Harnessing Wind Kinetic Energy to Power Electricity by Building Wind Turbines

San José State University, Charles W. Davidson College of Engineering,

E10 Introduction to Engineering,

Section 5

Group 1

by

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Project Summary

The purpose of this experiment is to demonstrate the process of converting wind energy into electrical energy, which is tested by determining the power output and stiffness of the wind turbine, using the following materials provided, and a blade created and printed by solidwork,

the Wind Turbine which is less than 17 inches in height and weigh less than 200 grams, a blower, a stand, a power meter, a wind meter and a load box. After testing the power output of the wind turbine, 0.77 watts of power was tested by the 1.58N/mm stiffness of the wind turbine.

Introduction

The purpose of the wind turbine project is to create a wind turbine with materials of their choice to show the conversion of wind energy to electricity. The 4 major activities of the project were designing a blade, building the support tower, determining the power output of the turbine, and measuring the stiffness of the tower. The specifications for the wind turbine were for it to be under 200 grams and be nothing taller than 17 inches. Also, the support structure must not extend beyond the envelope defined by the base dimension of 11.75 in. x 11.75 in. over the 17 in. in height. Creating the blade for the turbine was done with Solidworks which is a program used to build 3-D models and then scan and 3-D print them. After finishing building the wind turbine, next was testing its stiffness and finding the max power that the turbine could produce. The wind turbine had to be creative with the design to make it look good and for it to meet all the specifications that were assigned, The final product is shown in Figure 1 below.

Figure 1: Final product

Theory

I. Power Efficiency

Wind turbines produce power by using wind energy which is kinetic energy of air moving. This can be shown as kinetic energy [E] is equal to half of mass [m] times velocity [v] square.

$$E = \frac{1}{2}mv^2$$

Which the mass of air is determine by the air density [ρ] and air volume [V]

$$m = \rho V*$$

Then, insert the mass of the air to the kinetic energy equation.

Hence, the kinetic energy equation equals

$$E = \frac{1}{2}\rho V v^2 **$$

Knowing how wind produces energy, the most crucial step to understand is how wind turbines create power [P_{wind}] by using wind kinetic energy. Here, wind power is made by kinetic energy divided by a range of time [Δt]

$$P_{wind} = \frac{E_{wind}}{\Delta t}$$

$$P_{wind} = \frac{\rho V v^2}{2\Delta t}$$

$$P_{wind} = \frac{\rho A v^3}{2\Delta t}*$$

Assuming the air flow is continuous. Which would make the air flow have different areas to cover before the wind turbine wing and after the wind turbine. Resulting in two velocities and this produces the power net efficiency.

$$P_{eff} = P_1 - P_2$$

$$P_{eff} = \frac{\Delta V \rho}{2\Delta t}(v_1^2 - v_2^2)$$

$$P_{eff} = \frac{\rho A}{4}(v_1 + v_2)(v_1^2 - v_2^2) \; **$$

II. Stiffness

To determine the stiffness of the wind turbine structure the stiffness formula can be used. Thus, stiffness is equal to the load [F] dived by the deflection [δ]

$$S = \frac{F}{\delta}$$

But for this lab it will be the difference in load in relation to the difference in distance.

$$S = \frac{\Delta F}{\Delta x}$$

Hence, stiffness equation $S = \frac{F_2 - F_1}{x_2 - x_1}$ **

Wind Turbine Results and Analysis

A. Turbine Design

a. Wing Design

Creating the wing design, some basic research in order to figure out why wind turbines are designed the way they are along with what attributes make them so efficient. Before going into our research, it's important to go over the goals and constraints. The main goal of the wind turbine blade design is to be able to produce 2 watts of power while having a simulated speed of 25 miles per hour. One of the constraints is that the blade can not be longer than 2.5 inches. The blade also had to be integrated into the hub that was provided to us via solidworks, a 3D Computer Aided Design (CAD) software that was used to create the wind turbine blade design. The first research was based on why most wind turbines are 3 blade designs. According to the faculty of engineering in the University of Nottingham, three blade designs are mostly adopted due to being able to fit the environmental, economical, and commercial constraints that the wind turbine industry has. They also mention how a four wing turbine has a marginal increase in efficiency and overgoes the cost of construction and increase of complexity. It was decided to go with the industry standard and go for the 3 blade design as it is proven to be the most efficient. For the edges of the blade, a wind turbine design with edges that simulate bumps of a humpback whale was considered as well. According to a Havard research, wind turbine blades that have the edge that simulates a humpback whale were able to produce the same power at 10 mph that a conventional blade would produce at around 17 miles per hour. Due to time constraints, it was not possible to create a wind turbine design that had the edges simulating the bumps of a humpback whale. The next part is to come up with the general design of the blade itself. The inspiration for the blade design comes from modern residential ceiling fans that are capable of high cubic feet per minute (ft^3/min). These residential ceiling fans had an angled design and had a thicker base connecting to the hub and the end of the blade being thinner. For the wind turbine blade design, the length of the blade is 2.306 inches. On the base of the blade, the width of the blade is 0.753 inches.

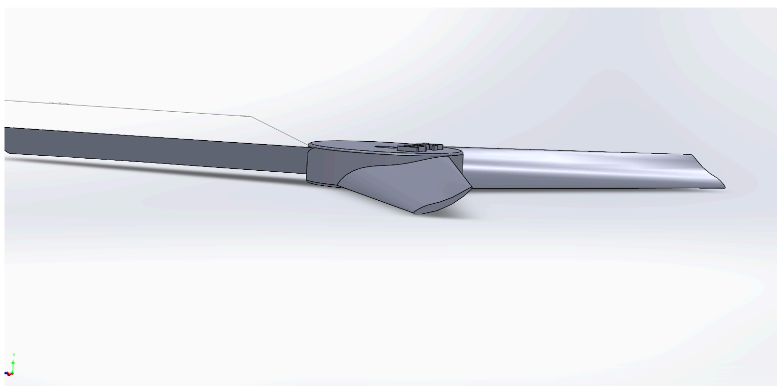

Figure 2: Side view of the blade design

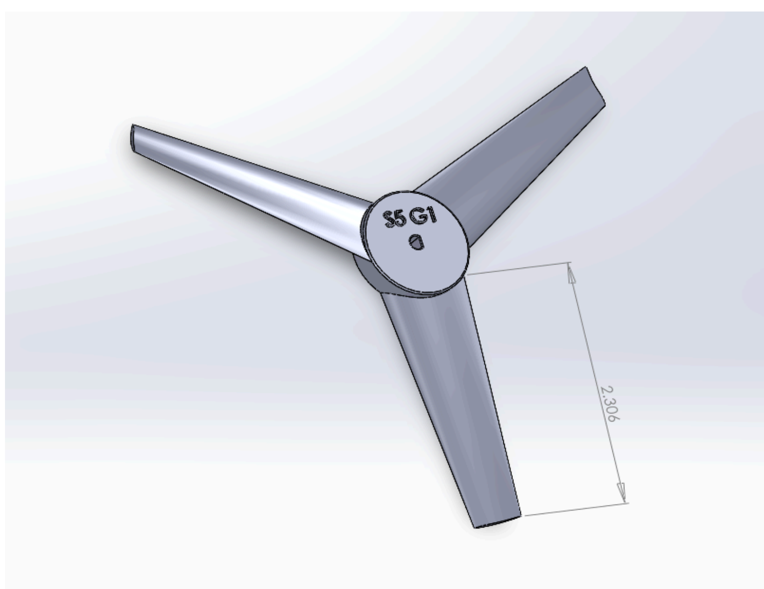

Figure 3: 3D Solid Work design model

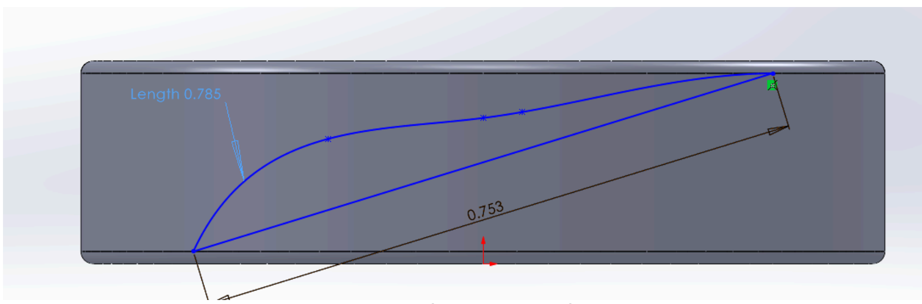

Figure 4: Dimensions of wide part of the blade

b. <u>Structure Design</u>

Knowing there were a few options to consider when looking into the structure for the wind turbine, but to replicate what the industry uses the team decided with a plastic hollow tube. By visiting hardware store sites like Lowes and Home Depot that provided plenty of information and examples of different pipes, the choice came down to two options: one bathroom sink kit made if polypropylene and the second was a combination of a plastic shower drain, an Acrylonitrile Butadiene Styrene (ABS) bushing, and an ABS 1’-½” schedule 40 pipe. There were pros and cons to using these materials. The ABS pipe was sturdier but when attached to the drain and bushing it made the weight of the structure over 400+ grams, to mitigate this issue two cut outs were made on each side along with making additional holes. The hope was to make the structure more aerodynamic along with minimizing the mass to meet the requirements, but they weren't enough and any further alterations would have impacted the sturdiness. The sink kit made of polypropylene was denser making it ideal for meeting the weight requirements, and over all no alterations were necessary that is why the choice was made to switch over to the sink polypropylene pipe. (Figure 5. Shows the two attempts, Figure 6. shows the ABS set up)

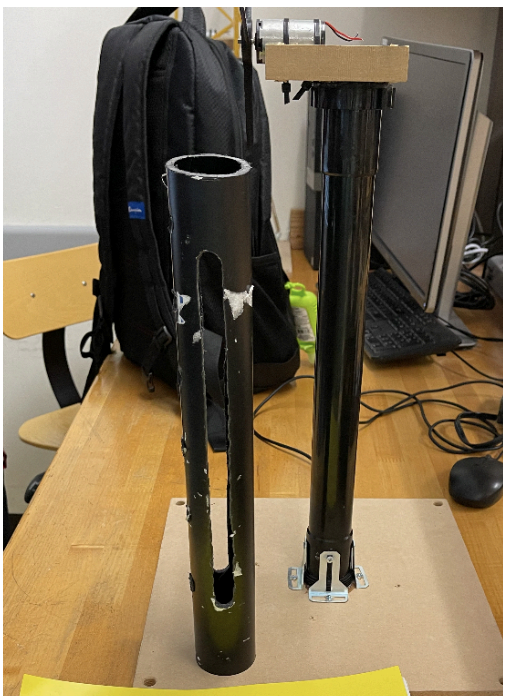

Figure 5: Comparison of the first and second structures

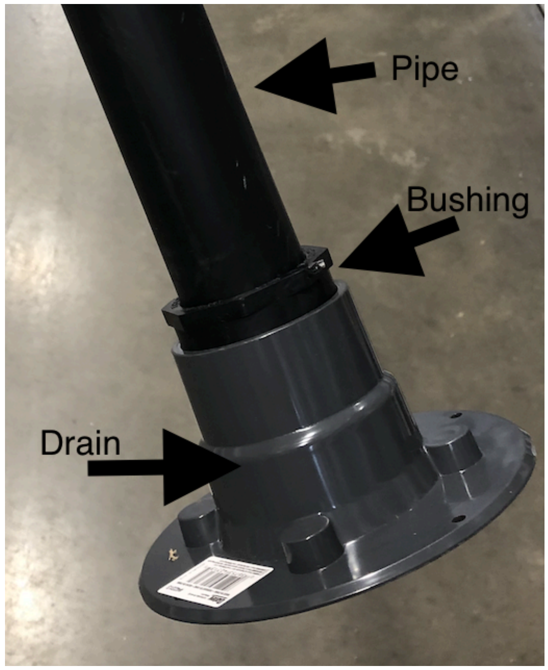

Figure 6: Initial Structure

B. **Stiffness**

For the stiffness there were few parameters based on the structure's mass of 120 grams and overall height of 16 inches long. That considered there were 12 attempts to measure the stiffness. The wind turbine was first placed in a table and was screwed down to a base. A micrometer was then placed to the front of the wind turbine in order to determine the displacement. The micrometer was also zeroed before the start of the stiffness test. Then, a hook was attached at the back of the wind turbine where weights were attached with a string. The first had no load and minimum displacement; this is shown on the graph in (Figure 7). For the measurements 2-12 there was a load of .100 Kilograms was added increasing each time by 100 grams until the final loading mass was 1.100 kilograms. The loads force effect on as it fell were as followed from the 2nd to 12th load. The results in stiffness are based on the load F_2 subtracted by F_1 divided by the displacement x_2 subtracted by x_1 (this formula is found in the theory part II). The results are reflected in the chart below in Figure 7.

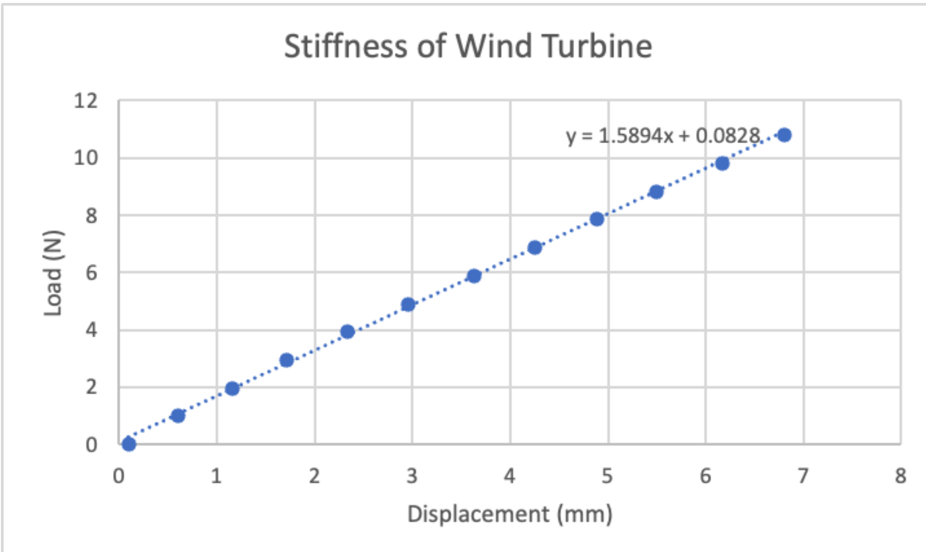

Figure 7: Stiffness graph Load vs. Displacement

C. **Power Produced**

In order to test the power produced by the wind turbine, the wind turbine was first placed into a base where it cannot move, then a piece of white reflective tape was placed on the top of the wind turbine blade. The piece of white reflective tape is used as a reading for a laser that will determine the RPM (Revolutions per minute) of the blade. A person would also hold the laser and point at the white tape through the testing session. A blower is also placed in front of the blade in order to simulate the wind speed heading towards the wind turbine. The position of the wind turbine and the blower is then adjusted accordingly in order to get the desired wind speed of 25 miles per hour which is measured using an anemometer placed next to the wind turbine. The wind turbine was placed approximately

45 centimeters from the blower. The wires from the wind turbine motor were then connected to a device used to measure power [W], Current [mA], and Voltage [V]. There was also a load box connected to the wind turbine which changed the resistance. The load box resistance was changed every 5 seconds in increasing increments up to 60 seconds. Results indicated that the wind turbine produced the highest amount of power at around the 50 second mark of 0.77 W. The highest speed achieved by the blade is 778.3 revolutions per minute. There is also a trend where the higher the current, the higher the higher power is produced up until around 500 mA. The results of power over current are reflected in the chart below in Figure 8.

I

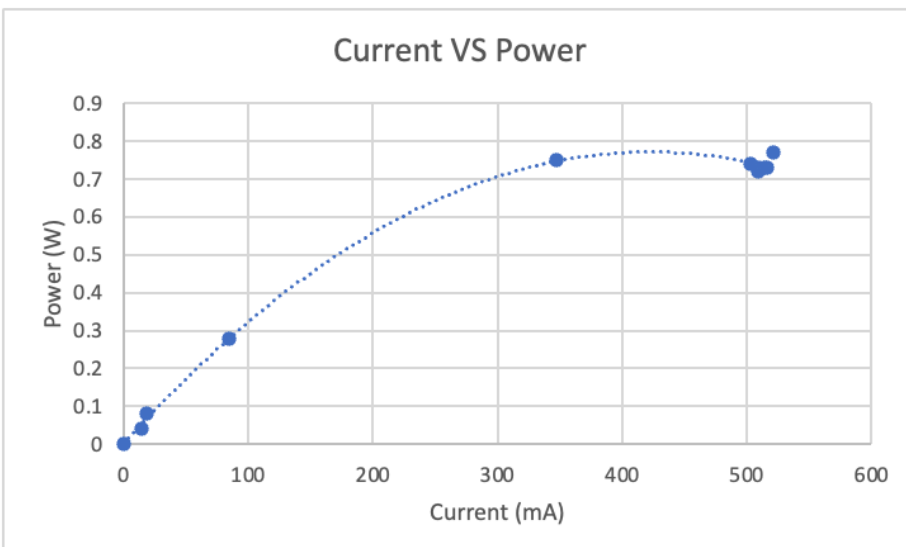

Figure 8: Graph of Current vs. Power

Conclusions

In conclusion, the wind turbine was strong enough to withhold strong winds but did not generate much power. In the case of the wind turbine stiffness unchanged, its distance and load proportional, voltage was also constantly changing because of the load box. When the voltage was getting smaller, the current was larger which also means that the power of the wind turbine was increasing. Finally, the maximum power of the wind turbine stopped at 0.77W in 45 seconds, the maximum number of blades stopped at 778.3 RPM in 30 seconds. After 30 seconds, the blade slows down, but the current and force continue to increase. Therefore, the power of the wind turbine was 0.77W, a value that requires the support of the current. When the current is insufficient, its power becomes smaller, after reaching maximum, the increase in current will no longer affect.

References

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[2] Kerrigan, Saoirse. "The Scientific Reason Why Wind Turbines Have 3 Blades." *Interesting Engineering*, Interesting Engineering, 10 June 2020, interestingengineering.com/the-scientific-reason-why-wind-turbines-have-3-blades.

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Appendices

Appendix A

SJSU: E10 LAB Project

Wind Turbine and Support Tower Performance Data

Section: 5, **Team #** 1, **Date:** 10-7-21, **Data collected by (Name):** Dulce Payán

1.0 Stiffness (deflection) Measurements

a. **Tower Height:** 16 **in.**

b. **Tower Net Weight:** 120 **g. (Total Assembly – Top/Bottom boards)**

c. **Stiffness Measurements:**

Data Points	LOAD (Kg)	LOAD (N)	DISPLACEMENT (mm)	Observations
1	0	0	0.1	with no load
2	100g		0.61	
3	200g		1.16	
4	300g		1.71	
5	400g		2.34	
6	500g		2.96	
7	600		3.63	
8	700		4.25	
9	800		4.89	
10	900		5.49	
11	1000		6.17	
12	1100		6.88	

Table 1.0 – Tower stiffness data

Comments