GOLDEN RATIO SECTIO IN OPTIONAL DESIGN OF MODIFIED SAVONIUS VAWT

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Abstract - Vertical axis wind turbine (VAWT) is one of the main windmills for wind energy conversion, which can be further divided into lift type and drag type. The term rotor solidity is defined by product of blade number and chord length divided by the rotor diameter for Lift Type VAWT, which has been identified as a key parameter on the performance of a lift type VAWT. Computational fluid dynamics (CFD) simulation indicated that there exists a maximum power coefficient when the solidity value varies between 0.2 and 0.5 for lift type VAWT. However, the solidity has not been well defined for Drag Type VAWT till now. In this article, the solidity is defined by product of blade number and blade radius divided by the effective diameter of rotor for Modified Savonius VAWT analogically, which is a typical drag type VAWT. CFD simulation indicated that there exists a maximum power coefficient when the value of solidity stands about 0.609 for each Modified Savonius VAWT with varying blades averagely, which is a new Golden Ratio Section appeared in Optimal Design of Modified Savonius VAWT and close to the universal Golden Ratio Section number, 0.618.

Keywords: Modified Savonius VAWT; optimized parameter; solidity; golden ratio section.

1. INTRODUCTION

Exploration and application of renewable energy have been the major issue of recent years.

Vertical axis wind turbine (VAWT) is one of the main equipments for wind energy conversion, which can be further divided into lift type and drag type. The term rotor solidity is defined by product of blade number and chord length divided by the rotor diameter for **Lift Type VAWT**, which has been identified as a key parameter on the performance of a lift type VAWT. Computational fluid dynamics (CFD) simulation has now been the important tool to realize the characteristics of wind turbine [1]. The results of CFD simulation indicate that there exists a maximum power coefficient when the solidity value varies between 0.2 and 0.5 for lift type VAWT [1], and the maximum power coefficient decreases with the increases of blade number and solidity in case of keeping the rotor radius constant [1].

The modified Savonius VAWT is a typical drag type VAWT. As compared to the original Savonius – type VAWT, the significant advantage of the modified Savonius – type VAWT is to provide a sufficient "blank space" in the central part of the wind turbine, which allows wind go through the windmill steadily without the mutual shading among blades, so that the windmill could get higher energy efficiency.

Zheng et al. completed a series of numerical simulations for the modified Savonius VAWTs by using CFD method to optimize the structural parameters of multi-blade VAWTs with semi-cylindrical shaped blades and the rotor radius R of 2 meters [2-6]. The variations of dynamic performance of the VAWT and its power efficiency with respect to the structural parameters were simulated. The structural optimization was carried out by using uniform test method, orthogonal test method and exhaustive algorithm method in taking the power efficiency of wind energy as the target function. The simulation of structural optimization study was conducted for VAWTs with 3 to 10 blades [2-6].

However, the solidity has not been well defined and studied for **Drag Type VAWT** till now.

In this article, the solidity for the Modified Savonius VAWT is defined analogically, furthermore the characteristic of solidity for the Modified Savonius VAWT is excavated.

2. GOLDEN RATIO SECTION IN THE OPTIMIZED STRUCTURAL PARAMETERS OF THE MODIFIED SAVONIUS VAWT

Fig. 1 is a schematic of the modified Savonius VAWT with 4-blades. In Fig. 1, the blade is in semicircle shape [2]. Four blades are arranged at equal intervals. R is the radius of the windmill, $R = 2m$ here in the study; r is the radius of the blade, $d = 2r$; the arm length of connection from the end of the blade to the vertical axis is $R–2r$; α is the angle between the outermost edge of the blade and the support, which is called "installation angle"; $2R$-d is the effective diameter of rotor, and it is specified that the clockwise rotation is positive and the counterclockwise rotation is negative.

The optimized structural parameters from literatures for the modified Savonius VAWTs with 3 to 10 blades are cited here in Table 1 [2-6].

Analogically, the solidity is defined by product of blade number and blade radius divided by the effective diameter of rotor for Modified Savonius VAWTs, i.e., η

$= n \times r/(2R-d)$, of which the data is shown in the last column of Table 1.

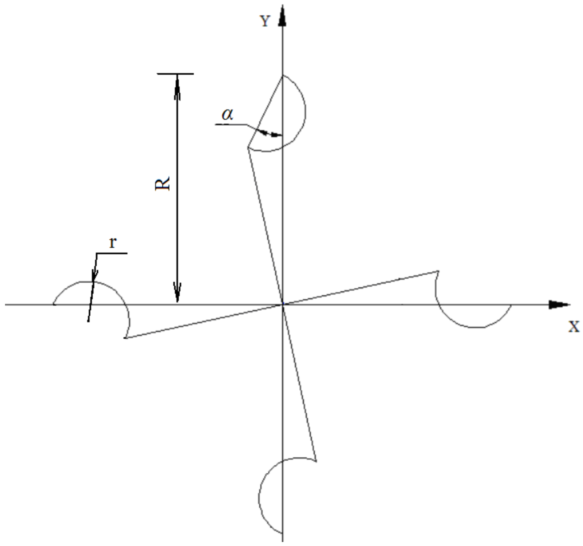

Fig. 1 - Schematics of 4-blade wind turbine

It can be seen from Table 1 that the averaged value of the solidity for the optimized structural parameters of the modified Savonius VAWTs is 0.609, which is close to the golden ratio 0.618. This is a new golden ratio section for the structural optimization parameters of the modified Savonius VAWTs with multi-blade.

In fact, the golden ratio (0.618) is a wonderful characteristic in nature. In biology and social life, it penetrates into many fields, such as natural ecological, aesthetics, astronomy, geography and economic management, etc., there exists such a magic number almost everywhere [7].

The leaves, branches or petals of many plants grow also in accord with the "golden ratio section". The ratio of two adjacent stem nodes of rice and wheat is 1:1.618 ≈ 0.618 [7].

Like thistle, plant leaves, rose petals, etc., they grow spirally around the stem. Seen from above, the 360° angle of the horizontal plane can be divided into two parts of 222.5° and 137.5°. The ratio of 137.5°° to 222.5 is 0.618, which also conforms to the "golden ratio". They continue to grow repeatedly, which stretch out along these two angles without overlapping each other, so as to ensure effective ventilation and breath-ability, and sufficient lighting as well [7].

Table 1 Optimization parameters of the modified Savonius VAWTs

Optimal method	n	d	α	η	S.D. (%)
Uniform Design Experiment	8	0.55	22.6°	0.636	4.4
	9	0.47	22.9°	0.593	2.6
	10	0.45	25.1°	0.631	3.6
Orthogonal Experiment	4	0.83	29°	0.524	13.5
	5	0.76	20°	0.587	3.6
	6	0.68	25°	0.615	1.0
Exhaustive Algorithm	3	1.32	0	0.739	21.3
	5	0.80	0	0.625	2.6
	6	0.68~ 0.70	0	0.614 ~ 0.636	0.8 ~ 4.4
Orthogonal Experiment	4	0.83	28°	0.524	14.0
	5	0.78	19°	0.606	0.5
	6	0.67	27°	0.604	0.8
Uniform Design Experiment	4	0.88	24.9°	0.566	7.0
	5	0.80	17.4°	0.628	3.1
	6	0.68	21.7°	0.616	1.1
				0.609	

In mechanics, when a simply supported beam with a span of L is subjected to an uniformly distributed load q, the bending moment at the midpoint of the simply supported beam is $0.125qL^2$ if it is constrained at both ends, and the midpoint deflection is $y_{max} = 5qL^4/(384EI)$. However, if the constraint is moved inward by $0.2L$, the simply supported beam becomes an overhanging beam, the bending moment at the midpoint of the beam is only $0.025qL^2$, and the deflection at the midpoint becomes $y_{max} = 0.3qL^4/(384EI)$ simultaneously. Thus, the bending moment and deflection at the midpoint are reduced significantly due to this moving, which results in a improvement of the strength and stiffness of the beam obviously. At this moment, the ratio of the length of the middle section to the original length is $0.6L/L = 0.6$, which is quite close to the golden ratio section *0.618* as well [8].

Zhu et al studied the gold segmentation effect for a class of vibration system of two degrees of freedom [9]. The characteristics of free vibration and the resonance mechanism of the forced vibration under harmonic loading are analyzed. It was shown that, the ratios of the structure circular frequency to the layer stiffness and mass, and that of the structural amplitudes at two points conform well to the golden section ratio [9].

Zhang et al conducted an analysis on the golden section in the tree crown. The cross section of tree crown bottom was regarded a rhomb whose diagonal lines were formed by the length (crown length) from east to west and from north to south, the cross section area of the rhomb area is calculated and remarked as Slx. Take the longer length of the rhomb as diameter of an ideal circle, the area of the ideal circle is calculated and remarked as St. The results show that the tree crowns in accord with the golden section ($0.599 \leq Slx/St \leq 0.637$) are well-balanced while those out of accord with the golden section ($Slx/St < 0.599$) are in bias crowns [10].

Dou et al applied golden ratio to the topology optimization of muzzle brake [11]. The results indicated that the optimal muzzle brake had good mechanical properties and high dynamic stiffness in terms of finite element analysis for both static strength and dynamic stiffness by using the golden section ratio in the case of smaller mass [11].

Taking into account the strength and rigidity of the beam, the aspect ratio of height to width should be between √2 and √3, which is close to the golden ratio of 1.618 [12]. According to the actual measurement of beam-type wooden members of 34 ancient buildings in my country from the 8th to the 12th centuries, wooden beams with an aspect ratio of height to width between √2:1 and √3:1 accounted for 53.7%. If these beam-like members are all intercepted by a log, it is consistent with the above analysis [12].

3. CONCLUSION

In this article, by defining the solidity as product of blade number and blade radius divided by the effective rotor diameter for Modified Savonius VAWT analogically, the effect of the solidity on the maximum power coefficient is excavated. The result of CFD simulation study indicated that there exists a maximum power coefficient when the value of solidity stands about 0.609 for each Modified Savonius VAWT with varying blades averagely, which is a new Golden Ratio Section appeared in Optimal Design of Modified Savonius VAWT and close to the universal Golden Ratio Section number, 0.618.

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