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A REVIEW STUDY ON MAGNUS WIND TURBINE FOR ACCESSING THE AERODYNAMIC PERFORMANCE

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ABSTRACT

Wind energy became an increasingly important and widespread renewable energy source in the last decades, while it is significant technical development has led to a wide variety with more effectiveness. Magnus wind turbine (MWT) represents one of main application of horizontal wind turbines that are viable in low wind speed regimes and also suitable for the urban areas. Numerous numerical and experimental investigations have been performed to analyse and improve the design and performance of MWT, However, most of these studies revolved around aerodynamic performance of magnus turbine. This paper reviews the application of Magnus effect devices and concepts especially in wind energy that have been investigated by various researchers and concludes with discussions on future challenges in their application.

KEYWORDS: Renewable energy, Magnus wind turbine (MWT), Aerodynamic performance, Design parameter.

1. Wind Turbines

According to an open review on historic of wind energy, the first device used to convert the kinetic energy of the moving air particles into mechanical energy and ultimately into an electrical energy via an electrical generator was in 1887, when Scottish academic James Blyth invented new configuration for electricity production to charge battery for lighting in his holiday house (Shen, 2012). Figure1.1 shows photograph of wind turbine used to produce of direct current by Paul La Cour et la in 1891. Various types of wind turbines have been developed from single bladed to multi bladed, upwind and downwind type, vertical axis, and horizontal axis type wind turbines (Divya & Joseph, 2014).

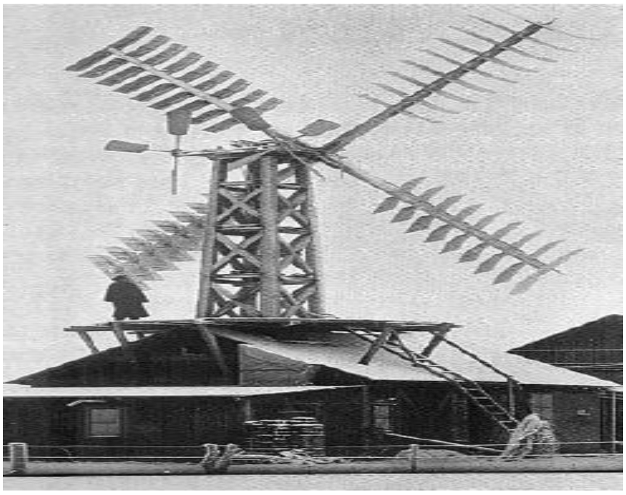


Fig 1.1: Wind turbine for the production of direct current by Paul LaCour et la, 1891(Gasch, 2012).

(a) Savonius type wind turbine *(b) Darrieus type wind turbine*

Fig. 1.2: Vertical axis wind turbine (Van Bussel, G.J.W., Mertens, S., Polinder, H., & Sidler, 2004).

(a) Commercial wind turbine ***(b) Small domestic scale wind turbine***

Fig 1.3: Horizontal axis wind turbine, (Wood,2011).

Horizontal axis wind turbines (HAWT) are the most common type of wind turbine employed commercially and domestically. HAWT are widely used and have the advantage Highly efficient in terms of extracted energy, quality of use, and Cost effective (ELFARRA, 2011).

Airfoils represents the most common cross section of wind turbine blades. However, the features of rotating cylinder aerodynamic characteristics that highlighted by magnus phenomena encouraging and leading to replace airfoil cross section with circular section providing an added tool or type to further develop. Horizontal axis magus wind turbine could be considered the most related prominent application (M. Ragheb, 2010).

2. Magnus Phenomena

Humans have been coping with natural phenomena since long time ago, where it has been representing the source of inspiration and design for many engineering applications. Magnus phenomena represents one of most scientific discoveries that revealed generation of lift force by a rotating object placed in fluid flow. In more details, Magnus as a word has resonated since the early mid-nineteenth century. Attributed to German professor Gustav Magnus in reference to a scientific phenomenon was discovered by him. He conducted his prominent experiment in 1852. His new configuration consisted of a brass cylinder held between two conical bearings to which he could convey high rotational rates by means of a string. He mounted the cylinder upon a freely rotatable arm and directed a current of air from a blower to ward sit, that clearly showed in Figure2.1. A strong lateral deviation due to spindle motion of the cylinders was observed. The spinning cylinders always tended to deflect toward the side of the rotor that was traveling in the same direction as the airflow coming from the blower. The magnitude of the deflecting forces was not measured by Magnus at that period (Seifert, 2012). From now on, the physical mentioned phenomenon was called Magnus effect.

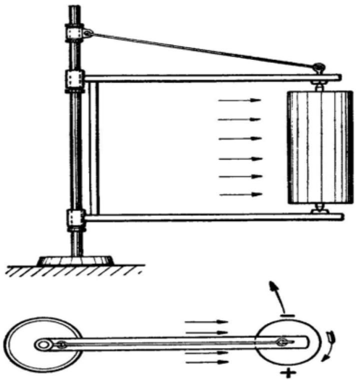


Figure 2.1: Experimental setup of Gustav Magnus (″Gustav Magnus", 1852).

In the year 1877 Lord John Rayleigh prepared an article on the irregular flight of tennis balls(Seifert, 2012). He had sought to clarify the curved path of a ball scientifically in terms of the Magnus effect by determining the Magnus force from the pressure distribution of a rotating object. At that time, he also stated that it was not possible to give a complete mathematical formulation which could define this physical fact.

2.1 Engineering Applications of Magnus Phenomena

As reported in open literatures, the engineering applications of magnus phenomena can be classified in terms of areas of use into three fields namely naval, aeronautical and wind energy.

2.1.1 Application of the Magnus Phenomenon in Naval

Naval engineering was distinguished by the first application of the phenomena through.

a successful configuration based on Magnus effect that was patented during the 1920s (Divya & Joseph, 2014; Marco, Mancini, Pensa, Calise, & Luca, 2016), when Anton Flettner has manufactured the first ship operating with Magnus force using two large cylinders to propel his ship that displayed in Figure 2.2. The Magnus Flettner rotors allow a sailing boat to turn about its own axis, apply brakes and go directly into reverse. The first vessel named Buckau, then renamed Baden-baden crossed the Atlantic in 1926. After the Atlantic crossing, Flettner orders for six more ships. He built one named Barbara, while the rest had cancelled as a result of the great depression during 1930s. Flettner used cylinders made of steel and, later aluminium. Today much lighter ones could be manufactured from Kevlar or carbon-reinforced epoxy materials.

Figure 2.2: Magnus Flettner rotor (Axis & Turbines, 2014).

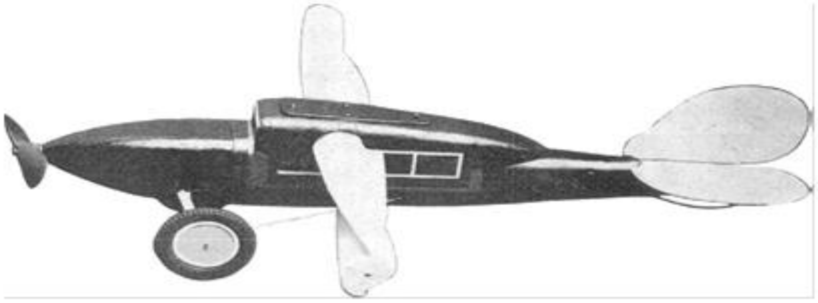
Since that success by Flettner, the potential of producing high lift forces by rotating objects in comparison with low lift force values of airfoil type configurations have attracted many researchers in different fields of Engineering. Many patents on Magnus effect were published in the areas of aerospace or naval engineering applications. Also, many researches have been focused on the generation of aerodynamic forces from the spinning cylinders. But, very few Magnus configurations were operated successfully. On the other hand, it should be noted that there was no clarity about the vibrations and their impact, while there was pointed on the possibility of obtaining accurate data through subsequent tests.

Recently, the Flettner type rotor is becoming again a hot topic in naval engineering because of the fuel costs and growing risks from global warming that has been leads to rise of problems with climate change(Nuttall & Kaitu, 2016). In the comprehensive review of the Magnus effect by (GROUP & SYSTEMS, 1986; Seifert, 2012), they had indicated them believe that ″ there are no specific methods available on how to design the lifting device of a rotor aeroplane or the rotor aeroplane airframe. This is particularly true on applications reported especially on Magnus type wind turbines.

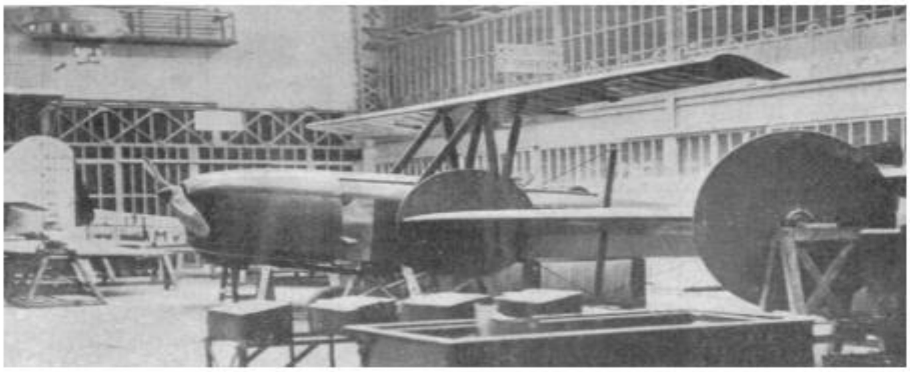
2.1.2 Application of the Magnus Phenomenon in Aeronautical

Generally, in aeronautics engineering field, the rotating cylinders were designed to produce high lift to drag ratio. The implemented applications in this field have been varied to rotor airplanes, autogyro of chappedelaine and test aircraft NASAYOV-10. Figure 2.3 presents a photograph of each mentioned applications (Seifert, 2012).

The main parts of the rotor airplane were a fuselage, a front propeller, a back tail and modified wing, where the modified part could summarize in installing of a modelled Magnus rotor instead of a fixed wing.



Rotor. Courtesy of Deutsches Museum Archive.



Autogyro of Chappedelaine. Courtesy of Deutsches Museum Archive

Modified YOV-10A prototype with an integrated rotating cylinder flap, registered N718NA. Courtesy of NASA

Figure 2.3: Photographs on some of applications of the Magnus phenomenon in aeronautical.

The merit of such an arrangement could be the safety in case of engine failure, where the generation of lift force continues in presence of rotary wing. Despite the encouragement raised after the first presentation of Buckau to the public in 1924 Flettner's rotor ship, researchers were commonly thought that drag, weight and vibrations would prevent the use of the Magnus effect.

2.1.3 Application of the Magnus Phenomenon in Wind energy

Magnus wind turbine has been embodying the application of the phenomenon in wind energy field, in which the rotating cylinders have been employing to generate the magnus force that lead to produce the torque and then producing the mechanical power.

Most of implemented research studies on MWT have been focused on the performance verification and improvement, by dealing with independent performance parameters such as number of blades, end plate of rotating cylinders(Aneesh, Stanly, S, Suneesh, & D, 2016; N.M. Bychkov, A.V. Dovgal & Khristianovich, 2008), the rotor diameter or wind turbine size (N M Bychkov, 2007)(N.M. Bychkov et la, 2007) and the roughness of cylinder's surface (Bai, Liu, Zhang, & Zou, 2014; Energy & Huang, 2015; Faruqi et al., 2018; O F Marzuki, Rafie, Romli, & Ahmad, 2015a; Omar Faruqi bin Marzuki, 2017). There have also been performed studies dealing with some of dependent performance parameters such as the aspect ratio(GROUP & SYSTEMS, 1986; N M Bychkov, 2007; Sedaghat, 2014) , the rotor's tip speed ratio and tip speed ratio of spindle cylinders (Energy, 2011; Mara et al., 2016; Mara, Mercado, Mercado, Pascual, & Stephen, 2014; Massaguer, Massaguer, Pujol, Comamala, & Velayos, 2014).

In addition, some previous investigations have focused their attention on the produced mechanical power and verified the effectiveness of turbine performance (Corrêa, L.C. et la, 2013; Maro Jinbo et la, 2015; Toni Pujol et la 2017), as well as research studies also were carried out on the torque Performance of MWT (O F Marzuki, Rafie, Romli, & Ahmad, 2015b).

Despite the above mentioned expansion in research, however, through the open literature review ; previous investigations deals with MWT has lacked studies that specialized on the effect of free-end status of spindle cylinders on rotor performance and risk of vibrations on the performance of MWT except the O. Marzuki's indication in his PhD thesis (Omar Faruqi bin Marzuki, 2017) as well also (Yuanzhe Li et la ,2017) was indicated to the effect of free-end blades status on the wind turbine performance, as well as the expected risks in impact of arising vibrations.

Due to the importance of the performance parameters of wind turbine in evaluating of its effectiveness, these criteria have been opted to present as shown in the following section.

3. Design Parameter of Magnus Wind Turbine

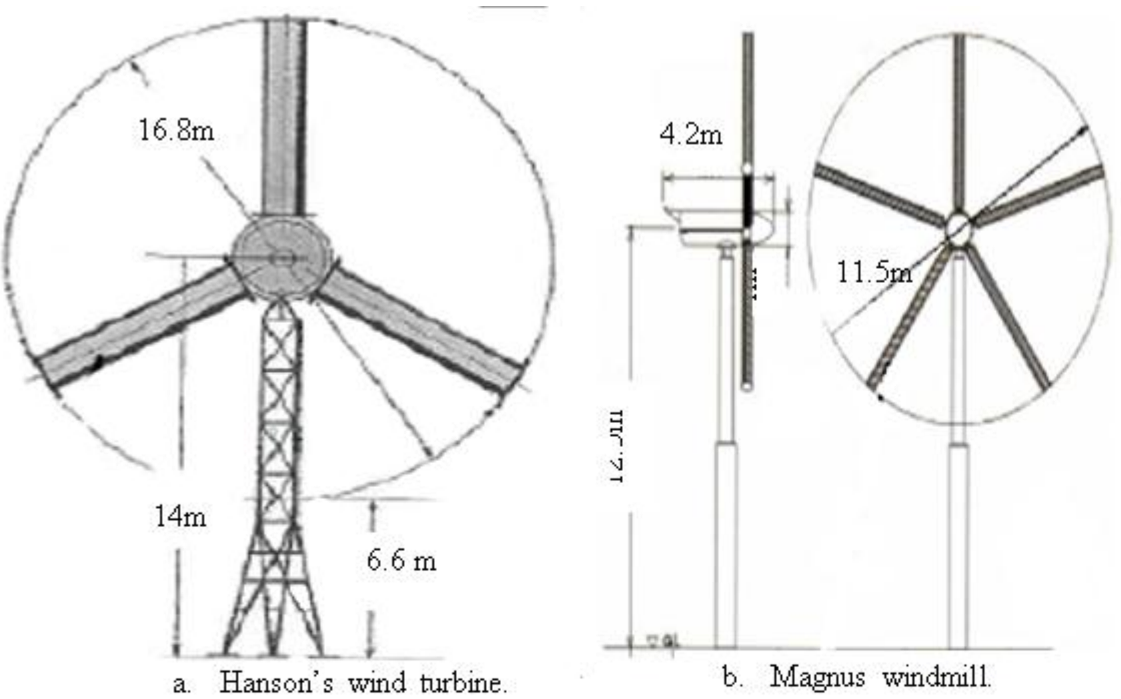
In order to design an efficient Magnus wind turbine, the study choses to organize presenting design parameters in the manner consistent whit its direct impact on the performance as following.

3.1 Design Parameter of Magnus Rotor

According to the considerations and conclusions of numerous previous studies, ones of major wind turbine design parameters that has directly related to its wheel or rotor were as:

3.1.1 Wind Turbine Size

It considers as one of the significant parameters that defines the capacity or size of wind turbine to achieve the request and more suitable to surrounding area. Mainly wind turbine sizing depends on the amount of power required, through which it classified to small, medium. and large wind turbines, where small wind turbine could was classified depending on range of produced power of ″P ≤ 20kw‶ (Prepared, Energy, Agency, Agreement, & October, 2017). The small wind turbines are the predominate wind energy extracting configurations in rural, suburban or even in the populated city areas, where large scale wind turbines could not be preferred due to space constraints and resulting noise. Moreover, low cost and ease of installation of small size wind turbines compared to large ones encourages to expand their use of. Outer diameter of magnus rotor which defines wind turbine size was mentioned in previous study performed by Radomír Goňo and his colleagues, when they performed experimental tests on a windmill of three Barrel-blades with rotary diameter of 16.8m ″ Hanson’s wind turbine‶, besides that, they also carried out experimental tests on MWT with rotor diameter of 11.5m. More recent, Bychkov et la. (2007), they performed tests on models of magnus rotor of diameter ranged from 1.3 to 2.0m. Figure 3.1 shows multiple sizes of magnus rotor.



a. Hanson's wind turbine. b. Magnus windmill.

Figure 3.1: Multiple sizes of magnus rotor.

In any case, risks of free end rotating cylinders of magnus wheel increases with increasing of rotor's diameter or size due to increase of spanwise of cylinders with other rotor's components.

3.1.2 Solidity Factor

Another prim parameter that affect the performance of MWT is the solidity factor (σ_{SF}) and is defined as the ratio of total area of the rotor to the swept area of the contents that includes the rotating cylinders and rotor's hub.

3.1.3 Rotor Tip Speed Ratio (λ_1)

This important parameter for wind turbine design is defined as the ratio of the blade tip speed over wind speed.

$\lambda_1 = (\Omega_1 * R)/ U_\infty$

Where: Ω is the angular velocity of the wind turbine rotor, R is radius of the rotor and U_∞ is the wind speed. A higher tip speed ratio generally indicates a higher efficiency but is also related to higher noise levels. Generally, the value of λ_1 could be chosen through region of wind speed, where it was selected to changing from 1 to 4 for low speed wind turbines, and from 5 to 9 for high speed ones (Han Cao,2011).

3.1.4 Number of Spindle Cylinders (B)

The number of spindle cylinders for MWT is an effective parameter depending on the operating conditions. five- cylinders wind turbines have shown a better performance over their six- cylinders counterparts. However, six- cylinders have a higher starting torque as compared to five- blade turbines.

3.1.5 Cut-in and Cut-out Wind Speeds

A further important design aspect is the correlation between turbine's rotor and its speed limitations. For each wind turbine, the cut-in and cut-out wind speeds require proper design attention. The cut-in speed is defined as the lowest wind speed at which the wind turbine produces useful power (Aslam Bhutta, M.M., Hayat, N., Farooq, A.U., Ali, Z., Jamil, Sh.R., Hussain, 2012). This speed is the first point at which the total torque of the rotor within a complete revolution is greater than zero. For a reliable design, the cut-in speed should be significantly lower than the site's average wind speed (Paraschivoiu, 2002). Furthermore, the rotor should be able to produce enough starting torque at the cut-in wind speed to overcome the inertia of the entire configuration (Hara, Y., Hara, K., 2012).

The cut-out speed is defined as the highest wind speed at which the turbine is allowed to extract power(Aslam Bhutta, M.M., Hayat, N., Farooq, A.U., Ali, Z., Jamil, Sh.R., Hussain, 2012) . The components of a turbine are not designed to withstand sustained loads above this speed. Thus, the cut-out speed needs to be sufficiently higher than the average wind speed. For that, the cut-out speed of 25 m/s is chosen in numerous research studies as this speed is considered as a stormy weather conditions(Aslam Bhutta, M.M., Hayat, N., Farooq, A.U., Ali, Z., Jamil, Sh.R., Hussain, 2012; Hau, 2013; Paraschivoiu, 2002). Moreover, according to safety constraints, wind turbine control system should shut down the rotor at cut-out speed, where yawing the rotor out of the wind or changing the pitch of the blades are the most prominent methods used to stop a typical HAWT.

3.2 Design Parameters of rotating cylinder

These parameters could be classified as more deeper ones for their direct association with the aerodynamic surfaces of magnus wind turbine. Where the design parameters of rotating cylinder are as follows

3.2.1 Speed Ratio

This significant parameter is derived through dividing cylinder's circumferential speed by free stream velocity. Swanson has demonstrated in his survey on Magnus Effect that an increase Ω_{cy} would lead to increase C_L. On other hand, he was indicated to that, at high rotation rates, very high lift coefficient can be produced via the Magnus effect. However, the amount of requested power for rotating the cylinder increases rapidly with rotation rate. Conceptual design study with extensive experimental tests have been performed recently by C. Badalamenti (Badalamenti & Prince, 2008), he has demonstrated that increasing of Ω_{cy} leads to a rapid increase in $C_{L.}$ Figure 3.2 shows how the lift force generated by a spinning cylinder rises with increasing its tip speed ratio.

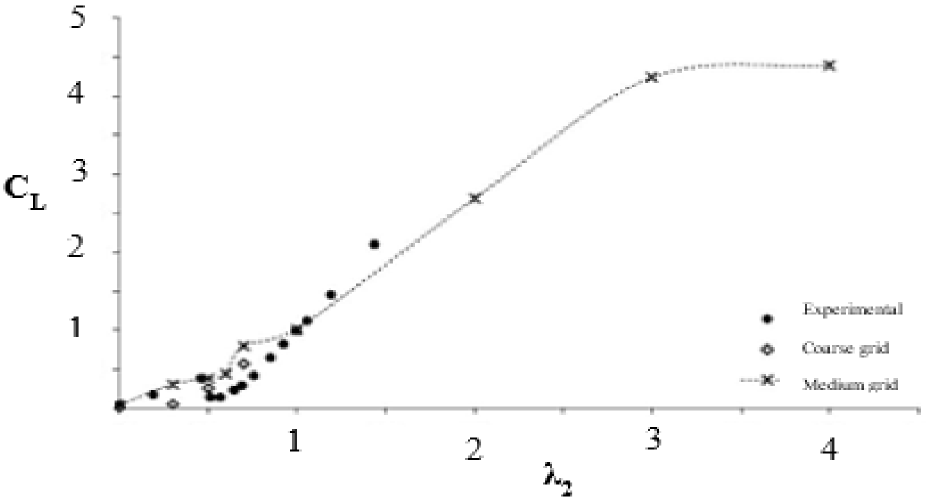


Figure 3.2: The effect of tip speed ratio of a circular cylinder on the amount of lift generated on spinning cylinder using of different methods.

Moreover, A lot of researchers have been performing analytic studies on the viscous flow past a rotating cylinder that demonstrated the effectiveness of the rotation rate's choosing in improve the aerodynamic performance(Cheng, Chew, & L, 1994; DIMOTAKIS, 1993; Omar Faruqi bin Marzuki, 2017).

3.2.2 Reynold Number

Is defined as the ratio of inertial force to viscous forces within a fluid. Where this dimensionless quantity. Many previous experimental and numerical studies have used this parameter in their analyses, which have contributed to the continuation of the research and its success. There were research studies performed at the case of laminar flow such as(Luo, Fan, Li, & Cen, 2009; Panda & Chhabra, 2010) , as well some research studies were undertaken at the case of transient flow such as. Besides that (Mgaidi et al., 2018), A lot of studies were carried out at case of turbulent flow such as (Johnson, 2011; Karabelas, Koumroglou, Argyropoulos, & Markatos, 2012; Nair & Chauhan, 1998; Rawat, Gupta, & Sarviya, 2013).

3.2.3 Aspect Ratio

Spanwise or aspect ratio of the cylinder is derived as a non-dimensional parameter through dividing the height of the cylinder (H) by its diameter(d).

Dependency of generating lift force on aspect ratio for spinning cylinder immersed in airflow was revealed by Swanson(Gowree & Prince, 2012). Later, more interest was taken by researchers to study the effect of AR on C_L, where Badalamenti and Prince demonstrated the recently experimental research study on the dependency of C_L on λ(Prince, 2008). Figure 2.11 shows how the lift force generated by a spinning cylinder rises with increasing its aspect ratio, Furthermore As can be seen in Figure 3.3, the lift coefficient have almost the same amount for $5.1 \leq AR \leq 30$ at $\Omega_2 \leq 2.5$.

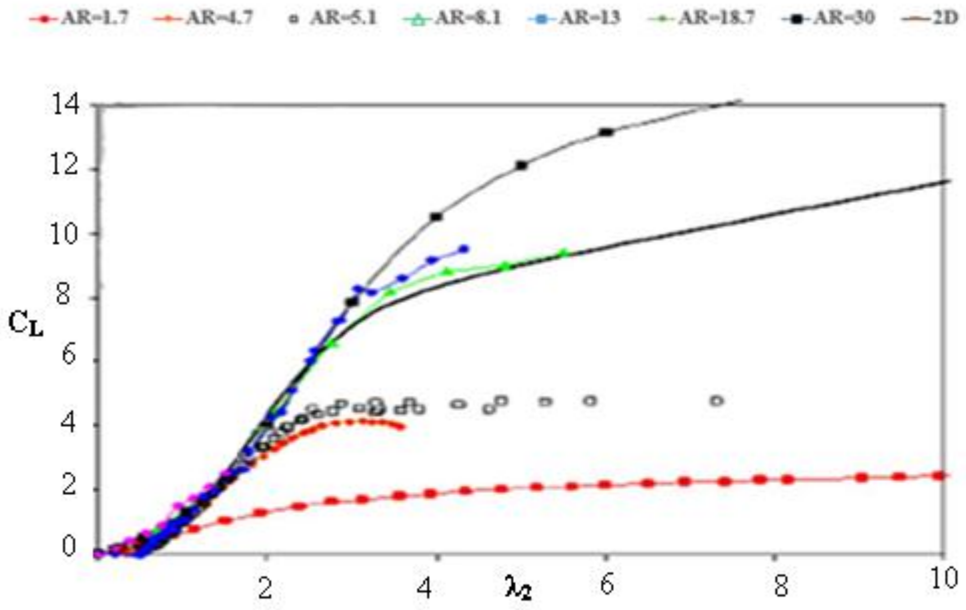


Figure 3.3: The effect of λ on the amount of lift generated on spinning cylinder.

As can be seen in Figure 3.3, the lift coefficient has almost the same amount for $5.1 \leq AR \leq 30$ at $\lambda_2 \leq 2.5$.

3.2.4 Surface roughness

In general, surface roughness affects the boundary layer flow. Merits and demerits s of applying a rough surface to a cylinder could be briefly summarized through researching on the purpose of dimples on the surface of golf ball (GROUP & SYSTEMS, 1986; Seifert, 2012). The effect of the dimples of a golf ball is to delay separation of the boundary layer by inducing transition to turbulent flow, it leads to decrease the drag coefficient for around four times (Hoffman J, 2007; Seifert, 2012). Furthermore, a lone rotating cylinder has been affected slightly on the lift and drag coefficients in effect of its roughness, while it produces a torque higher than smooth one.

The effect of surface roughness on the lift and drag coefficients of a lone rotating cylinder is very small, but the air torque is approximately doubled for the sanded surface.

An extensive experimental study on the of the effect of surface roughness on aerodynamic performance of spindle cylinders have been performed recently by O. Marzuki (Faruqi et al., 2018; O F Marzuki et al., 2015a; Omar Faruqi bin Marzuki, 2017) , he has demonstrated that the sanded surface roughness produces five times higher torque in comparison with smooth surface cylinder. Figure 3.4 shows one of the most prominent previous application on MWT with rough Surface of its circular cylinder.

Figure 3.4: Circular cylinders with rough Surface (″MWT‶, 2010).

3.2.5 End Plates

Another important parameter influencing the flow around the spinning cylinder is the shape of its ends. End plates is a simple part with a negligible thickness and installed as a cap on the end of the rotating cylinder. Figure 3.5 shows a circular cylinder with endplates.

Tom was one of the first interested in studying the impact of this parameter, when he carried out an experimental study on the effect of square and rounded ends on the flow around the rotating cylinder with a diameter and a height of 0.08m and 0. 350 m respectively. In his findings he was indicated to that the lift and drag slope decreases likewise for a cylinder with rounded ends above a speed ratio closed to 2. Also, he performed a study on the effect of large end plate, Thom concluded that through the addition, an increase in the amount of C_L to nearly doubled at ($\Omega_{cy} > 2$). Later, Busemann (A., 1932; Seifert, 2012) performed study on two cylinders of aspect ratio of 1.7 and 12 to investigate the effect of installing endplates with a diameter ratio ranging from 1.5 to 3. He indicated to that installation of end plates leads to varying increase in with changing of and diameter ratio of end plate, where the increase in C_L was slight at $\Omega_{cy} < 2$, and was more at $2 < \Omega_{cy} < 4$, and was turned to linear increase at $\Omega_{cy} \geq 4$. More recent study was undertaken by Badalamenti (C, 2008) for a cylinder with aspect ratio A=5.1 and diameter ratios ranging of ($1 \leq de/d \leq 3$), his finding was in agreement with previous results with regard to the effective contribution of end plate installing on the amount of C_L.

Figure 3.5: Circular cylinder with endplates.

In Consistent with the pursuit to harness the magnus rotor in better performance, it is therefore more appropriate to present the rotor aerodynamic and parameters affecting the characteristics.

3. Aerodynamic performance of magnus wind turbine

The aerodynamic behaviour of magnus wind turbine determines the flow field around its wheel, and thus it is closely related with the overall turbine performance. A good evaluation of the rotor aerodynamics is needed to efficiently predict the interaction of the aerodynamic forces with the elastic structure of the rotor cylinders and ensure their structural integrity.

4.1 Lift force on spindle cylinder

It represents the major source of generated torque that leads to rotate the rotor and so produced the power. So that, the study is compelled to take some importance to this parameter and its methods of determination. Kutta-Joukowski Theorem embodied the most famous theory used to describe and determine the lift force generated on spindle cylinder immersed in fluid flow. Figure3.6 shows a rotating cylinder immersed in fluid flow.

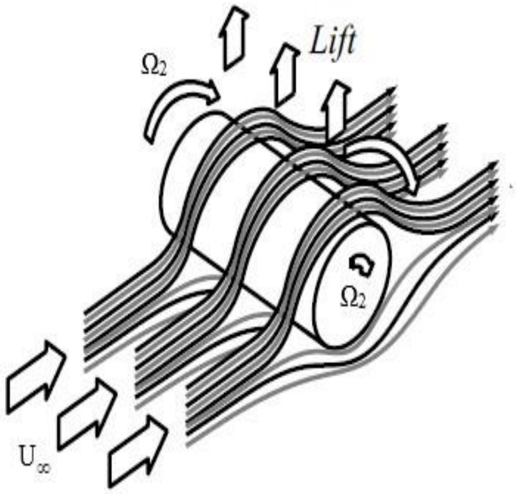


Figure 3.6: Lift force on a rotating cylinder immersed in fluid flow.

The scientists concluded through their research that, the amount of lifting force per unit length, which generated on the surface of a rotating cylinder in effect of an air flow is equal to the product of the velocity, the density of the fluid, and the strength of the vortex that is established by the rotation. Kutta -Joukowski reached a relationship that defined the lift achieved by airflow around a spinning cylinder(And & Carpenter, 2003). It was as following:

$$l = \rho \, U_\infty \, \Gamma \qquad (2.1)$$

And

$$\Gamma = 2\pi \, \Omega_2 \, r^3 \qquad (2.2)$$

Where

l: The lift on the cylinder per unit length, **ρ**: density of the fluid, U_∞: Velocity of the flow, Γ: The strength of the vortex that is established by the rotation, ω: the angular velocity of spin of the cylinder, and r: radius of cylinder.

4.2 Aerodynamics of the magnus rotor

Figure3.7 shows the major components that represents the main source of the generated force and produced torque for magnus rotor.

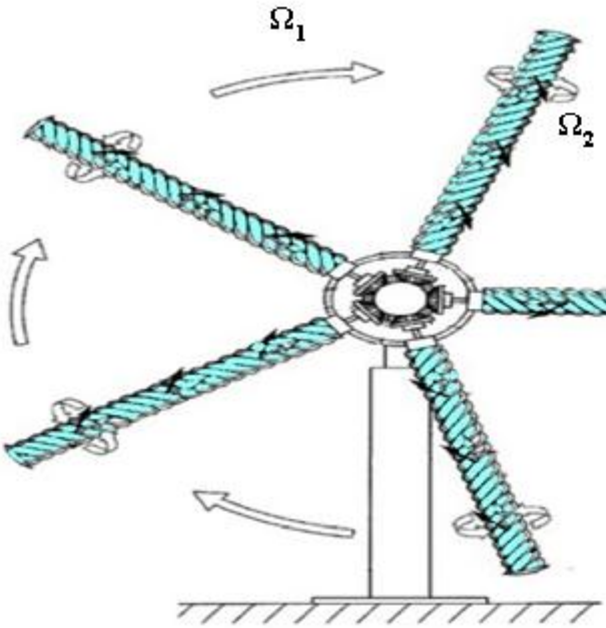


Figure 3.7: Generated Lift force and rotating rate of speeds on a rotating cylinder (Sedaghat, 2014).

The produced torque force can be determined from the generated lift force on the rotating cylinders. Where the torque, Q is product of lift force, L and the perpendicular distance from rotor's centre to the acting point of the force.

Furthermore, the power can be calculated from the produced torque and rotating rate of the rotor (Letcher, 2016), where:

$$P = Q^* \Omega_1 \qquad (2.3)$$

4. A brief Review on Magnus Wind Turbine

As reported in open literatures, the first actual Magnus wind turbine was constructed in the USA, 1984. It was similar to of traditional blade wind turbines except of installing of cylindrical blades instead of traditional ones, where it was consisting of 3 cylindrical blades with aspect ratio of λ = 6 (N M Bychkov, 2007). Available research studies have indicated significant research effort has been made into study the over a wide range of Aspect ratio up to λ = 40 on aerodynamic performance of spinning cylinders, that was performed by a team work in the Institute of Theoretical and Applied Mechanics SB RAS. (N M Bychkov et la, 2007). Thereafter, aerodynamic performance of MWT with the aspect ratio of $3.5 \leq \lambda \leq 10.7$, $\lambda = 11.5$ and 14 were examined in details. As a result, it was demonstrated that the performance of WT improved with growth of λ and the number of cylindrical blades. Also, it was found that the maximum power coefficient of the MWT can be achieved starting from $U_\infty = 1$ to 2 m/s instead of U_∞ close to 8 m/s for the blade turbines, which leads to increase daily operating rates of the wind turbine and then the power generation.

N.M. Bychkov with his colleagues (2008) has performed an experimental methodology on optimising a wind turbine equipped with spinning cylinders instead of traditional blades. He demonstrated that the optimal Magnus wind turbine should consist of 6 cylinders with $\mathbf{\Omega_2}$ of 8000 rpm and λ of 15. He believes his Magnus wind turbines can compete with the conventional wind turbines at low wind speeds below 8 m/s. His findings indicate that the Magnus wind turbine can operate at as low as 1-2 m/s cut-in wind speeds. Figure 3.8 displays graphic description of Magnus wind turbine with 6 rotating circular cylinders.

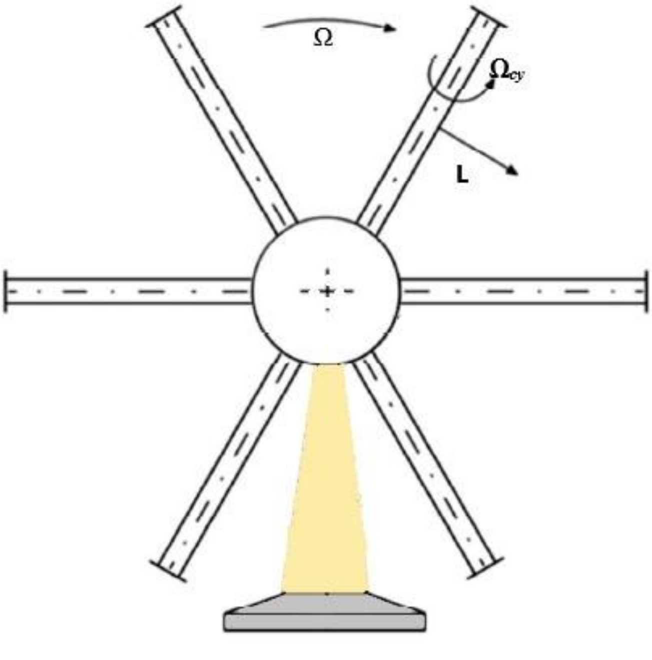


Figure 3.8: Horizontal axis Magnus wind turbine with 6 rotating circular cylinders.

Giudice F and La Rosa (2009) have designed and prototyped a chiral blade configuration of Magnus type for hydroelectric microgeneration. Their performed practical testing of low velocity flow is combined with some simple analytical approach based on the ideal potential flow solution for two-dimensional spinning cylinders. In their findings, they have indicated to the great potential of the chiral device with regard to both wind and hydro power production particularly for the low head water flow conditions such as rivers without dams, tidal streams and ocean currents (Giudice F, 2009).

Then and later in 2010, Murakami discovered new patent for a new design of MWT, he indicated that his new configuration could operate with 5 rotating cylinders and generates electrical power at cut-in wind speeds of above 4 m/s and at the rated wind speeds of 8 m/s which generates the net rated power of 3 kW (Murakami N, 2010).

Figure 3.9: Magnus wind turbine operates with 5 rotating cylinders ("MWT-MURAKAMI," 2010).

More recently, A. Sedaghat (2014) indicated in his work on progress in magnus type to Murakami patent, which is summarized in a Magnus wind turbine with 6 and 5 wavy cylinders through implementing some of spiral ribs around the cylindrical blades. The wind turbine has been produced by Mecaro Co. in Japan. Figure 3.9 shows MWT of 5 rotating circular cylinders with spiral ribs (Sedaghat, 2014).

On the other hand, as noted above, some previous studies focused directly on the power efficiency. Corrêa, L.C. et la. (2013) demonstrated through his numerical study on MWT performance for reaching the maximum power point to that controlling the rotation speed of the cylindrical blades is an essential asset for MWT. Besides that, another subsequent numerical study was performed by Maro Jinbo et la (2015), that was concerned with the generation of maximum mechanical power through determining the appropriate cylinders rotating rate at three different wind speed. The most benefit was their determined correctly wind speed steps passing delimited range from 3.0 m/s to 7.5 m/s and from 7.5 m/s to 5.5 m/s in order to improve the efficiency of produced mechanical power. Furthermore, Toni Pujol et la (2017) carried out numerical study on net power coefficient of wind turbines, he verified experimental results on MWT; moreover, he expanded his investigation by determining the performance of MWT at specific operating condition.

Although the Magnus wind turbine has many advantages over conventional blade-type wind turbines, and as any wind turbine, it could be developed towards the better performance through improving utilization efficiency, where the maximum value of power coefficient of 0.592 represents the optimal theoretical non-reached value that defines Betz threshold(Kullmann, 2015). Therefore, it is important to introduce effective amendments of improving the Magnus rotor performance in order to promote its application. As the free end rotating cylinders are the main tool for generating lift and then producing torque in MWT, each cylinder exhibit alternating vortex shedding causing large fluctuating pressure force that influencing the Magnus wind turbine performance and could lead to vibration or even structural failure (Bourguet & Jacono, 2014; Mathematics, 1996). Besides that, oscillation of lift force on free end cylinders at low wind speed leads to reduce the performance and could consider as a cause of collapse.

Yuanzhe Li et la (2017) performed one of more recent numerical study that drew attention on demerits of free vibration in terms of free end status, where the vibration may lead to damage the internal structure of the object. Moreover, He was also encouraged others to develop in future research when he indicated on that the risk of vibrations cannot be vanished but, in some case; it can be reduced. Also with more importance, O. Maruki (2017) was indicated to the impact of vibration on free end rotating cylinders of MWT when he mentioned on that the rotating cylinders rate of his model can only rotates up to 1000 rpm in impact of observed vibration growth on the spinning cylinders.

5. Conclusion and Future Work

Based on the previous studies that have been displayed through achieved open literature review on MWT which could summarized in continuous research work to design the configuration, verify the results and improve performance. Numerous theoretical and practical studies were performed on MWT included distinguished patents, experimental results that contribute to the implementation of subsequent studies, in addition to numerical studies that keep pace with software developments. This review attempts to create a window of opportunity to help researchers' and practitioners' efforts and also to meet their requirements for easy access to sustainable tourism publications. While the previous studies have been investigated the impact of MWT design parameters on its effectiveness and performance, a few of available researches have been indicated to the effect of free-end spinning cylinder on MWT performance. Where free end status of each rotating cylinder exhibits alternating vortex shedding causing large fluctuating pressure force that can lead to vibration or even structural failure. Besides that, the vibration amplitude of free end rotating cylinders has exhibited the bell shape, that indicates to the losses in consumed power and leads to reduce the efficiency. Perhaps one of the most prominent proposals that lead to overcome the effects and risks of mentioned problem could be summarized in adding of a supportive outer ring surrounded the magnus wheel.

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