Performance evaluation of vertical axis hydrokinetic turbine (VAHT) helical blade using duct system for low current speed application

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Abstract. This study evaluate the performance of vertical axis hydrokinetic turbine (VAHT) - Helical Blade using duct system. Experimental study has been performed in the open channel with measured current speed of 0.7 m s\textsuperscript{-1}, 0.9 m s\textsuperscript{-1}, and 1.1 m s\textsuperscript{-1}. Rotational speed and torque were measured to obtain the performance factor ($C_P$) and tip speed ratio ($TSR$). The gain of current speed has good response on rotational speed and torque. VAHT - Helical Blade using duct system has greater $C_P$ than non-duct system at three different current speed. The maximum $C_P$ is 0.44 reached on TSR of 2.92. The addition of duct system has good response on $C_P$ of VAHT - Helical Blade due to increasing current speed around the turbine.

Keywords: vertical axis hydrokinetic turbine, helical blade, duct system

1. Introduction

Renewable energy sources are presently the most assuring alternative energy source considering their green and wealthy characteristic. They can be gathered from nature, applied, and reprocessed frequently. A lot of investigation has been implemented on renewable energy sources such as wind energy, solar energy, hydropower, geothermal energy, and bioenergy [1]. Among the renewable energy sources, hydropower has obtained the most interest due to its environment friendly process [2]. Hydrokinetic systems are a group of zero-head hydropower whereby the operation of energy conversion implies implementation of kinetic energy involved in river streams, tidal currents, ocean currents, or some constructed waterways for electricity production [3].

Turbine systems are perceived as prime option for energy conversion on hydrokinetic systems. Vertical Axis Hydrokinetic Turbine (VAHT) is suitable for low current speed application, since it can generate electricity and can operate in any direction perpendicular to the flow. Another advantages of VAHT are easy to maintenance and no require yaw mechanism [4]. Helical Blade is one type of VAHT, it first invented by Gorlov [5]. VAHT - Helical Blade has technical convenience of refining unsteady torque at the shaft and representing an enhancement in total power output compared to straight blade [6]. A lot of research has been applied to enhance VAHT performance.
High performance of VAHT can be obtained by optimizing geometric parameters. Several methods have been developed such as modification of blade airfoil [7], blade number [8], height to radius ratio [9], and blade inclination angle [10].

Attempts against obtaining a steady torque and improving the power conversion by using a duct have been conducted severally. Ducts for flow augmentation have been advanced, aside from the gain in obtained power, operation of a suitable duct has many more conveniences [11]. The effect of a brim type diffuser for hydrokinetic applications has been observed. This research suggested a design for two-way brim type diffuser for operation in tidal streams, whereby the orientation of the stream switched with the tide [12]. A duct for Darrieus turbine has been developed [13]. The results represent that the total power output of Darrieus turbine using duct is improved. The objective of this study was to evaluate the performance of VAHT - helical blade using duct system.

2. Experimental method

VAHT - helical blade manufacturing used fiberglass as blade material. Meanwhile shaft, arm, frame, and ducting used steel as material. Geometric parameters of VAHT - helical blade using duct system are shown in Table 1. Dimension of VAHT - helical blade using duct system are shown in Figure 1.

| Blade number (N) | 3          |
|------------------|------------|
| Blade chord (C)  | 0.1 m      |
| Height (H)       | 0.8 m      |
| Diameter (D)     | 0.4 m      |
| H/D              | 1          |
| Blade inclination angle (δ) | 60°        |
| Blade airfoil    | NACA0018   |
| Duct input width (w_i) | 0.45 m    |
| Duct output width (w_o) | 0.9 m     |
| Duct length (L)  | 1.25 m     |
| w_o/w_i          | 2          |

**Table 1. Geometric parameters of VAHT - helical blade using duct system**

**Figure 1.** Dimension of VAHT - helical blade using duct system: a) front view, b) top view
Experimental study was performed to evaluate the performance of VAHT - Helical Blade using duct system. The performance was influenced by several factors such as flow fluctuation, bearing effect, and channel blockage. Therefore, the characteristics of channel used for turbine testing should be observed. The channel should have stable flow and low turbulence characteristic. VAHT - Helical Blade using duct system was tested in the open channel. Current speed was measured at three different point using current meter. VAHT - Helical Blade using duct system was subjected to three current speeds, i.e. 0.7 m s\(^{-1}\), 0.9 m s\(^{-1}\), and 1.1 m s\(^{-1}\).

Rotational speed was measured at the surface of water using tachometer mounted on the end of a shaft. Static torque was measured using torque wrench at five different azimuths, i.e. 0°, 90°, 120°, 180°, and 240°. Therefore, the torque fluctuation during turbine rotation could be predicted. Total static torque generated by the turbine was calculated from the average torque of all azimuth angles. Rotational speed and static torque measurement of VAHT - helical blade using duct system was illustrated in Figure 2.

![Figure 2. Measurement of VAHT - helical blade using duct system: a) rotational speed, b) static torque](image)

3. Result and discussion

VAHT - Helical Blade using duct system performance can be expressed in performance factor (\(C_p\)). \(C_p\) is a main factor to identify the turbine performance. The quantity of mechanical power obtained from current through the turbine can be presented as \(C_p\) value. The greater the \(C_p\), the greater the power that can be reached by the turbine. \(C_p\) can be calculated using equation 1 [14]. Where \(T\) is torque (Nm), \(\omega\) is angular velocity (rad s\(^{-1}\)), \(\rho\) is water density (kg m\(^{-3}\)), \(A\) is cross section of the stream (m\(^2\)), and \(V\) is current speed (m s\(^{-1}\)) (equation 1).

\[
C_p = \frac{T\omega}{0.5\rho AV^3}
\]  

The relation between tangential velocity of the blade and current speed can be expressed in tip speed ratio (TSR). TSR value specifies how quick the turbine is operating towards a definite current speed. TSR can be calculated using equation (2) [14]. Where \(R\) is turbine radius (m), \(\omega\) is angular velocity (rad s\(^{-1}\)), and \(V\) is current speed (m s\(^{-1}\)) (equation 2).

\[
TSR = \frac{R\omega}{V}
\]  

The proportional relation between rotational speed and current speed can be described in Figure 3. The greater the current speed, the greater the rotational speed. VAHT - helical blade using duct system has greater rotational speed than non-duct system at three different current speed. The maximum rotational speed of 113.56 RPM is reached by VAHT - helical blade using duct system at current speed of 1.1 m s\(^{-1}\). The gain of current speed has good response on rotational speed.
The proportional relation between torque and current speed can be described in Figure 4. The greater the current speed, the greater the torque. VAHT - helical blade using duct system has greater torque than non-duct system at three different current speeds. The maximum torque of 3.94 Nm is reached by VAHT - helical blade using duct system at current speed of 1.1 m s⁻¹. The gain of current speed has good response on torque.

$C_P$ and $TSR$ value can be calculated based on current speed, rotational speed, and torque data using equation 1 and equation 2. The graph of the relation between $C_P$ and $TSR$ is presented in Figure 5. VAHT - helical blade using duct system has greater $C_P$ than non-duct system at three different current speed. The maximum $C_P$ is 0.44 reached by VAHT - helical blade using duct system at TSR of 2.92. Meanwhile the smallest $C_P$ is 0.20 reached on TSR of 2.05 by VAHT - helical blade non-duct system. The addition of duct system has good response on $C_P$ of VAHT - helical blade due to increasing current speed around the turbine.

![Figure 3. Rotational speed - current speed curves of VAHT - helical blade](image3.png)

![Figure 4. Torque - current speed curves of VAHT - helical blade](image4.png)
For the next research, VAHT - helical blade performance can be improved using the blade cascaded technique [15]. Furthermore, research on VAHT should continue on other aspects such as blade material development and damage detection while VAHT is operating. Bio-resin material [16] has the potential to be developed as a tough blade material. Damage detection in VAHT can use natural frequency [17-19], dynamic modal analysis [20], and optimization method [21].

![Figure 5. $C_P$ - TSR curves of VAHT - helical blade](image)

4. Conclusion
In this research, experimental study has been performed in the open channel to evaluate the performance of VAHT - helical blade using duct system. Current speed, rotational speed, and torque were measured to obtain $C_P$ and $TSR$. The greater the $C_P$, the greater the power that can be reached by the turbine. VAHT - Helical Blade using duct system has greater $C_P$ than non-duct system at three different current speed. The addition of duct system has good response on $C_P$ of VAHT - Helical Blade due to increasing current speed around the turbine.

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