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STRUCTURAL DESIGN OPTIMIZATION OF VERTICAL AXIS WIND TURBINE TYPE DARRIEUS-SAVONIUS

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ABSTRACT

The design of wind turbine is always interesting to be studied. Studies on the optimal structure design of wind turbine have been studied by many researchers but are still continuing up to now. The present study is intended to investigate the optimal structure design of Darrieus-Savonius Vertical Axis Wind Turbine (DS VAWT) type by using numerical simulation method. A small 500 W DS VAWT was investigated in this research. Design modifications were begun with several tasks to find the critical parts of wind turbine, after that the modifications were analyzed and improved according to the source of weakness. Several modifications were simulated: shorten the inner shaft and change the inner shaft material. The simulations results show that the critical part from DS VAWT system is the inner shaft, by shortening the inner shaft, the structure strength will improved significantly. Changing the inner shaft material did not show a great improvement.

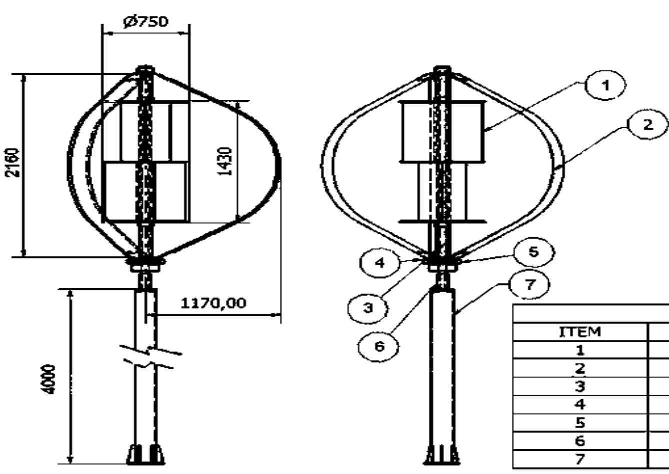
Keywords: darrieus-savonius, wind turbine, structure design, optimization, inner shaft.

INTRODUCTION

Daerrius-Savonius type wind turbine is one kind of vertical axis wind turbine. Darrieus-Savonius Vertical Axis Wind Turbine is categorized as a small size wind turbine. Because of the small torque that may be generated by wind turbine, the 500 W DS type needs high rotation speed in order to generate the power required. Due to safety and acoustic noise requirements, the rotational speed of wind turbine was restricted [1, 2]. Several structural requirements that should be fulfilled based on the design restriction and market demands are listed as: sturdy, strong enough to bear up the strong wind; durability, endurance from fatigue problem; stable, no significant vibration that may cause wind turbine destruction in operational speed; light, compact; easy to manufacture and install, easy to uninstall during maintenance; green product, not using material that may harm the environment [3, 4].

Figure-1 shows the first prototype made by combining the Darrieus type of wind turbine with Savonius wind turbine. There are three pieces of Darrieus type blades, and one unit two level Savonius wind turbine. The electric generator (including mechanical break system) was installed below the entire blade system. Detail specification of Darrieus-Savonius VAWT is shown in Table-1.

The wind turbine has some defects during the first run. The defects are the wind turbine swing in some specific rotational speed and the shaft is categorized as soft shaft (the natural frequency is beneath the operation condition). Therefore, it needs some modifications. The goals of modifications are aiming at the optimization design of 500W DS VAWT. The best optimization implies less swing motion, more sturdy and shifting the first natural frequency of VAWT system lower than the original design.



Parts List

ITEM	QTY	PART NUMBER
1	1	Savonius wind turbine
2	3	Darrieus Blade
3	1	Inner Shaft
4	1	Outer Shaft
5	1	Electric Generator
6	1	Shaft Holder
7	1	Tower

Figure-1. Layout of Darrieus-Savonius VAWT.

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Table-1. Specification of Darrieus-Savonius VAWT.

Moving Parts	
Darrieus Blade:	3 Blades (each 120˚)
Airfoil Type:	Symetric type with chord length : 10cm
Savonius Blade:	2 level Savonius Blade (each level has 2 blades)
Airfoil Type:	Half Round type
Shaft:	Double Shaft System (inner and outer).
Statis Parts (Tower)	
High:	4 m (measure from the ground)
Diameter:	±14 cm with thickness 0.8 cm

NUMERICAL METHODS

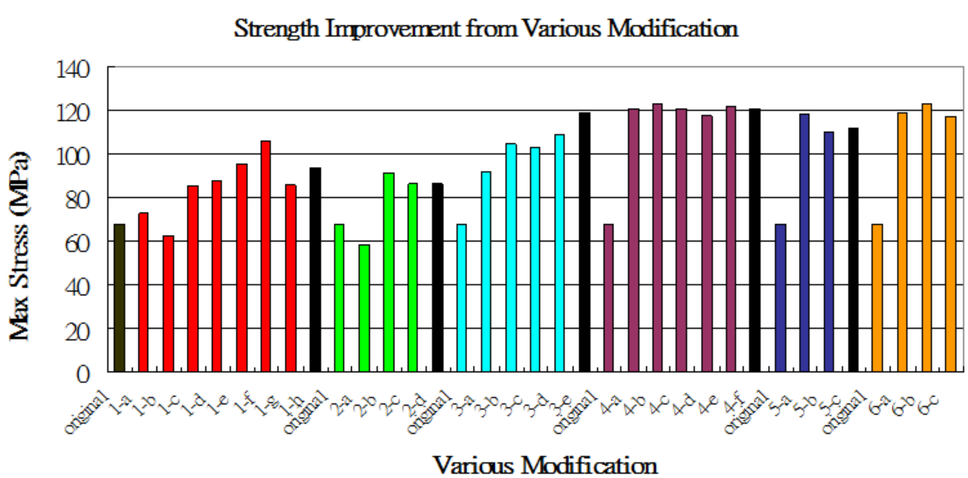
With the aim of improving the structural sturdiness of wind turbine, several modifications were examined by using numerical simulation method [5, 6]. In order to identify the critical parts of wind turbine, finite element analysis software ANSYS was used. Some output parameters from the ANSYS, that were used to identify the most critical parts, are maximum load stress, maximum swing displacement of the VAWT system, and the natural frequencies of the system. All the designs were modified using CAD software before they were automatically uploaded to ANSYS software for finite element analysis simulation.

MODIFICATION AND OPTIMIZATION DESIGN

Several hypotheses about the defect source are: deflection, unbalance, soft shaft (natural frequency is below the operation condition), misalignment, unbalance, torsion vibration, bearing defect [7]. To simplify the simulation process, the defect caused by aerodynamic, was neglected in this section. The effect can be shown in Figure-2. From this figure, the entire graphics showed that the strength of wind turbine is enhanced by enlarging the outer-diameter of outer-shaft and/or inners-shaft. Enlarging the outer-diameter of outer-shaft and/or inner-shaft improved the strength of wind turbine because the highest stress load and the lowest displacement are appeared in the simulation results.

The highest stress load means the highest stress load may be endured by the VAWT system before it failed. And the lowest displacement means the maximum displacement which is generated when the swing motion swing in its 1st natural frequency. However enlarging the outer-diameter of outer-shaft and/or inners-shaft were not the best solution, since this improvement results in a much heavier system.

The most possible modification and easiest to apply was shortening the inner shaft. Even all the shaft system was modified, but the electric generator, airfoil blade still remains the same. This modification included moving the bearing position, cutting the outer-shaft into two pieces (top-outer-shaft and bottom-outer-shaft). Only the position of entire blade, electric generator, and mechanical break system remain constant.



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	original
	Various length of inner-shaft
	Various position of upper side bearing
	Various position of bottom side bearings
	Various outer-diameter of inner shaft (inner-diameter of outer-shaft was constrained)
	Various outer-diameter of the upper side of outer-shaft (Top Shaft)
	Various outer-diameter of the bottom side of outer-shaft

Figure-2. The results of VAWT due to various modifications.

From the hypotheses of all defect sources, it is showed that the most critical part is the inner shaft. The first modification is changing the material of inner shaft. The inner-shaft was made of SS400 material, which has good strength ability, but a little bit heavy. The purpose of changing the material of inner shaft is to reduce the weight of shaft system. Even though the natural frequency will increase, it may cause another benefit for aerodynamic performance. By reducing the weight of the system, VAWT was easily getting started and required less start-rotating torque generated.

The second modification to apply was shortening the inner shaft, as shown in Figure-3. Even all the shaft system was modified, but the electric generator, airfoil blade still remains the same. This modification included moving the bearing position and cutting the outer-shaft into two pieces (top-outer-shaft and bottom-outer-shaft). Only the position of entire blade, electric generator, and mechanical break system remain constant.

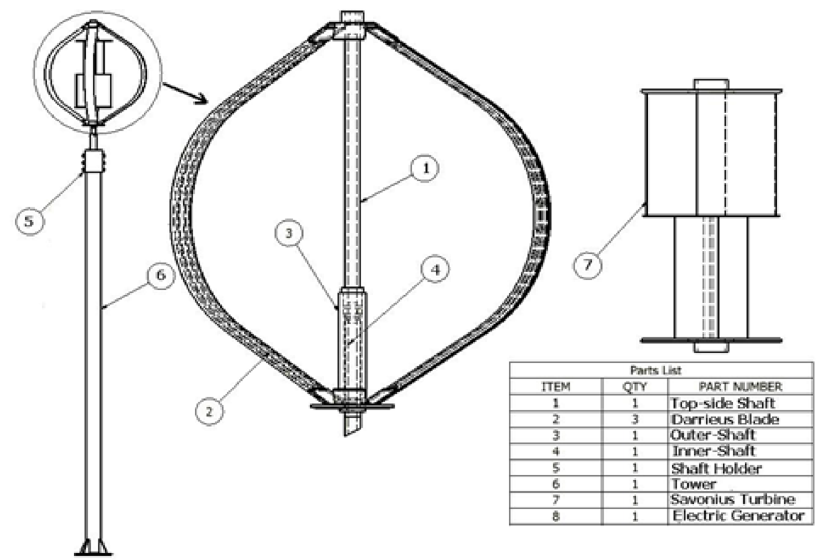

Figure-3. Layout of modification design.

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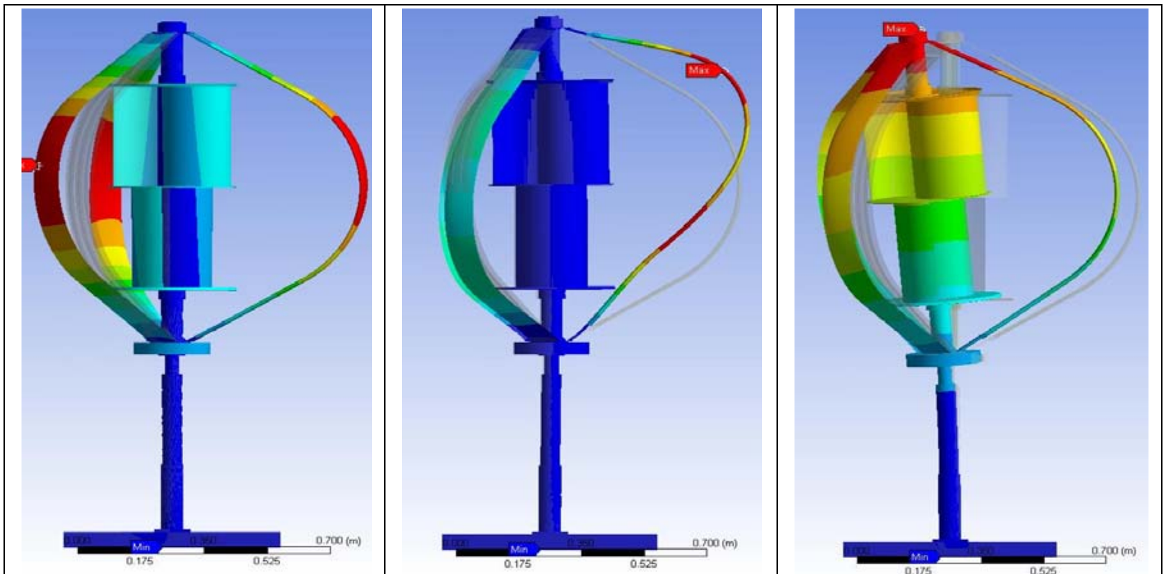

Design A	Design B	Design C

Figure-4. The system mode shape prediction.

Figure-4 showed two kinds of wind turbine mode shape: the Darrieus blades deflection and shaft system bending mode shape. Design A showed that the blade was yawning in radial direction. Design B showed that the blades nodded in up-down motion. Design C showed that the shaft was swinging in one direction.

The simulation results for different designs are shown in Table-2. Design A and B showed the strength condition of VAWT system when the inner shaft material was changed. There was an improvement of structural strength. However the improvement was not as significant as that obtained with other method. Both of them show a well strength structure. Design C showed a well strength structure especially for enduring the swing motion of the first natural frequency mode vibration. The smallest swing displacement was found when the inner shaft was reduced. Therefore design C was chosen as the optimization result.

In order to improve the sturdiness of shaft system, design C is combined with the shaft splitting method. The splitting position and bottom-side support length of the design C shaft are considered as key variables, where x is the length of original splitting position, and A is the original bottom-side support length. From Figure-5, the maximum stress of the wind turbine increases when the bottom-side support becomes longer. For a certain bottom-side support length, there exists an optimization splitting position. With longer bottom-side support and higher position of electric generator, higher first natural frequency is attained. This may happened because higher electric generator position makes the distance between electric generators to center of gravity shorter. If we assumed the electric generator as a lump mass, the nearer lump mass to the center of gravity, shaft system becomes more rigid. Therefore the natural frequencies also increased.

From Figure-5, it can be concluded that longer bottom-side support length created a more rigid system. But in contrary, the rising of natural frequencies should be avoided along the rotating speed operation condition. It implies that, to acquire the best condition, the first mode natural frequency should be as low as possible to avoid the rotation operation speed, and the maximum stress should be greater to reduce the swing motion of the wind turbine.

Table-2. The simulation results for different design.

	Material part - support (mm)	**Top-side shaft**	**1st natural frequency**	**Structural strength at 1st natural frequency**			**Overall structural strength**	
				Max stress (MPa)	**Deflection** (mm)	**Deflection at 50 MPa** (mm)	**Max load by bending force 500N**	**Deflection** (mm)
A	S400 - 130.73	560	15.16	566.54	1.13	0.0776	195.440	0.743
B	S45c - 130.73	560	15.10	544.84	1.13	0.0810	196.120	0.749
C	S400 - 130.73	460	14.84	602.11	1.15	0.0743	191.130	0.687

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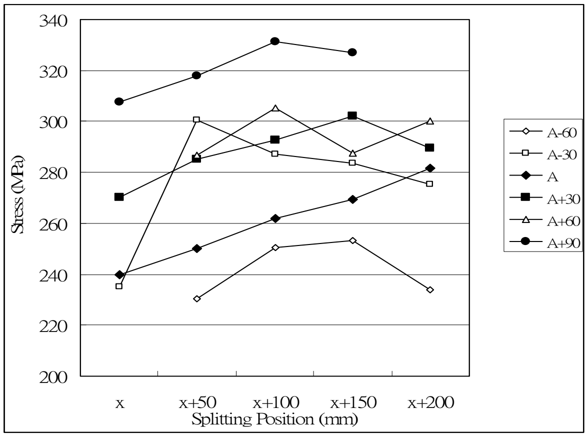

Figure-5. Stress from optimization process.

SUMMARY

Optimization of the structure design of vertical axis wind turbine type Darrieus-Savonius are studied numerically. The critical part from Darrieus-Savonius VAWT system is the inner shaft. The numerical simulations show that by shortening the inner shaft, the structure strength will improved significantly. The numerical results also indicate that changing the inner shaft material did not show great improvement.

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