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OPTIMIZATION POWER OUTPUT OF HORIZONTAL WIND TURBINES BY USING CONE TUNNEL

Rahmad Samosir[1], Kimar Turnip[2]

Mechanical Engineering Study Program Faculty of Engineering Christian University Indonesia-Jakarta

E-mail : rachmadsamosir@yahoo.com

Abstract

Wind turbine is an energy conversion tool (renewable energy). In line with the decrease in fossil oil reserves, therefore, renewable energy will be used as the replacement, including wind energy. Many agricultural areas have not received electricity from the Electricity Company, so that wind turbine is suitable for these agricultural areas. For areas with high wind velocities, the utilization of wind turbines is very effective and efficient, but for areas with low wind velocities, the utilization of wind turbines is less effective. The increase of wind velocity can be engineered by using cone tunnel namely by using the continuity equation. Thus, the author wants to use the wind velocity engineering to optimize the power generated by the wind turbines.From the calculation results, the wind velocity will increase 1.5 folds when flowed through the cone tunnel with dimension of 2.2 m to 1.7 m and for the wind velocity of 5 meters per second will generate 39 Watt power, and if using the cone tunnel as mentioned above will generate 150 Watt power. By performing testing using wind turbine with outer diameter of 1.64 m and inner diameter of 0.44 m, the following results were obtained: in a wind turbine without cone tunnel, the 4 m/sec wind velocity generates 12.75 Watt power, while with cone tunnel generates 17.1 Watt power. The increasing power is not comparable with the theory that should reach 37 Watt. Since the testing was performed in the mechanical engineering laboratory of UKI with the wind source from fan, therefore from the observations performed, we can guess that the increase of power is not comparable to the theory because the wind generated is uneven and even turbulence occurs.

Keywords: Wind turbine, Cone tunnel, Power Output.

1. INTRODUCTION

1.1. Background

Currently, there are still many remote areas that have not been served by Electricity Company, especially in agricultural areas that are in small groups and far from the power network. Such areas require small power plant with as minimum operational cost as possible. One of the plants suitable for the above mentioned areas is wind turbine.

In 2011, the UKI Department of Mechanical Engineering made a relatively big wind turbine (3.4 m). The energy generated by the wind turbine has been used as lighting to light the lamp above the Mechanical Engineering laboratory, Christian University Indonesia. Looking at the output power generated by the wind turbine, it is not too big despite the big size, since the wind velocity around UKI is considered low. According to the turbine theory, the energy generated by turbine is cube of wind velocity, therefore the used of wind turbine in low wind velocities area is not very effective.

Many researches have been performed on how to optimize the power generated by wind turbine at low wind velocities. As the research performed by Sevvel P and Santhosh P (2014), to increase the velocity of vertical wind turbine is by making some modification, including adding steering tail, nozzle and also deflector.

Other than the aspect above on how to increase the wind velocity to generate maximum power, Arvind Singh Rathore in his previous research (2011), the aspect of blade's strengths against pressure and deflection should also be noted, especially for long blades. In this research, horizontal wind turbine rotor model was presented, where the turbine blades are an important part of rotor by performing strength tests with the help of ANSY software as a comparison to analyze the designs made. Still with the help of the research software performed by Asis Sarkar, Dhiren Kumar Behera (2012) to determine the efficiency and power with the help of software in 1 m diameter turbine, the maximum efficiency generated also increased.

Back to the subject of increasing wind velocity, or improving the performance of vertical axis type of wind turbine, Pankaj Kumar Mishra, Dr. Arvind Saran Darbari, and Ansar Ali (2014) used the nozzle. Although the study performed had not reach the theoretical studies in general, but rather on the aspects of learning the configuration factors of various design such as adding nozzle for the purpose of developing theoretical models.

Rakesh Rohan (2014) conducted a research on horizontal axis wind turbine with varied wind velocity and blade angel change factor. It was found that the efficiency increase as the wind velocity increase.

Dr. Ulan Dakeey (2015) with diffuser method added cone dimension section in at the end of the diffuser to direct the wind only on the blade tip only,from the power output generated with different blade type variation between conventional and specially made, their research results showed that there is an increase in power.

Meanwhile, in the research conducted by Grady M. Isensee1, Hayder Abdul-Razzak (2012), in the research conducted in horizontal axis wind turbine by adding an expanded diffuser in which the inlet dimension is smaller than outlet dimension before the winds hit the turbine blades, which can increase the power of turbine axis. In the same way, Peace-Maker Masukume et all (2016) conducted experiment with expanded cone diffuser method with the purpose to increase the wind velocity before entering the turbine blade, which shows increasing wind velocity from before.

Based on the above facts, the power of turbine axis actually can be increased by engineering the wind path before leading to the wind turbine blades. For this reason, different from previous studies, therefore what we were going to do in this research was to increase the wind velocity by design engineering through nozzle con wind tunnel, in which the inlet dimension was made larger than the outlet dimension toward the wind turbine blade.

1.2. Research objective

General Objectives: Determine the impact of tunnel cone design changes ofwind turbine in the velocitychanges of the wind turbine in increasing the generated axis power.

2. Research Methods

2.1. Tools used

The research was conducted by first building a wind turbine complete with the cone tunnel. Other than wind turbine unit, tools were also required to conduct the research.

Tools and materials used for research:

- Fan that capable of moving the wind turbines
- Amperemeter, to measure the current generated by the generator
- Voltmeter,to measure the potential difference (voltage) generated by the wind turbine.
- Anemometer, to measure the wind velocity generated by the fan
- Fitting and LED lamp, the lamp was used as load (adding load just by adding the on lights).

2.2. Order of implementation

- Preparation of tools and equipment needed to make the wind turbine
- Building the wind turbine to be tested
- Preparing gutters for measurement

2.3. Implementation of the test

Implementation of the test conducted repeatedly consistent with the needs, to obtain optimal results.

3. Basic Theory

3.1. Wind power

The wind blowing with V velocity(kinetic energy) can generate the power according to the following equation: [2]

$W_{tot} = \dot{m} \times \dot{E}_k = \dot{m} \times \frac{V^2}{2g_c}$ so that the total turbine power: $W_{tot} = \frac{1}{2g_c} \rho A$ ^{3}

in which:

W_{tot} = the total power generated

E_k =Kinetic energy from the air

$\dot{m}$ = air mass flow rate kg/sec→ $\dot{m} = \rho AV$

g_c = conversion factor 1,0 $\frac{kg}{Ndet^2}$

A = cross dimension area of the flow

ρ = air density (wind) kg/m3.

3.2. Increasing Wind Velocity

Using the continuity equation, the wind velocity coming out from the outward (smallest) side can be determined as follows:

$A_1 V_1 = A_2 V_2$

in which:

A_1 = *inlet* dimension area (m)

A_2 = *outlet* dimension area (m)

V_1 = inlet wind velocity (m/sec)

V_2 = outlet wind velocity (m/sec)

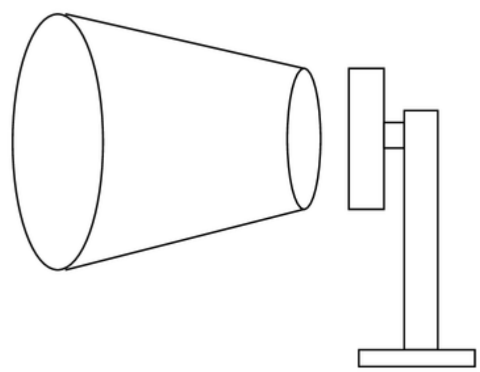


Fig 1. *Nozzle Cone* Design Shape

In theory the wind velocity will increase 1.5 foldsor more, so theoretically the power generated will also significantly increase.

3.3. Building Wind Turbine and Testing

In order for the test can be conducted, then a wind turbine was made along with all the necessities.

Turbine was made with 6 blades, which the blade material was made of aluminum plate.

3.3.1. Size of turbine

Outer diameter of turbine : 1.64 m

Inner diameter of turbine : 0.44 m

Area of one blade : 0.24 m^2

Total area of blade : 1.44 m^2.

Generator used : many poles

The rotary shift tools from the turbine axis to the Generator used chain transmission with a ratio of 9: 60, so that if the rotation of the rotor axis was 9 rpm then the rotation of the generator axiswas 60 rpm.

Fig. 2.1. Building and installing wind turbine

Fig 2.2. Installed wind turbine with cone tunnel

3.2. Testing (data retrieval)

Performance testing of the turbine was performed 4 times, namely:

a. Testing the turbine without using a cone tunnel
b. Testing the turbine using a cone tunnel, where the tunnel distance to the turbine blade was 10 cm
c. Testing the turbine using a cone tunnel, where the tunnel distance to the turbine blade is 20 cm
d. Testing a mill using a cone tunnel, where the tunnel distance to the blade was 30 cm

The four tests were each tested with 3 variations of wind velocity, namely 3 m/sec, 3.5 m/sec and 4 m/sec.

The testing was performed in Mechanical Engineering Laboratory starting from September 4th to September 6th 2017.

Fig 3. Measurement of rotation speed generator

3.2.1. First testing

Table 3. 1. Table of Testing Result of Wind Turbine (Without Tunnel)

Velocity	Load (LED lamp of 7 Watt)	Generator Rotation	Volt	A	Power (Watt)	Note (Lamp condition)
3 m/sec	Without load	202	14	-	-	
	1 lamp (7 W)	160	9	0,4	3,6 W	Bright
	2 lamps (14 W)	150	7,5	0,6	4,5 W	Dim
	-	-	-	-	-	-
3,5 m/ sec	Without load	286	18	-	-	-
	1 lamp (7 W)	170	9,5	0,5	4,25 W	Bright
	2 lamps (14 W)	165	9	0,7	6,3 W	Bright
	3 lamps (21 W)	160	7,5	0,9	6,75 W	Dim
4 m/ sec	Without load	350	20	-	-	-
	1 lamp (7 W)	201	11	0,6	6,6 W	Bright
	2 lamps	184	10	1,1	11 W	Bright
	3 lamps	178	9	1,4	12,6 W	Bright
	4 lamps	162	7,5	1,7	12,75 W	Dim

Fig.4. Testing with 3 lights on

3.2.2. Second testing

Table 3. 2. Table of Testing Result of Wind Turbine' (With Cone Tunnel of 10 cm from the blade)

Wind Velocity	Load (LED lamp of 7 Watt)	Generator Rotation	Volt	A	Power (Watt)	Note (Lamp condition)
3 m/sec	Without load	282	16	-	-	-
	1 lamp (7 W)	170	10,5	0,6	6,3 W	Bright
	2 lamps (14 W)	164	0,8	0,9	7,65 W	Starting to dim
	3 lamps (21 W)	156	7,1	1,1	7,81 W	Dim
3,5 m/ sec	Without load	326	18	-	-	-
	1 lamp (7 W)	187	11,5	0,6	6,9 W	Bright
	2 lamps (14 W)	180	10	1	10 W	Bright
	3 lamps (21 W)	170	9,5	1,3	12,35 W	Bright
	4 lamps (28 W)	162	8	1,6	12,8 W	Starting to dim
4 m/ sec	Without load	360	22	-	-	-
	1 lamp (7 W)	201	13	0,5	6,5 W	Bright
	2 lamps	192	11,5	1,2	13,8 W	Bright
	3 lamps	184	10	1,6	16 W	Bright
	4 lamps	178	9	1,9	17,1 W	Bright

3.2.3. The thirt Testing

Table 3.3. Table of Testing Result of Wind Turbine' with Cone Tunnel of 20 cm from the blade

Wind Velocity	Load (LED lamp of 7 Watt)	Generator Axis Rotation (rpm)	Volt	A	Power (Watt)	Note (Lamp condition)
3 m/sec	Without load	368	23	-	-	-
	1 lamp (7 W)	190	11	0,6	6,6 Watt	Bright
	2 lamps (14 W)	177	9,7	0,9	8,73 Watt	Bright
	3 lamps	159	8,5	1,1	9,35 Watt	Dim
3,5 m/ sec	Without load	390	27	-	-	-
	1 lamp (7 W)	186	11,5	0,6	6,9 Watt	Bright
	2 lamps (14 W)	182	9,6	1,1	10,56 Watt	Bright
	3 lamps (21 W)	178	9,2	1,3	11,96 W	Bright
	4 lamps (28 W)	167	8,6	1,5	12,9 Watt	Bright
4 m/ sec	Without load	405	30	-	-	-
	1 lampu (7 W)	230	13,5	0,5	6,75 Watt	Bright
	2 lamps (14 W)	201	12	1,2	14,1 Watt	Bright
	3 lamps (21 W)	195	10,5	1,4	14,7 Watt	Bright
	4 lamps (28 W)	188	9,5	1,8	17,1 Watt	Bright

Fig 5. Turbine testing with 4 lamps on

3.2.4. Fourth Testing

Table 3.4. Table of Testing Result of Wind Turbine with Cone Tunnel of 30 cm from the blade

Wind Velocity	Load (LED lamp of 7 Watt)	Generator Axis Rotation (rpm)	Volt	A	Power (Watt)	Note (Lamp condition)
3 m/sec	Without load	345	23	-	-	-
	1 lamp (7 W)	198	12	0,6	7,2 Watt	Bright
	2 lamps (14 W)	170	9,6	0,9	8,64 Watt	Bright
	3 lamps (21W)	166	8,2	1,2	9,84 Watt	Starting to dim
	4 lamps (28W)	162	7,5	1,6	12 Watt	Dim
3,5 m/sec	Without load	450	27	-	-	-
	1 lamp (7 W)	198	12,5	0,6	7,5 Watt	Bright
	2 lamps (14 W)	193	11	1	11 Watt	Bright
	3 lamps (21	183	10,5	1,3	13,65	Bright

	W)				Watt	
	4 lamps (28 W)	177	9	1,6	14,4 Watt	Bright
4 m/sec	Without load	490	32	-	-	-
	1 lamp (7 W)	216	13	0,5	6,5 Watt	Bright
	2 lamps (14 W)	202	11.5	1,1	1 2,65 Watt	Bright
	3 lamps (21 W)	195	9,5	1,5	14,25 Watt	Bright
	4 lamps (28 W)	188	9	1,9	17,1 Watt	Bright

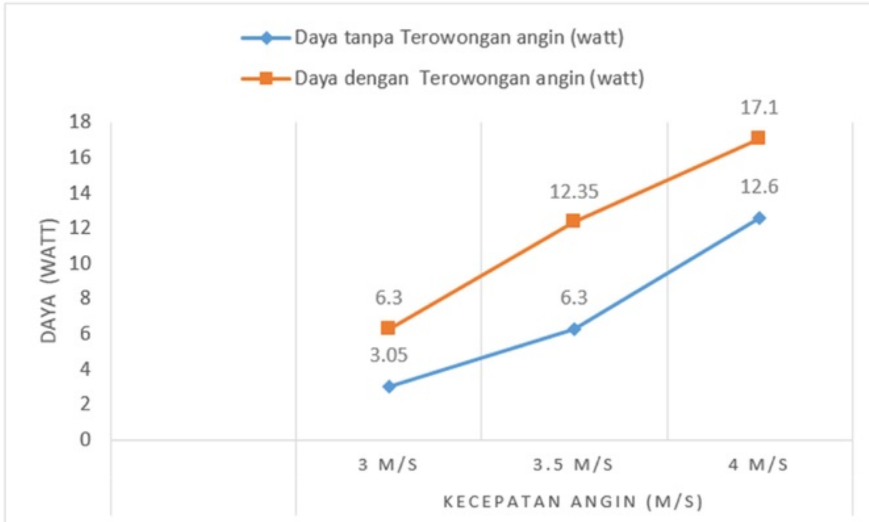
4. Data analysis (testing results)

4.1. Power generated

One of the objectives of this research was to determine the effect of the distance of the tunnel to the turbine blade. However, from the test results presented in table 2.3 and 4, the distance does not affect the power generated by the turbine, on the test with wind velocityof 4 m/s, the three tests generated the same power, namely 17.1 Watt. As for the wind velocity of 3 m/s and 3.5 m/s generated different power, according to our observations it was due to the accuracy of the measuring tool. From Table 1 it can be seen that in test 1 without using cone tunnels, the maximum power generated by the turbine is 12.75 Watt, while in the tests 2, 3 and 4, shown in Table 2, 3 and 4 namely by using the cone tunnel the maximum powergenerated by the turbine is 17.1 Watt. In the graphic form,the test result is shown on graph infigure 4.1 and figure 4.2 below. The increasing power is clear in Table 4.1 and graph 4.1.

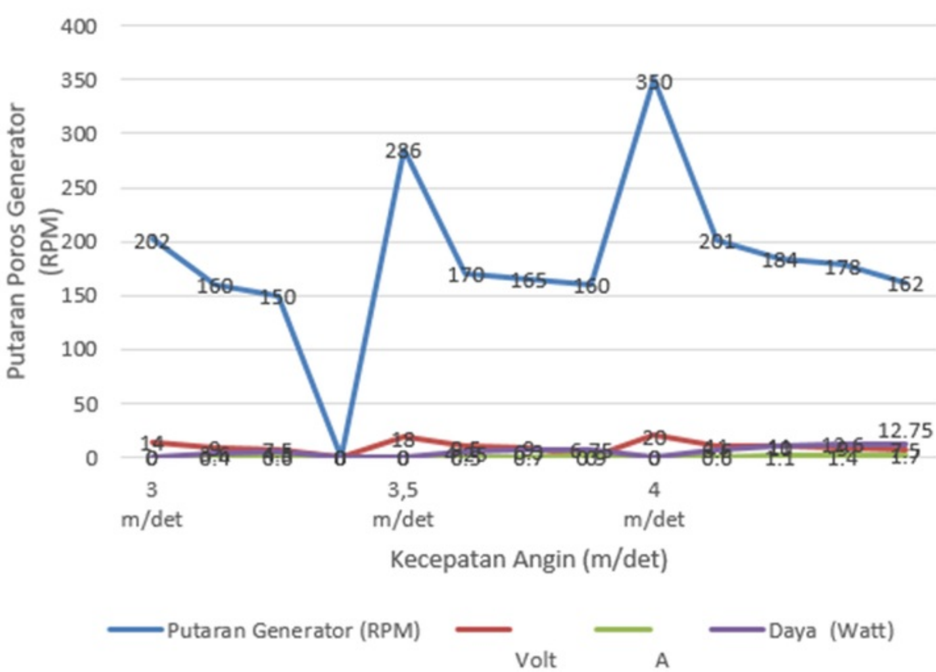
Table 4.1. Differences in output power with and without tunnels

Testing	Velocity (m/s)		
	3 m/s	3.5 m/s	4 m/s
Power without wind tunnel (watt)	3.05	6.3	12.6
Power with wind tunnel (watt)	6.3	12.35	17.1

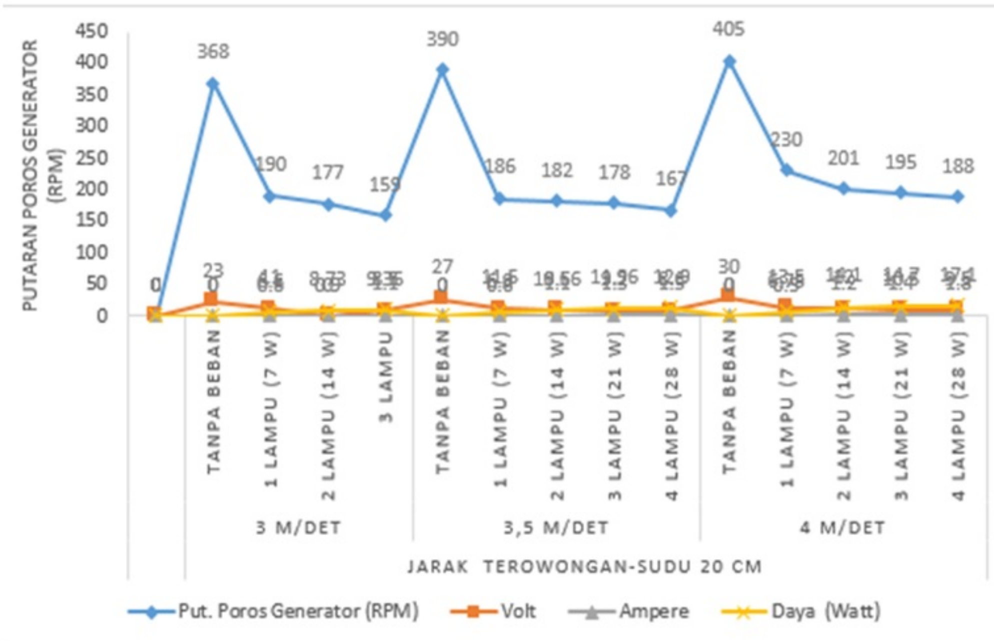


Graph 4.1. The increase of turbine power by using cone tunnel

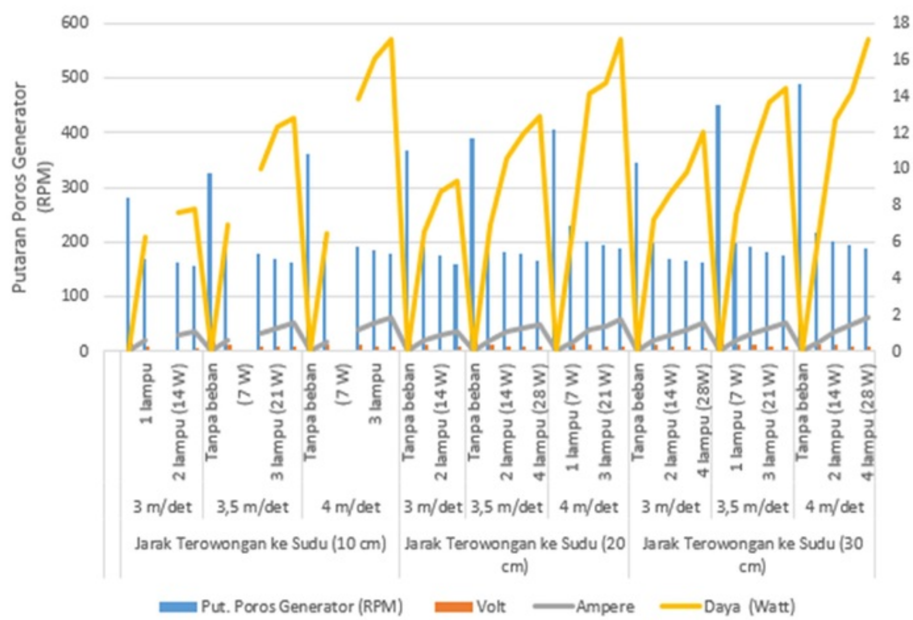
Graph 4.2. Graph of wind turbine testing without using cone tunnel



Graph 4.3. Graph of wind turbine testing with using cone tunnel



Graph 4.4. Relationship Between Tunnel Distances – to the Blade on the Rotation and the Power Generated



4.2. Theoretical Power and Output Power

Theoretically, wind turbine without cone tunnel tested at the wind velocity of 4 m/sec can generate the power of:

$W_{tot} = \frac{1}{2g_c}\rho A V^3$ = 0,5 x 1,1 kg/m^3 x 1,24 m^2 x(4 m/sec)^3 = 43,6 Watt.

Output power: 12.75 Watt

Efficiency : 12,75/43,6 x 100% = 29 %

By using cone tunnel, the power generated by turbine is 17.1 Watt.

Efficiency : 17,1 /43,6 x 100% = 39 %

By using cone tunnel for input wind velocity (V_1) 4 m/secthe output will be

V_2= A_1V_1 =A_2 V_2

V_2 = A_1 /A_2 x V_1= 2,2^2/1,7^2 x 4m/sec

V_2 = 6,5 m/sec.

The power generated should be (Wttot) = 0,5 x 1,1 kg/m^3 x 1,24 m^2 x(6,5 m/det)^3=187W.

If the wind turbine efficiency is 29 %, the output power should be: 187 Watt x 0,29 = 54 Watt.

Theoretically, by using the tunnel, then the above turbine will have an increasing power of: **54 W/12.75W = 4.2 folds**, but the fact is, the increase obtained is: **17.1 W/12.75 W = 1.34 folds**.

In testing this wind turbine, there are some things that are considered not meet the theoretical expectations, they are expected to occur because of the following reasons:

a. Although the turbine efficiency by using cone tunnel reached 39 %, however, the value has not met the expectations, it occurs because the wind velocity exited from the V_2 cone tunnel is not consistent with the continuity equation.

b. The wind velocity exited from the V_2cone tunnel follows the continuity equation because the wind generated by the fan does not have the same velocity at all the V_1inlet dimension of the cone tunnel.

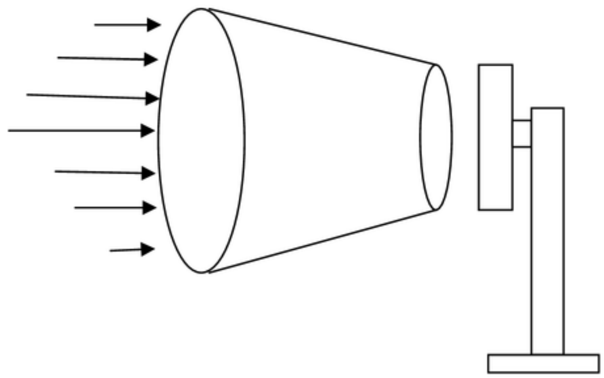


Fig 4.3. The difference in wind velocity entering the cone tunnel

V. Conclusions and Suggestions

V.1. Conclusion

After testing and analyzing test data results, the following conclusions can be drawn:

1. The efficiency of a wind turbine without the use of a cone tunnel of 29% is reasonable for a wind energy conversion machine.
2. The efficiency of a wind turbinewith a cone tunnel of 39% is considered very low (incompatible with the theory)
3. It is estimated that the low efficiency in the wind turbine testing with the cone tunnel occurs becausethe wind velocity entered the tunnel is uneven and even turbulence occurs.

V.2. Suggestions

1. To ensure the assumption that the wind velocity entering the tunnel is uneven, further research is needed.
2. To avoid wind turbulence leading to the wind turbine, steering blades should be made.

3. If the test is performed in an open space by utilizing natural wind, it is necessary to build comparator turbine with the same dimension to obtain the actual output power differences.

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