Vertical Axis Wind Turbine with Dynamic Blades

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Introductio

Abstract

Wind power represents one of the most promising sources of renewable energy and improvements to wind turbine design and control can have a significant impact on energy sustainability. This proposal is about a new design for efficient VAWT.

Typically, VAWT power output is generated from the difference between the forces on the forward and backward facing blades to the wind direction. That reduces their efficiency as compared to the Horizontal Axis Wind Turbine (HAWT). The current innovation, eliminates the forces on the backward facing blades using dynamic blades which improve their efficiency to be comparable with the HAWT.

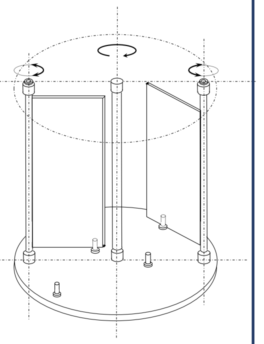
In addition, the turbine is fitted with aerodynamic brakes that safely stop the turbine at low and high wind speeds. This safety feature does not exist in any Vertical Axis Wind Turbine in the market. The innovation received the Accelerator to Commercialization award in 2014 from the state of Ohio and University of Cincinnati. Several small size prototypes were built which validated the concept.

VAWTs are capable of catching wind from all directions which avoid the need for yaw mechanisms, rudders or downwind coning. The electric generators can be positioned near the ground and are easily accessible for maintenance. The new invention will revolutionize the wind turbines and wind farms technology by improving the VAWT efficiency and safety.

Description

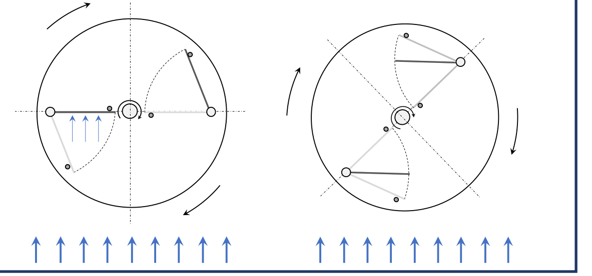
The turbine of dynamic plates has the following distinctive properties:

- There is a relative rotation between the base (solid that joins all the plates) and the plates.
- In the case of 3 plates, there are 4 rotation axes. Three of them correspond to the axes that connect each of the dishes to the base. The fourth is the central axis of the turbine, axis of rotation of the base, the transports the useful power of the turbine.
- In the relative movement of the plates with respect to the base, each plate has an alternative rotary movement. That is, the direction of rotation depends on the position of the plate. In addition, there is no complete turnaround at any time.
- At the base, supports have been arranged that serve as a mechanism for locking the plates. The plates have to be blocked at the precise moment so that when they are restricted, they provide the necessary rigidity to rotate the base with them, the effective thrust.



In this study, the following analyzes have been carried out:

- Stationary dynamic state analysis. Analysis of the resulting forces in the plates and in the structure as a whole, being subjected to a constant flow of fluid and homogeneous distribution of pressures.
- Resonance analysis. Study of the natural modes of the 3-plate system and comparison with the possible rotation frequencies of the turbine.



Expositio I

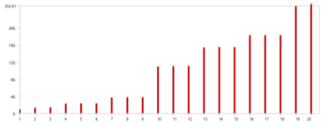
Natural Frequencies

In this section we have studied the resonance modes and the natural frequencies of the structure of 3 flat plates. For the study, carbon fiber, aluminum and stainless steel materials have been considered.

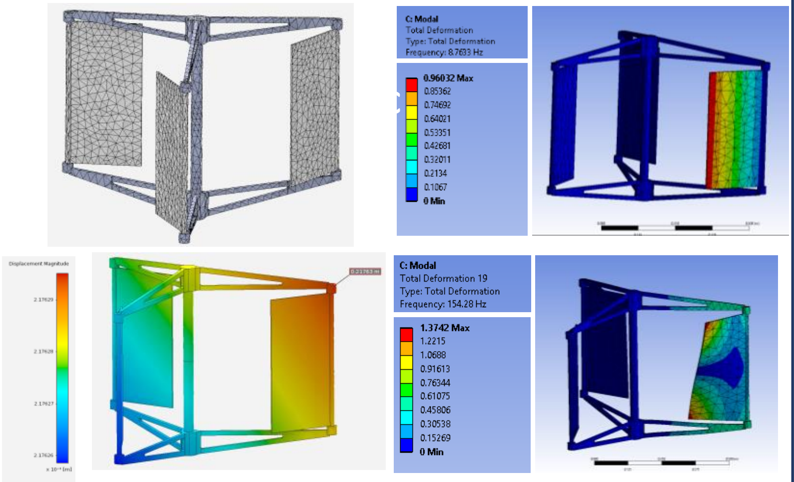
The results that have been obtained from this analysis will be compared later with the force and moment patterns that are generated for specific climatic conditions.

As it can be seen, the values of natural excitation frequencies appear in groups of three. This is due to the differences in the orientation of the dishes. This is explained below:

The orientation of the plates varies according to the angle of rotation, and each of them varies in a different way. In the finite element analysis, specific and different opening angles have been selected for each dish. In this way, the result of the study can be observed the range of resonance that can lead to the excitation of any of the three dishes. That is why in the study you can observe groups of three, relatively similar.



	Mode	Frequency [Hz]
1	1.	8.7633
2	2.	12.571
3	3.	13.479
4	4.	22.266
5	5.	22.865
6	6.	23.104
7	7.	37.01
8	8.	37.507
9	9.	37.641
10	10.	109.37
11	11.	110.26
12	12.	110.51
13	13.	154.28
14	14.	154.55
15	15.	154.99
16	16.	182.47
17	17.	182.53
18	18.	182.8
19	19.	250.36
20	20.	252.01



Conclusio

Among the conclusions to be mentioned of this comparative study between both analyzes, the following stand out:

- For the estimated rotation frequencies based on the weather conditions of the environment, force patterns such as those shown above are produced. The values of these force and momentum functions do not coincide with any of the natural modes of the three-plate structure. Therefore, it is an effective approach for the design of this type of turbines.

The force patterns that are generated for the case of 3 plates, are closer to a constant value of force resulting. As it is considerations:

- In a more advanced study, an aerodynamic flow-interference analysis between the turbine plates should be incorporated. In the work carried out, the shadow effect of one plate on another has been considered, but the additional thrust generated by the movement of the fluid in the transverse direction has not been taken into account.
- logical, without considering the aerodynamic interferences, the more plates are arranged in the periphery, the more uniform the resulting force in the structure will be, and therefore, the power generated and injected into the electrical net will be more constant.

Future The effect of the system of braking and blocking of the plates generates a peak of force, an impulse, in the contours of the plates. To solve it, it is necessary to redesign this system and thus make a more cushioned stop. Therefore, one of the next steps will be to conceive a prototype with a spring-piston braking system that minimizes the current percussion effect.

Expositio II

Force Analysis

In this section we have studied the resulting force curves applied to the plates and moments generated in the turbine shaft for each plate.

First, the following physical parameters (inputs) have been defined, both those related to the turbine and those external to it.

In the outputs column the equivalent static forces due to the impact of the plate against the blocking system have been obtained. A linear polynomial transformation of the percussion was developed, getting from it the value of Em and En (equivalent static forces of the percussion with the M and N blocking systems respectively).

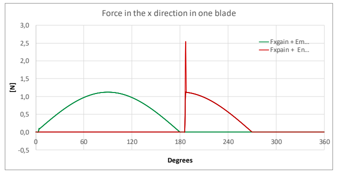
The three cases have been analyzed, for one, two and three plates. In addition, shadowing effects have been taken into account for the calculation of the results.

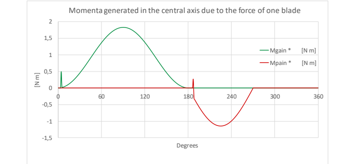
Inputs

Blade Properties	a	0,75	[m]	Width
	b	0,75	[m]	Height
	A	0,5625	[m²]	Area of the flat blade
Bed Properties	R	2	[m]	From axis 1 to axis 2
P = f(V)		2	[N/m²]	Pressure on the blade
Angles	α1	4	[Degrees]	Angle at which the blade touches the pin M
	α2	180	[Degrees]	Angle at which the blade separates from pin M
	α3	187	[Degrees]	Angle at which the blade touches the pin N
	α4	270	[Degrees]	Angle at which the blade separates from pin N

Outputs

Em	0,386323636	[N]	Module of the equivalent static force due to the impulse/collision with pin M
Emx	0,026948575	[N]	Projected in the x direction
Emy	0,385382571	[N]	Projected in the y direction
Cm	1,1		Dependent term of the force
Dm	0,3		Independent term
En	1,428275863	[N]	Module of the equivalent static force due to the impulse/collision with pin N
Enx	1,417629711	[N]	Projected in the x direction
Eny	-0,174063042	[N]	Projected in the y direction
Cn	1,1		Dependent term of the force
Dm	0,2		Independent term



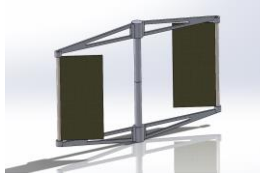


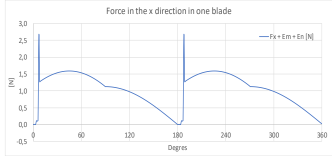
$$F_x^{gain} = A\ P\ sin(\theta) \quad if \quad \alpha_1 < \theta < \alpha_2$$

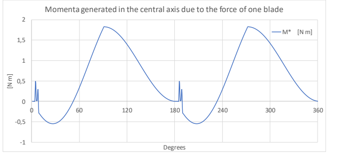
$$F_x^{pain} = A\ P\ sin(\theta) \quad if \quad \alpha_3 < \theta < \alpha_4$$

$$M_x^{gain} = F_x^{gain}\left(R - \frac{a}{2}\right)\sin(\theta) \quad if \quad \alpha_1 < \theta < \alpha_2$$

$$M_x^{pain} = F_x^{pain}\left(R - \frac{a}{2}\right)\sin(\theta) \quad if \quad \alpha_3 < \theta < \alpha_4$$

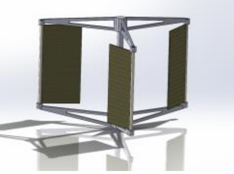


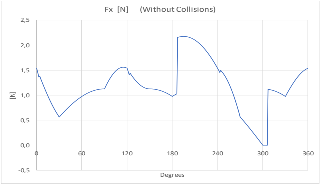




To obtain the graphs of the cases of two and three plates, the results of the case of a plate have been used. In such a way that, depending on the angle of rotation, at each moment one of the plates is in front of the rest, this having a greater influence than the others.

For this, linear interpolation methods have been used, taking into account the opening of each blade, its orientation, and its interference in position with the rest, it is possible to calculate the final result of the force exerted.4





The peaks shown in the graphs are a direct consequence of the impulses produced by the collisions of this design.

It should be noted that as more plates are incorporated, the approximation of these functions to a sinusoidal curve becomes increasingly complex.

To understand the modes that are being excited in each of the situations, a Fourier transform of these curves has been carried out, thus verifying that for the specified climatic conditions the frequencies of the forces and moments do not coincide with the natural values of the entire structure.