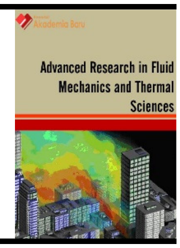
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Effect of the Blade Curvature Angle to Power Generation on the Drag Type Horizontal Axis Water Turbine

Open Access

Muh Alwan Rosyidi[1], Arif Hidayat Purwono[2], Dominicus Danardono Dwi Prija Tjahjana[1], Eko Prasetya Budiana[1], Syamsul Hadi[1,*]

[1] Department of Mechanical Engineering, Universitas Sebelas Maret Jl. Ir. Sutami 36 A, Surakarta, Central Java, Indonesia
[2] Department of Mechanical Engineering, Akademi Teknologi Warga Surakarta Jl. Raya Solo-Baki Km.2, Sukoharjo, Central Java, Indonesia

ARTICLE INFO

Article history:
Received 15 March 2018
Received in revised form 15 May 2018
Accepted 21 July 2018
Available online 10 September 2018

Keywords:
Water turbine, drag type, blade angle, development

ABSTRACT

The water flow in sewage pipes found in high-rise buildings has the potential of creating a pico-scale power generator. However, low head and debit rate condition should be taken as a consideration in turbine design choice. The design of turbine blade is an important factor in improving the turbine's performance. In this research, drag-type turbine designs with various blade curvature angles of 100, 110, 120, 130, and 140 degrees were studied to understand the performances. The specimens were manufactured by the 3D printer. The turbines were installed with the head of 2 m on a pipe with the diameter of 82 mm. The performance of the turbines was analyzed based on power output, power coefficient, and tip speed ratio. The result shows that drag-type horizontal axis water turbine with the blade curvature angle of 140 degrees performed best by generating 7.4 Watt of power. The power coefficient generated was 0.07 at the Tip Speed Ratio of 0.76.

1. Introduction

Potential of water as renewable energy resource is spread in almost every place in Indonesia and is estimated to reach 75 GW; while only 2.5 % of it is used. The high average rainfall on Western Indonesia region, such as Sumatra, Java, Kalimantan and South Sulawesi (except North Sumatra) [1], and an on-going trend in high-rise building development in Indonesia create a good potential in developing pico or nano hydro water turbines. Pico hydro turbine is a type of hydroelectric power generator, capable of producing power less than 5 kW. Many countries prefer pico hydro power plant because of lower manufacturing cost, lower head requirement, and smaller debit comparing to other hydroelectric power station. Low head pico hydro turbines were also researched in Nepal, where 13 types of water turbine were investigated to find the best performance of the turbine [2]. Furthermore, the reaction turbine at a very low head in Australia was installed and studied [3]. Other research using the pump as turbine (PAT) as an alternative to pico hydro power station was used to

* *Corresponding author.*
E-mail address: syamsulhadi@ft.uns.ac.id (Syamsul Hadi)

generate electricity in rural areas in Laos, where PAT reduced the energy until 53% compared to the cross-flow turbines.

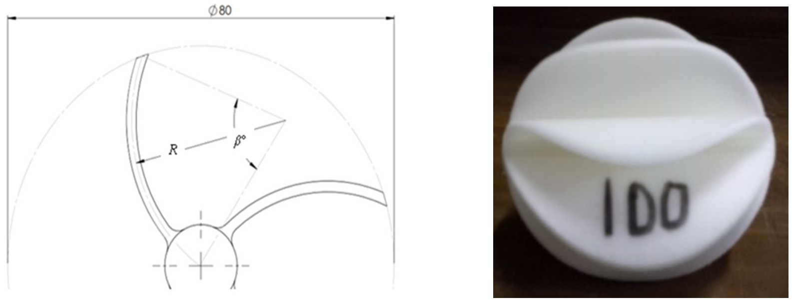
The application of wind turbine (Savonius turbine and Darrieus turbine) on the water flow has also developed [4-8]. The Savonius turbine using aqueous media performs better because of the bigger momentum of fluids [9-12]. The blade curvature angle influences the performance of both the Savonius hydrokinetic rotors or Savonius turbine and Wind Turbine. Modification of the rotor shape in Savonius turbine improves the turbine performance [13-16]. Some studies have been conducted to improve the Savonius turbine performance. The blade curvature angle in Savonius water turbine could be optimized to determine optimum revolving speed [17]. Each rotor having various blade curvature angles was tested in the wave channel tests to determine the rotation velocity produced as the result of the variations [17]. Rotational speed continued to increase at the blade curvature angle of 60° to 70°. Then, the rotational speed started to decrease at the blade curvature angle of 76° to 85°, while at the blade curvature angle of 90°, the rotational speed of the rotor was found to be inconsistent. Moreover, rotor achieved maximum performance at the blade curvature angle of 70° to the specific speed value of 1.3 rpm. Non-dimensional rpm is the ratio between the rotation speed generated by each rotor and the smallest rotational speed of all variations. Furthermore, research on the drag-type of Vertical Axis Water Turbine (VAWT) was conducted on the pipeline in order to generate electrical power, as supply monitor controlled the water quality [18]. The maximum electrical power of 88.2 W was obtained at the water velocity of 1.5 m/s, and the pressure dropped to less than 5 m. Another study examined the influence of blade curvature angle to the generated power coefficient at a modified Savonius Wind Turbine [19]. The blades with 110°, 124°, 135°, and 150° of curvature angle respectively were used, and the optimum performance was found at the blade curvature angle of 124°, generating 0.20 W.

In this study, a Horizontal Axis Water Turbine (HAWT), modified from a Savonius wind turbine, and mounted on an exhaust pipe of rainwater or wastewater, with the maximum head of 2 m was proposed for the application. Horizontal axis turbine was used in this study because proposed turbine could be directly installed to existing building piping, which usually is installed vertically. This research focused on the influence of the curvature angle of the blade on drag-type turbines in generating electrical power.

2. Methodology

At the beginning of the simulation process, turbines with various blade curvature angles were designed with Solidworks software. The designed turbines used 8 blades since it has been stated in the various literature that 8 blade turbines have the best performance. The making of blade curvature angle in turbine design is shown in Figure 1.

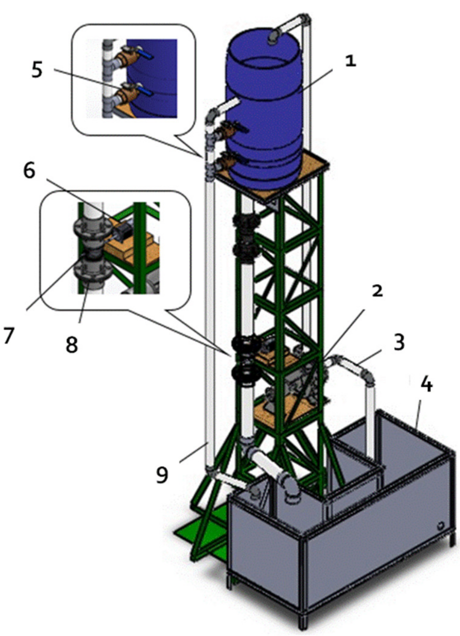
Figure 1 show the method of measurement of turbine blade curvature angle and sample of the blade by 3D printing process. Blade curvature angles were measured using the circle arc angle principle, where the center point of a circle was defined as a cross point between two lines measuring blade curvature angle (β) which one line is crossed to the center of the turbine. In this study, R was the radius of the blade curvature angle, while the rotor diameter was 80 mm. The rotors used in this research were made by layer by layer method to measure blade curvature angles accurately, and then 3D printed. This research was conducted by making comparisons of turbine designs using 5 different curvature angles, namely: 100^0, 110^0, 120^0, 130^0, and 140^0.



(a) (b)

Fig. 1. (a) Scheme of blade curvature angle and (b) the blade sample by a 3D printing

Figure 2 shows the design of test apparatus. The rotor was installed on the acrylic turbine housing in an 82 mm in diameter of water pipe. A blocking system was attached to the turbine system directing water flow to the blade rotor. The laboratory-scale experimental equipment was then assembled consisting of water tanks (1, 4), pumps (2), pipeline (3), valves (5), generator (6), turbine (7), flanges (8), and overflow system (9) in a vertical steel frame of test apparatus. Water was pumped from source tank in the bottom of the frame to the upper tank, placed on top of the frame, by the two water pumps. The incoming debit of fluid flow to the turbine was obtained by calculating of debit between exit and overflow pipe in order to keep the head in a constant value of 2 m. The generator is an AC Servo motor with merk Yasakawa Electric which has a maximum capacity of 100 Watt and highest velocity of 3000 rpm. The generator was attached directly to the axis of the turbine. The experimental research focused on the effect of HAWT blade curvature angle on the power output. The effect of the blade curvature angle on the voltage, power output, and power coefficient was observed.



Figs. 2. Test apparatus

3. Results and Discussion

Turbine performance analyzed by electrical power output. This power value is measured based on a multimeter. The magnitude of the output power is the multiplication between the voltage and the electric current. Figure 3 shown the angular relationship of the blade curvature with the electrical output power, describes the performance of the turbine as blade curvature angle was varied from 100° to 140°. The data explained the rotor performance with rated power output. The electric power output is directly proportional to the magnitude of the curvature angle of the turbine blade. The turbine at blade curvature angle of 100° generated power output of 2.6 Watt and then increases at a curvature angle of 140 with a power output of 7.4 Watt. The larger blade curvature angle means wider catching area of the blade which will affect the torque acting on the turbine. The amount of torque acting on each corner of the blade causes the voltage and electric current to vary, so the electrical output at each corner of the blade is different.

Another essential parameter showing the performance of the turbine is power coefficient (C_p) which declare the comparison of the potential power from the water to the obtained power from the turbine. Figure 4 show the value of *Cp* as the effect of the blade curvature angle of the blade. The blade curvature angle of 100º generates the lowest Cp value of 0.026, then increased until 0.073 at the angle of 140º. The efficiency still low because of the blade has not wide enough to convert the energy-water to the power output.

Tip speed ratio (TSR) is another important parameter in describing the performance of a turbine. Tip speed ratio is defined as the ratio of the tangential speed at the blade tip with the actual speed of the fluid, which determines the optimum speed of the blade to transfer energy from water to generate power [20]. Figure 5 describes that the maximum *TSR* was at the blade curvature angle of 140°. Initially, a rotor at the blade curvature angle of 100° only had *TSR* value of 0.493. The *TSR* continued to increase as the blade curvature angle bigger, and *TSR* reaches 0.758 at the angle of 140° as a depiction of the capability of the curvature angle in converting the fluid velocity to tangential velocity.

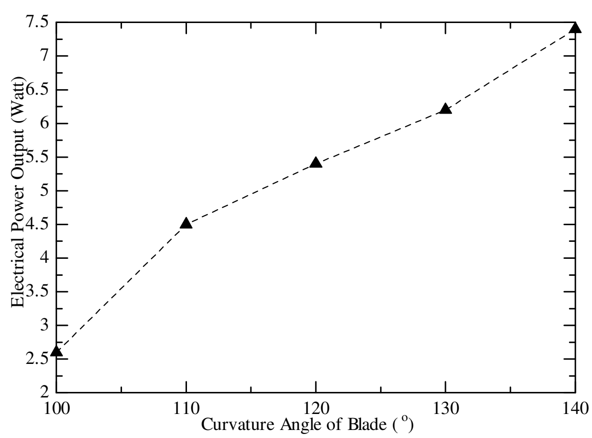


Fig. 3. The relationship between blade curvature angle with the electrical power output

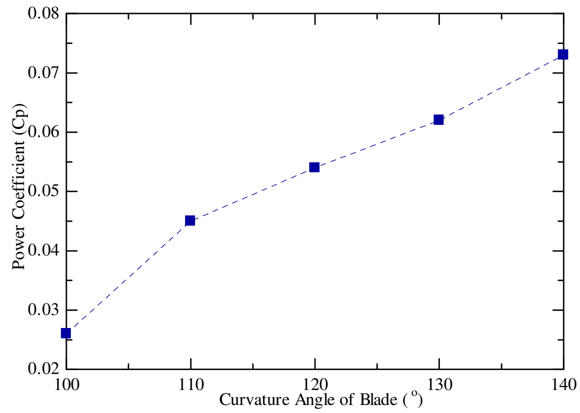


Fig. 4. Effect of the angle of curvature to the power coefficient

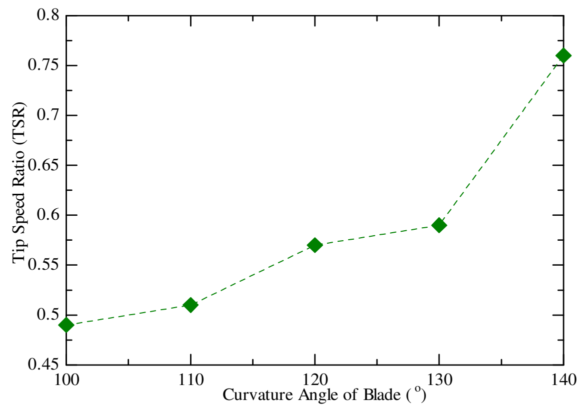


Fig. 5. Tip Speed Ratio in the turbine

4. Conclusion

This paper has successfully demonstrated the development of drag-type Horizontal Axis Water Turbine (HAWT) as an alternative way in generating the electricity in building pipe directly and also the measurement of the performance of the turbine which was influenced by the blade curvature angle. The maximum angle of blade curvature constructed was set to 140º because of a factor which limited manufacturing process. The best performance was measured at the blade curvature angle of 140°, generating power output of 7.4 Watt, TSR of 0.76, and the *Cp* of 0.073.

Acknowledgments
This work is part of the research supported by the Ministry of Research, Technology and Higher Education Indonesia via Universitas Sebelas Maret research grant of PUPT. The author would like to thank Mechanical Engineering Department of Universitas Sebelas Maret for using the facility to do this work.

References
[1] Aldrian, Edvin. "Pola hujan rata-rata bulanan wilayah Indonesia; tinjauan hasil kontur data penakar dengan resolusi ECHAM T-42." *Jurnal Sains & Teknologi Modifikasi Cuaca* 1, no. 2 (2000): 113-123.
[2] Williamson, S. J., B. H. Stark, and J. D. Booker. "Low head pico hydro turbine selection using a multi-criteria analysis." *Renewable Energy* 61 (2014): 43-50.

[3] Date, Abhijit, Ashwin Date, Aliakbar Akbarzadeh, and Firoz Alam. "Examining the potential of split reaction water turbine for ultra-low head hydro resources." *Procedia engineering* 49 (2012): 197-204.

[4] Sarma, N. K., A. Biswas, and R. D. Misra. "Experimental and computational evaluation of Savonius hydrokinetic turbine for low velocity condition with comparison to Savonius wind turbine at the same input power." *Energy conversion and management* 83 (2014): 88-98.

[5] Golecha, Kailash, T. I. Eldho, and S. V. Prabhu. "Influence of the deflector plate on the performance of modified Savonius water turbine." *Applied Energy* 88, no. 9 (2011): 3207-3217.

[6] Iio, Shouichiro, Yusuke Katayama, Fuminori Uchiyama, Eiichi Sato, and Toshihiko Ikeda. "Influence of setting condition on characteristics of Savonius hydraulic turbine with a shield plate." *Journal of Thermal Science* 20, no. 3 (2011): 224-228.

[7] Kirke, B. K. "Tests on ducted and bare helical and straight blade Darrieus hydrokinetic turbines." *Renewable Energy* 36, no. 11 (2011): 3013-3022.

[8] Shimokawa, Kai, Akinori Furukawa, Kusuo Okuma, Daisuke Matsushita, and Satoshi Watanabe. "Experimental study on simplification of Darrieus-type hydro turbine with inlet nozzle for extra-low head hydropower utilization." *Renewable energy*41 (2012): 376-382.

[9] Prasetyo, H., E. P. Budiana, D. D. D. P. Tjahjana, and S. Hadi. "The Simulation Study of Horizontal Axis Water Turbine Using Flow Simulation Solidworks Application." In *IOP Conference Series: Materials Science and Engineering*, vol. 308, no. 1, p. 012022. IOP Publishing, 2018.

[10] Hamzah, Imron, Ari Prasetyo, DDD Prija Tjahjana, and Syamsul Hadi. "Effect of blades number to performance of Savonius water turbine in water pipe." In *AIP Conference Proceedings*, vol. 1931, no. 1, p. 030046. AIP Publishing, 2018.

[11] Hadi, Syamsul, Rio Jevri Apdila, Arif Hidayat Purwono, Eko Prasetya Budiana, and Dominicus Danardono Dwi Prija Tjahjana. "Performance of the drag type of Horizontal Axis Water Turbine (HAWT) as effect of depth to width ratio of blade." In *AIP Conference Proceedings*, vol. 1788, no. 1, p. 030004. AIP Publishing, 2017.

[12] Prasetyo, Ari, Budi Kristiawan, Dominicus Danardono, and Syamsul Hadi. "The Effect of Deflector Angle in Savonius Water Turbine with Horizontal Axis on the Power Output of Water Flow in Pipe." In *Journal of Physics: Conference Series*, vol. 979, no. 1, p. 012043. IOP Publishing, 2018.

[13] Kamoji, M. A., Shireesh B. Kedare, and S. V. Prabhu. "Experimental investigations on single stage modified Savonius rotor." *Applied Energy* 86, no. 7-8 (2009): 1064-1073.

[14] Kacprzak, Konrad, Grzegorz Liskiewicz, and Krzysztof Sobczak. "Numerical investigation of conventional and modified Savonius wind turbines." *Renewable energy* 60 (2013): 578-585.

[15] Akwa, Joao Vicente, Horacio Antonio Vielmo, and Adriane Prisco Petry. "A review on the performance of Savonius wind turbines." *Renewable and sustainable energy reviews* 16, no. 5 (2012): 3054-3064..

[16] Roy, Sukanta, and Ujjwal K. Saha. "Wind tunnel experiments of a newly developed two-bladed Savonius-style wind turbine." *Applied Energy* 137 (2015): 117-125.

[17] Ahmed, M. Rafiuddin, Mohammed Faizal, and Young-Ho Lee. "Optimization of blade curvature and inter-rotor spacing of Savonius rotors for maximum wave energy extraction." *Ocean Engineering* 65 (2013): 32-38.

[18] Chen, J., H. X. Yang, C. P. Liu, C. H. Lau, and M. Lo. "A novel vertical axis water turbine for power generation from water pipelines." *Energy* 54 (2013): 184-193.

[19] Kamoji, M. A., Shireesh B. Kedare, and S. V. Prabhu. "Experimental investigations on single stage modified Savonius rotor." *Applied Energy* 86, no. 7-8 (2009): 1064-1073.

[20] Sarma, N. K., A. Biswas, and R. D. Misra. "Experimental and computational evaluation of Savonius hydrokinetic turbine for low velocity condition with comparison to Savonius wind turbine at the same input power." *Energy conversion and management* 83 (2014): 88-98.