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STRENGTH ANALYSIS ON HORIZONTAL AXIS WIND TURBINE PROPELLER BLADE PVC PIPE WITH ANGLED ENDS

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Abstract. The basic problem of appropriate wind energy technology is how to design wind turbines from materials that are easily available on the market, one solution is PVC pipe as the blade material. For this reason, it is necessary to analyze the working stress that occurs in the blade construction, so that the PVC pipe propeller wind turbine is safe when applied in society. The purpose of this study was to determine the effect of wind speed and tip elbow width on working stress. The simulation test method uses SolidWorks Flow Simulation Software and then the results are exported to Static Simulation to determine the strength of the material. Simulation tests were carried out with wind loads on PVC pipe propellers with wind speeds of 5 m/s, 6 m/s, and 7 m/s and elbow tip widths of 100 mm, 110 mm, and 130 mm. The results of the maximum stress value in the wind turbine simulation test with the addition of an elbow tip were obtained at a wind speed of 7 m/s and an elbow tip width of 130 mm.

Keywords : HAWT, Propeller, PVC Pipe, Tip Elbow, and CFD Simulation.

1. INTRODUCTION

Compared to fossil fuels, such as coal and natural gas, wind is an environmentally friendly source of energy, no air pollution is released into the environment after consumption. Wind energy is one of the most promising because it is available in a wide geographical area, in contrast to other energy sources which are concentrated in several countries [1]. Wind energy is a renewable energy potential that can make a significant contribution to the need for electrical energy, especially in remote areas. Wind energy can be utilized as electrical energy in the presence of wind turbines [2]. In the design of wind turbines the most important part is the blade, because this part is the core in making wind turbine rotors. Most windmill designs use NACA profile blades, but in this study the blades used were made of PVC pipe, then the pipe was cut by splitting and twisting in order to optimally absorb wind energy.

Horizontal Axis Wind Turbine (HAWT) is a type of wind turbine that is widely used in Indonesia. HAWT is one type of wind turbine that has the ability to convert energy with the greatest efficiency because the blades always move perpendicular to the wind, receiving power through all rounds. The geometry, dimensions and number of blades determine the efficiency of the turbine. [3]

Wind is one of the renewable energy sources which is very abundant and easily available in nature. Based on its geographical location, each place has different wind potential, in the tropics and subtropics it has different wind potential. Based on the topography, if it is in a mountainous area, the wind tends to rise and if the topography is flat, the wind will tend to be straight and flat.

Model simulation tests using Computational Fluid Dynamic (CFD) software are generally used to determine the effect of interaction variables such as wind speed and number of blades on output power and to obtain the most optimum power coefficient.[4]

With CFD simulation, it is possible to predict fluid flow patterns, heat transfer, chemical reactions and other phenomena through mathematical equations or mathematical models. In general, the fluid flow calculation process is solved by using the energy equation, momentum equation and continuity equation. Numerical modeling of flow

(Fluent Manual, Fluent Inc.) was carried out using the conservation of mass equation and momentum equation in integral form at stationary and steady state.

Wind turbine models can also be tested experimentally using wind tunnels, the function of wind tunnels in aerodynamic research is to study airflow characteristics. Wind tunnels are also used to simulate the actual state of an object under the influence of aerodynamic forces in the field of aeronautics, namely to analyze the performance of flying mechanics of an object [6]. The magnitude and direction of the Lift and Drag force vectors depend on the shape of the airfoil profile, for example a fluid moving on a curved surface will be shown in detail the flow lines and aerodynamic forces due to changes in momentum. The schematic diagram of the aerodynamic forces is shown in Figure 1. It is therefore very important to understand the significance of the phenomena behind various Airfoil shapes [7].

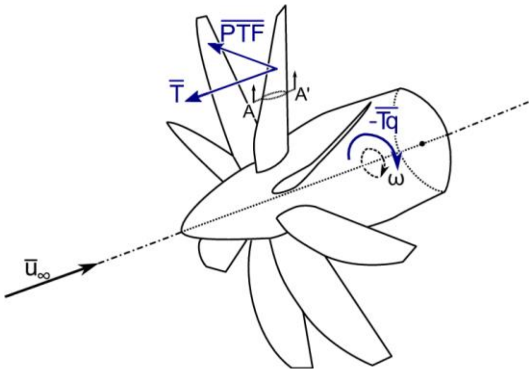

Figure 1 Aerodynamic Force on the Propeller Blade [8]

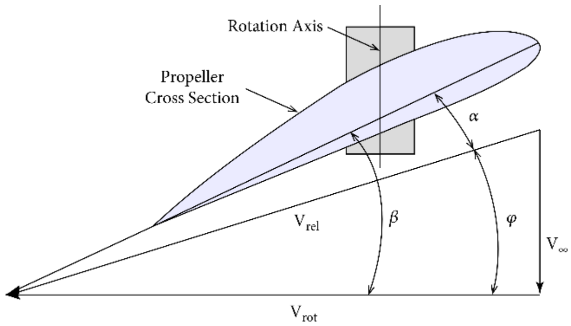

Figure 2 Blade Cross-sectional Velocity Diagram [9].

The increase in the lift coefficient occurs gradually as the separation point shifts above the airfoil body and the influence of the turbulent flow that is formed thus affecting the pressure resistance [9]. Based on Bernoulli's principle, because the air flow over the airfoil produces a low pressure zone and a high pressure zone is on the bottom surface, so that due to the pressure difference a lift force will be generated [10].

Previous studies on blades described a useful methodology for optimizing small size wind turbine blade geometries obtained from circular pipes with optimal chord distribution and airfoil sweep obtainable with proper cutting paths. Significant reductions in production costs and time can be achieved for blades which are an important element in wind turbine systems, especially in the case of renewable energy generation in developing countries [11], as shown in Figure 2 is the geometry of turbine blades made of pipes that divide by turning the clock wisely

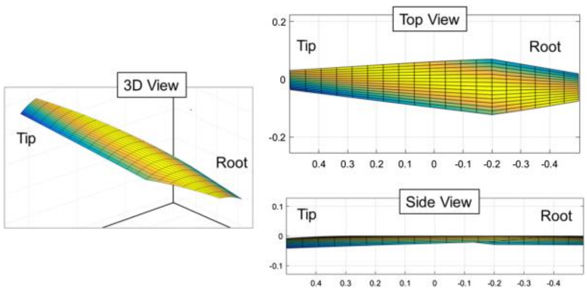

Figure 2: Geometric and braided pipe blades[11]

According to classical physics, the kinetic energy of wind for an object with mass m and speed v is E=½×m×v [2], but with the assumption that the speed v is not close to the speed of light. Since mass can be replaced by air density, area A, and velocity v, it can be written: m = .Av is the mass flow rate of the wind. [12]

$$E = \frac{1}{2} \times m \times v^2 \quad (1)$$

where: E = Energy (joules); m = Mass of air (kg) and
v = wind speed (m/s).

Then the wind turbine power that can be generated per unit time is:

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

P_w : wind power (watts).

Energy Conversion from Wind energy potential is able to rotate the turbine rotor, where the rotor is connected to a shaft that has been connected to a generator to generate an electric current. The parameters obtained from wind turbine testing are usually wind speed (v), rotation speed (n), current strength (I) and voltage (V). The value of electric power (P) is obtained using the following equation:

$$P = V \times I \quad (3)$$

where: P = Electric Power (Watts)
V = Voltage (Volts)
I = Electric current (Amperes)

The tip speed ratio is the ratio of the rotor tip speed to the free wind speed. For a certain nominal wind speed, the tip speed ratio will affect the rotor speed. The lift type wind turbine will have a relatively larger tip speed ratio compared to the drag type wind turbine. Tip Speed Ratio is calculated by the following equation [13]:

$$\lambda = \frac{2.\pi.n.r}{60 \times v} \quad (4)$$

where: λ= tip speed ratio
r = rotor radius (m)
n = rotational speed (rpm)
v = wind speed (m/s)

According to the Betz limit theory that the maximum power coefficient that can be achieved is 59.26 percent. But in practice, the value that can be obtained from the center of the power coefficient is about 45 percent. This value is below the theoretical limit due to inefficiencies and losses caused by different configurations, blade geometries, finite flange, friction, and turbine design. Figure 3 shows the various types of wind turbine blades, and the actual wind turbine power coefficient (Cp) as a function of Tip Speed Ratio (TSR). [14]

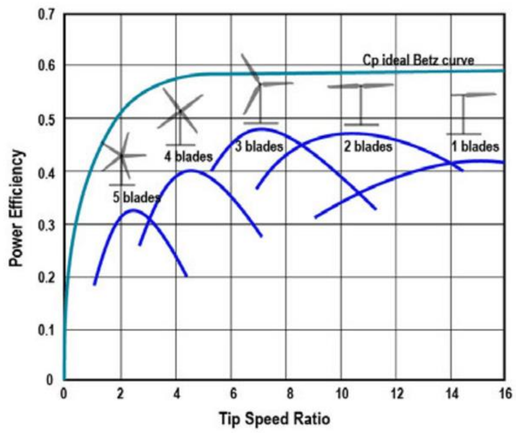

Figure 3. Wind Turbine Performance Diagram [14]

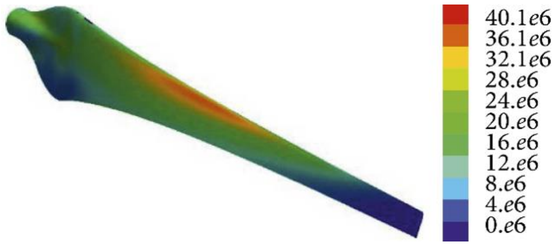

Figure 4. Von Mises stress evaluation for E-glass-epoxy and basalt-epoxy at 40 m/s using CFD simulation [15]

In the strength study of basalt-epoxy composite materials for wind turbine blades, maximum stresses were identified in two zones which could be considered critical, the first close to the shaft and the second in the center zone of the blade due to the pressure contours generated by the wind impacting the turbine blades. Based on the von Mises stress formula in CFD simulations, it was found that positive basalt fiber-based compounds for conventional material substitution can reduce deformation by up to 96%. [15]
The von Mises stress is a measure of the total overall stress acting on a material including the normal stresses in the x and y directions as well as the shear stresses.

$$\sigma_{VM} = \sqrt{\sigma^2 x + \sigma^2 y + \sigma x \sigma y + 3\tau xy} \quad (5)$$

Von Voltage Mises
x is the normal voltage of the x component
y _ is the normal y component of Voltage
xy is the Shear Stress

Wind turbine blades require high bending stiffness properties as they are subject to phenomena such as fatigue, traction and flexion. Therefore, the use of PVC pipe material to produce rigid but flexible wind turbine blades is still being debated because the fatigue properties cannot be predicted accurately.

2. METHODS

In this study, the numerical method used is in accordance with field conditions or actual conditions. The numerical method used is based on Computational Fluid Dynamics (CFD) simulations using AnSys and Solidwork, where the airfoil used is designed to be a blade that is used as a single rotor reference. Then the design results are simulated and will be validated with experimental results using wind tunnels and measurements on sensors attached to the blades. This study also refers to the experimental report of Bartl and Sætran using 4 blades obtained CP max = 0.468 at TSR = 6 with a wind speed of 11.5 m/s (rotor rotation 1395 rpm) [16]. Numerical calculations for the analysis of the static strength of the propeller blade structure were carried out using the commercial FEA SolidWorks Simulation software (SolidWorks, 2016).

The novelty of the blade shape of a windmill using a pipe with a torsion section is inspired by Newton's Second Law, when a force occurs due to a change in momentum when a fluid flows through a pipe elbow. The blade end of the pipe as shown in Figure 5 is made of elbow PVC pipe which is attached to the end of the propeller. The radial wind flow in the vane of the inner wall pipe and the wind flow from the main stream will strike the ends of the elbows which generate additional force due to the change in momentum.[17]

The wind turbine construction built in this study has the following parts: (1) Hub, (2) Blade, (3) Elbow Tip, (4) Shaft, (5) Generator Box, (6) Tail, (7) Tower, as shown in Figure 5.

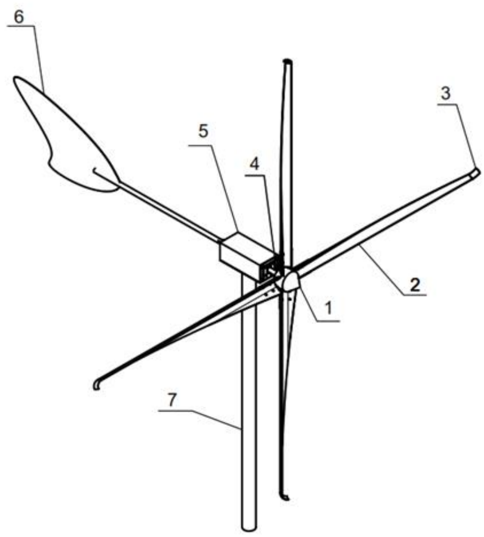

Figure 5. Wind Turbine PVC Pipe Propeller Design [17]

DOE (experimental design) comprises statistical and mathematical techniques for the development and improvement of optimization processes, which utilize experimental design, regression analysis, and analysis of variance. In this case, the working stress response variable "S" (y) is influenced by two independent variables, namely the width of the elbow "w" or (x1) and the wind speed "V" or (x2). The significant influence of the independent variables (x1, x2) on the maximum working stress can be obtained from the appropriate model formulation. Analysis of variance and regression equations can be used to estimate regression coefficients in quadratic polynomial models and to produce measures of uncertainty in the coefficients. [18].

3. RESULTS AND DISCUSSION

Based on the theory of fluid mechanics, water turbine designers always rely on changes in momentum to generate maximum torque and power. The design geometry is manifested in the diameter, the angle of curvature of the blade, the angle of the guide blade or nozzle, and others. Whereas in the design of wind turbines, especially horizontal turbines, the designer always considers the limitations of the Betz theorem (max Cp <0.59), as well as optimization of wind speed variables and geometric variables to produce lift and drag vectors in producing maximum torque. or power.

In previous research [19]-[21] a knife model of a spiral split PVC pipe was produced with an optimum angle of attack of 30 degrees to the wind direction on the hub side. Meanwhile, at the outer radius end the blade plane is twisted up to 90 degrees (the concave plane of the pipe is facing tangentially) as shown in Figure 6 below.

In the current study, the design in Figure 6 adds an elbow at the end using a standard elbow accessory on the market. Standard elbows are split to various widths and then connected to the tip of the blade so that the concave surface faces tangentially. By making the width of part number 3 in Figure 5 the research variable, it is hoped that it will be possible to find out how wide the size of the standard elbow section will be to be connected to the outer edge of the outer blade of this new windmill model.

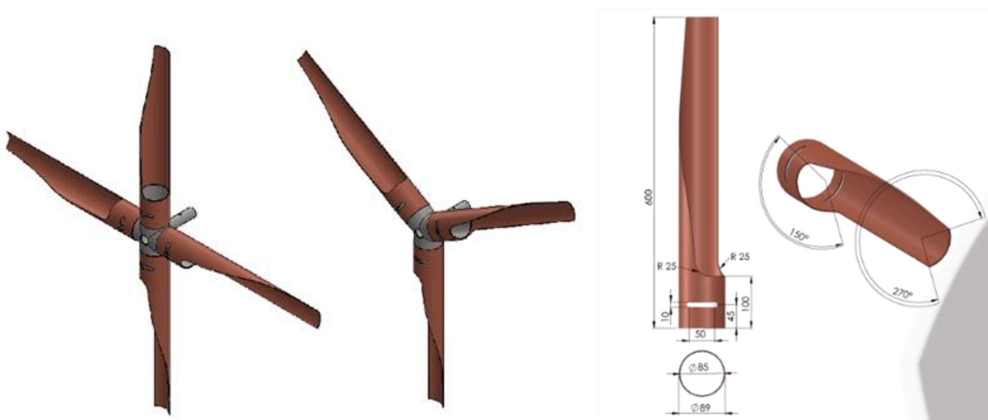

Figure 6. PVC pipe propeller without Elbow End [21]

Table 1. Variable Speed and elbow width

Elbow width (mm)	Wind velocity (MS)		
100	5	6	7
110	5	6	7
130	5	6	7

In this study, the CFD simulation test uses wind speed and angle width variables as shown in table 1. With these variables, we want to know how the aerodynamic behavior in and around the blades is in the form of images of stress distribution, displacement (blade deflection) and current lines.

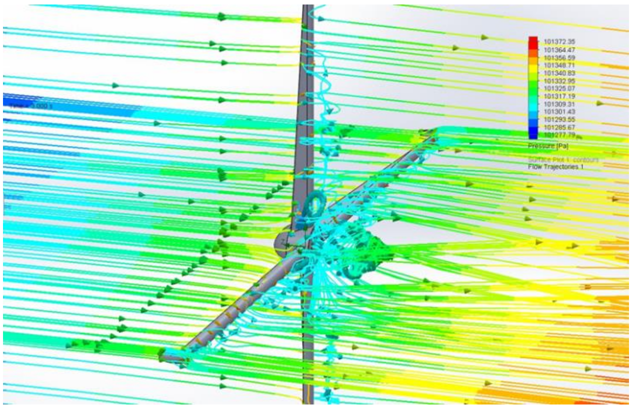

Figure 7. Aerodynamic flow lines around the blade when the wind speed is **7** m/s and the angle width is 110 mm.

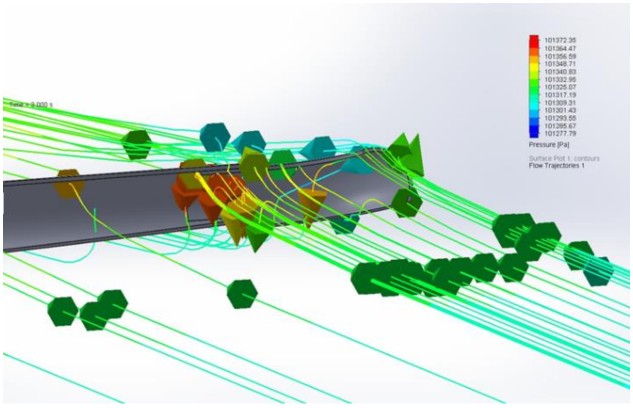

Figure 8. Current line density occurs on the outside of the blade radius when the wind speed is 7 m/s and the angle width is 110 mm.

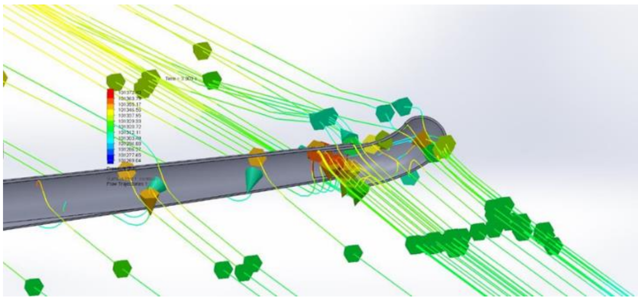

Figure 9. Current line density occurs outside the blade radius when the wind speed is 7 m/s and the angle width is 130 mm.

Simulation testing with an elbow width of 110 mm and a wind speed of 7 m/s results in Figure 8 shows that streamline compaction occurs in the direction of propeller rotation without any turbulence behind the blades. The air impact from the main stream direction on the concave section of pipe is transmitted in a radial direction to the end of the elbow, giving rise to the dual effect of increasing the torque. Usually this phenomenon is interpreted as a coanda effect on aircraft wings, which are equipped with flaps at the ends so as to increase lift. With the simulation results, the turbine with an elbow width of 110 mm works best among the other variables as shown in table 2 and produces a maximum torque of 12,031 Nm.

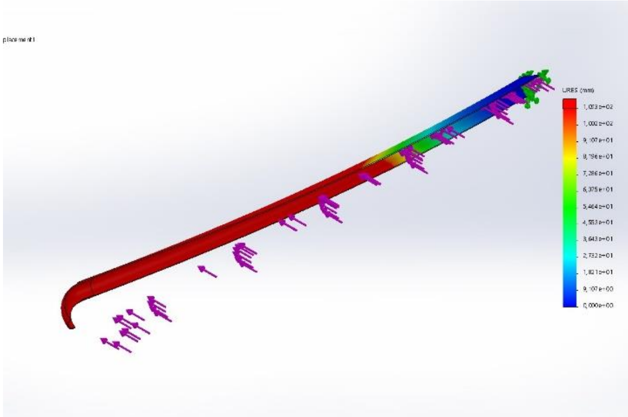

Figure 10. Von Mises Stress and displacement at a wind speed of 7 m/s and a 100 mm elbow width

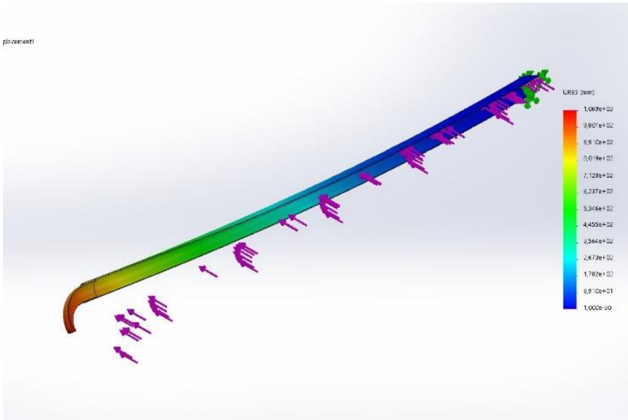

Figure 11. Von Mises Stress and displacement at a wind speed of 7 m/s and an elbow width of 110 mm

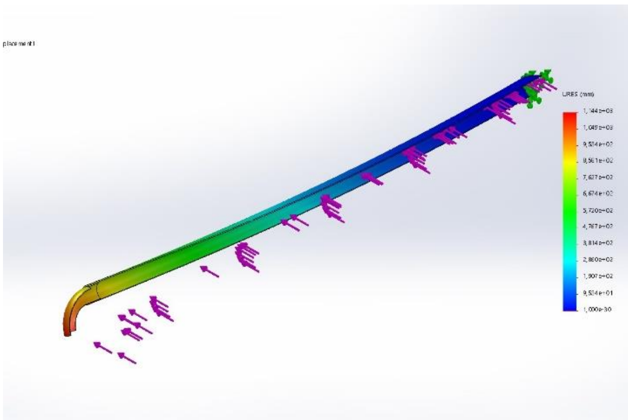

Figure 12. Von Mises Stresses and displacements at a wind speed of 7 m/s and an angle of 130 mm

It can be seen from table 2 and Figure 10 that shows critical operating conditions, the simulation results show a Von Mises stress of 39187892 N/m2 or 39.1 MPa and a total displacement of 1071 mm with a red mark on the blade body which is a very dangerous condition. when using a 100 mm wide elbow with a wind speed of 7 m/s. However, by using a 130 mm wide angle at the same speed, it can be seen in Figure 12 that the critical von Mises stress value of 39026256 Pa or 39.0 MPa appears near the hub. Stress analysis based on simulation results obtained under normal or critical conditions to ensure the safe operation of wind turbines. Based on Figure 11 and

Figure 8 of the CFD simulation for typical operating conditions of PVC pipe split twist blade by equipping the end elbow at the outer radius with an equivalent stress of 37931224 N/m2 or 37.9 MPa and a total displacement of 1069 mm when the wind speed is 7 m/s at elbow width 110 mm. The use of PVC pipe as a blade is better at capturing wind energy and is able to increase the strength and stiffness from the hub zone to the end zone.

3. CONCLUSION

The simulation results show that the Von Mises stress is 39187892 N/m2 or 39.1 MPa and a total displacement of 1071 mm with a red mark on the blade body is a very dangerous condition. when using a 100 mm wide elbow with a wind speed of 7 m/s. However, using a 130 mm wide angle at the same speed, the critical von Mises stress value of 39026256 Pa or 39.0 MPa appears near the hub. Stress analysis based on simulation results obtained under normal or critical conditions to ensure the safe operation of wind turbines. From the CFD simulation for typical operating conditions of PVC pipe split twist blade by equipping the end elbow at the outer radius with an equivalent stress of 37931224 N/m2 or 37.9 MPa and a total displacement of 1069 mm when the wind speed is 7 m/s at an elbow width of 110 mm. The use of PVC pipe as a blade is better at capturing wind energy and is able to increase the strength and stiffness from the hub zone to the end zone.

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