cavity in the pipe. The wind will be caught by the web and flowed through the cavity in the pipe towards the radial end.

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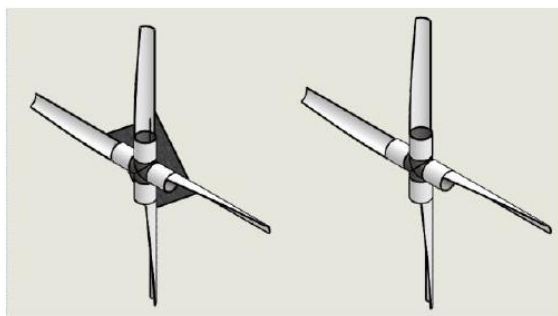


Figure 4. The pipe propeller wind turbine model using the web and without web'.

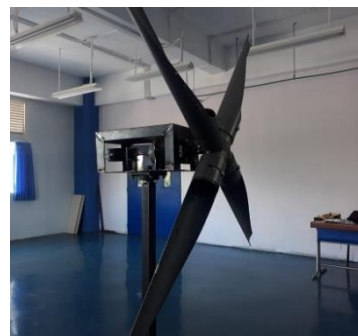


Figure 5. The pipe propeller wind turbine without web model on position testing.

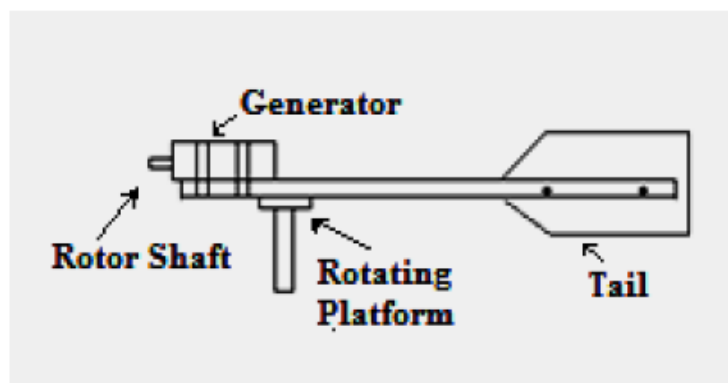


Figure 6. Sketch of wind turbine arrangement.

DOE (design of experiment) is comprised of statistical and mathematical techniques for optimization process development and improvement, which utilizes the experiment design, regression analysis, and variance analysis. In this case, the response variable Efficiency " C_p " (y) is affected by two independent variables: Angle of attack " α " or (x_1) and wind speed " V " or (x_2). The significance effect of those independent variables (x_1 , x_2) that lead to maximum power (and working stress) can be obtained from an appropriate model formulation. Variance and regression analyses can be used to estimate regression coefficients in the quadratic polynomial model and to generate an uncertainty measure in the coefficients [14].

3. Results and discussion

The geometry design of the propeller pipe wind turbine was tested using CFD simulations to produce data to be analyzed using Minitab 19 software. This working stress study used the Regression and ANOVA analysis method. It has two independent variables consisting of wind speed and angle of attack. Likewise, the aerodynamic study of turbine performance also uses variable wind speed and angle of attack. With the DOE method, it can be seen the effect of the independent variable on the dependent variable, as well as the effect of the interaction between the two independent variables on the dependent variable or the response in the form of working stress on the turbine body (σ) as well as the turbine power coefficient (CP).

Table 1. Regression analysis of working stress using minitab.

Analysis of Variance					
Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	2,42492E+12	1,21246E+12	77,50	0,000
Wind speed	1	2,27797E+12	2,27797E+12	145,61	0,000
Angel of Attack	1	1,46953E+11	1,46953E+11	9,39	0,022
Error	6	93868333333	15644722222		
Total	8	2,51879E+12			
Coefficients					
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-1749333	309203	-5,66	0,001	
Wind speed	616167	51063	12,07	0,000	1,00
Angel of Attack	12227	3989	3,06	0,022	1,00
Regression Equation					
Working stress = -1749333 + 616167 wind speed + 12227 Angle of attack					

The maximum working stress value in the wind turbine simulation test with the addition of a web was obtained at a wind speed of 7 m / s and a blade angle of attack -12.8° , that is $1.736\text{E} + 08 \text{ N / m}^2$ or 173600 MPa, while in the wind turbine simulation test without additional web obtained at a wind speed of 7 m / s and an angle of attack of 12.8° , that is $2.893\text{E} + 06 \text{ N / m}^2$ or 2893 MPa. In a wind turbine with an additional web, the higher the wind speed and the smaller the angle of attack of the blade, the greater the value of the resulting working stress. In a wind turbine without additional web, if the wind speed and angle of attack of the blade are greater, the greater the value of the resulting working stress. Based on coefficient value of the working stress regression equation on table 1, the wind speed giving more dominant effect than angle of attack.

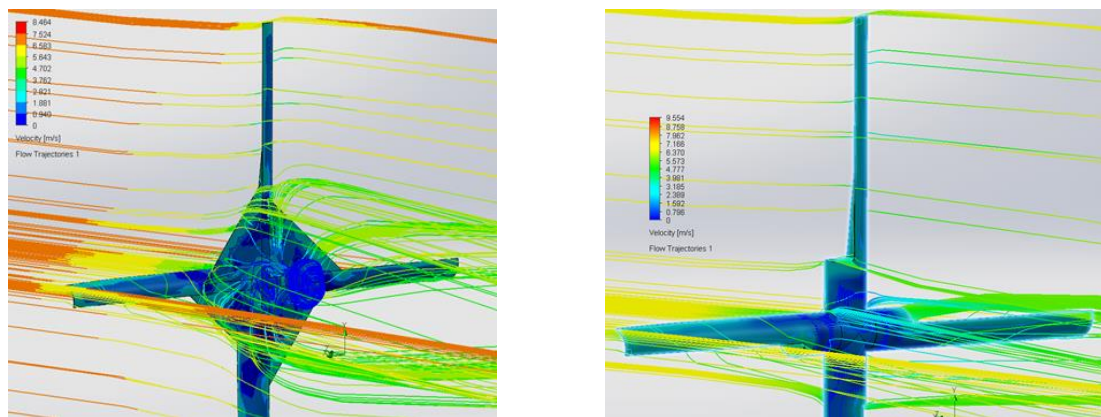


Figure 7. Stream line on the pipe propeller wind turbine with addition web and without web.

Figure 7 shows that in a turbine with additional web there is a perfect vortex behind the blade, whereas in a turbine without a web there is no vortex or turbulence. From the two images above, it can be seen that a relatively large vortex is obtained by the wind turbine with the addition of a web. From the simulation results, it shows that the wind turbine using the web addition can rotate optimally compared to the wind turbine without a web.

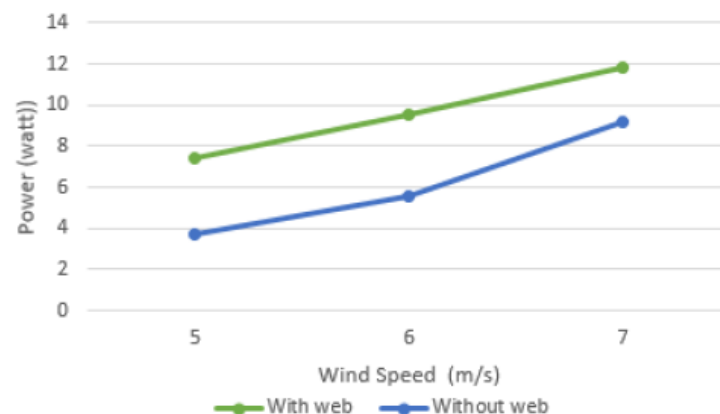


Figure 8. Comparison of power generation between pipe propeller wind turbine using web and without web resulted from model testing wind tunnel laboratory.

From the results of model testing in Figure 8, it shows a large power difference between the turbines using the web and without using the web. At a wind speed of 7 m / s, it is shown that the wind turbine using the web produces a power of 11.84 watts, while the wind turbine without using the web is only 9.20 watts.

4. Conclusion

The simulation test using *Solidwork* software is now equipped with the Computational Fluid Dynamics (CFD) feature, the test results show that the wind turbine with the addition of the web has a wider vector distribution than the wind turbine without using the web so that the power generated by the wind turbine is also greater and more stable. However, this type of wind turbine with the addition of a web produces a larger vortex.

The use of PVC pipe material to build propeller wind turbines has proven to be quite strong in simulation tests using *Solidwork* software and experimental tests in wind tunnel laboratories up to a speed of 8 m / s.

Acknowledgments

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