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ENHANCED PERFORMANCE OF THE GORLOV HYDROKINETIC TURBINE THROUGH BLADE PROFILE MODIFICATION

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ABSTRACT

The Gorlov turbine is a widely used hydrokinetic turbine for household-scale hydroelectric power generation, known for its superior performance compared to other turbine types. Despite its high efficiency, the Gorlov turbine has a significant drawback: it cannot operate effectively at low water speeds due to its blade design, which relies solely on lift force. This study aims to address this limitation by modifying the blade profile to harness drag force in addition to lift force. The modified blade profile retains the original crescent shape while enhancing its design. For data validation, two models were created: the conventional Gorlov turbine and a modified version. Laboratory-scale tests were conducted using a water pump to simulate flow in an artificial channel, with water speeds ranging from 0.185 m/s to 0.225 m/s. Correlation regression analysis was employed to evaluate the experimental results and strengthen the reliability of the findings. The results indicate a correlation between changes in water flow speed and increases in turbine rotation, turbine torque, torque coefficient, and power coefficient. Specifically, the conventional Gorlov turbine exhibited an average torque of 0.014 Nm, a torque coefficient of 0.0209, and a power coefficient of 0.32. In contrast, the modified Gorlov turbine demonstrated an average torque of 0.016 Nm, a torque coefficient of 0.239, and a power coefficient of 0.308.

Keywords: Hydrokinetic Turbine; Gorlov; Blade Modification.

ABSTRAK

Turbin Gorlov adalah turbin hidrokinetik yang banyak digunakan untuk pembangkit listrik tenaga air skala rumah tangga, yang dikenal dengan kinerjanya yang unggul dibandingkan dengan jenis turbin lainnya. Meskipun memiliki efisiensi yang tinggi, turbin Gorlov memiliki kelemahan yang signifikan: turbin ini tidak dapat beroperasi secara efektif pada kecepatan air yang rendah karena desain sudu yang hanya mengandalkan gaya angkat. Penelitian ini bertujuan untuk mengatasi keterbatasan ini dengan memodifikasi profil bilah untuk memanfaatkan gaya hambat selain gaya angkat. Profil baling-baling yang dimodifikasi mempertahankan bentuk bulan sabit asli sambil meningkatkan desainnya. Untuk validasi data, dua model dibuat: turbin Gorlov konvensional dan versi modifikasi. Pengujian skala laboratorium dilakukan dengan menggunakan pompa air untuk mensimulasikan aliran di saluran buatan, dengan kecepatan air berkisar antara 0,185 m/s hingga 0,225 m/s. Analisis regresi korelasi digunakan untuk mengevaluasi hasil eksperimen dan memperkuat keandalan temuan. Hasilnya menunjukkan adanya korelasi antara perubahan kecepatan aliran air dan peningkatan putaran turbin, torsi turbin, koefisien torsi, dan koefisien daya. Secara khusus, turbin Gorlov konvensional menunjukkan torsi rata-rata 0,014 Nm, koefisien torsi 0,0209, dan koefisien daya 0,32. Sebaliknya, turbin Gorlov yang dimodifikasi menunjukkan torsi rata-rata sebesar 0,016 Nm, koefisien torsi 0,239, dan koefisien daya 0,308.

***Kata Kunci**: Turbin Hidrokinetik, Gorlov, Modifikasi Blade.*

1. Introduction

Hydropower is a highly promising renewable energy source, significantly reducing dependence on fossil fuels. Hydrokinetic turbine technology has been a major focus in harnessing the kinetic energy of water to generate electricity [1-3]. Among the various hydrokinetic turbines, the Gorlov hydrokinetic turbine has garnered considerable attention and research interest.

The Gorlov hydrokinetic turbine, discovered by Viktor S. Gorlov [4,5], is a vertical-axis water turbine specifically designed for underwater use [6]. It operates by rotating and converting kinetic energy into mechanical energy as water flows through its blades. Fundamentally, the Gorlov hydrokinetic turbine harnesses the lift force generated by water flow impacting the turbine blades [7,8]. While the Gorlov turbine boasts a simple design and the ability to operate at various water flow speeds, its main drawback is its ineffectiveness in slow water flows, posing a challenge to its performance in low-flow conditions [9,10].

Turbines that operate primarily on lift force struggle to rotate at low water flow rates, as the force from the water flow is insufficient to turn the turbine. This limitation is problematic since not all rivers have fast water speeds, and some river flows are inconsistent. This challenge significantly affects the deployment of Gorlov hydrokinetic turbines [11].

The development of hydrokinetic turbines faces various technical challenges. One significant issue is the poor performance of hydrokinetic turbines, exacerbated by fluctuating water flows in river or sea environments, which often exhibit varying speeds over time. Addressing the low performance of Gorlov hydrokinetic turbines, particularly in slow-flow conditions, requires exploring several potential solutions.

Bachant and Wosnik (2020) compared the performance of helical blade models with spiral blade models. Their results indicated that helical blade models exhibited superior performance in terms of rotation capability and kinetic energy conversion from water flow, achieving a maximum Cp value of 0.28 and a TSR of 2.1 [12].

P. K. Talukdar et al. (2015) tested hydrokinetic turbines under zero head conditions. Their research, conducted in an open channel with flow velocities ranging from 0.6 to 3.0 m/s, showed that the turbine generated slower rotations. The power coefficient (Cp) performance values increased, with a significant improvement of 0.14 at a tip-speed ratio of 1.01 for a flow velocity of 0.8 m/s [13].

Niharman and Sipahutar (2015) investigated the influence of blade angle variation on hydrokinetic turbine performance. They varied turbine blade angles at 0°, 30°, 45°, and 60°, testing at a flow velocity of 0.85 m/s. The optimal performance was obtained with a 60° blade angle, achieving turbine efficiency up to 28.5% [14].

Try Antomo (2020) analyzed the development of a Gorlov hydrokinetic turbine with an increased capture area. This study enhanced the Gorlov turbine by adding paired components to the turbine arms, giving it a DNA-like shape. Using a turbine geometry with a height (H) of 0.38 m, a diameter (D) of 0.25 m, and three blades, the findings revealed that the addition of paired components increased the turbine torque at low water speeds [15,16].

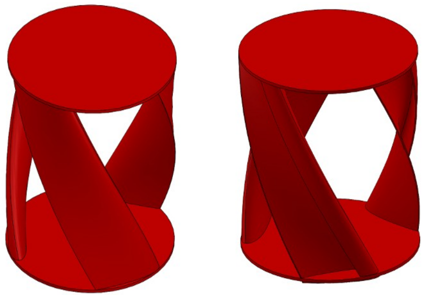
To address the limitations of the Gorlov turbine, this research proposes combining the working principles of lift force and drag force. This requires modifying the blade profile by cutting a quarter of the blade, giving it a sickle-like shape. Consequently, a quarter of the blade operates with drag force, while the remaining three-quarters utilize lift force [17-19].

The objective of this research is to enhance the performance of the Gorlov hydrokinetic turbine by modifying the blade profile to efficiently utilize both lift and drag forces, enabling operation in slow-flowing currents. This study aims to provide an alternative solution in developing environmentally friendly renewable energy sources, expanding the options for efficient and economical hydrokinetic turbine technology.

2. Methods

This research aimed to improve the performance of the Gorlov hydrokinetic turbine through blade profile modification using an experimental method. The experiment required several pieces of equipment, including a channel designed as sketched in Figure 3 and the modified Gorlov hydrokinetic turbine as shown in Figure 1. The measurement instruments used included a tachometer for measuring the shaft rotation speed of the turbine, a scale for measuring the loading, and a flow meter for measuring the water flow velocity [20].

The geometry of the turbine under examination is illustrated in Figure 2, presented as both a working drawing and a 3D printed model. The model was printed using a 3D printer and PLA+ material. Teflon bearings with an inner diameter of 6 mm and an outer diameter of 19 mm were employed in the turbine construction.



(a) (b)

Figure 1. Geometric shape of (a) Gorlov turbine conventional and (b) Modified Gorlov turbine

Figure 2 shows the modified blade section; essentially, this blade is made from the NACA 0024 profile and then cut on one side to form a scythe.

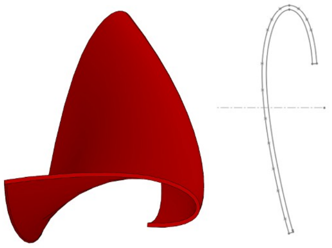


Figure 2. Gorlov turbine blade profile Modification development of the Gorlov blade profile

Table 1 presents the specifications of the turbines tested.

Table 1. Turbine Specifications

Parameter	Dimensions	Unit
Number of Blades	3	unit
Blade Geometry	NACA 0024	-
Cord Length	0.080	m
High	0.20	m
Diameter	0.18	m
Aspect Ratio	1.11	
Blade Thickness	1.5	mm

The variables used in this research are categorized into three types. First, the independent variables, which include the Gorlov turbine model and the modified Gorlov turbine model. Second, the dependent variables, which encompass the turbine performance parameters observed during testing, such as turbine rotation, torque, coefficient of moment, and coefficient of power. Third, the constant variables, which include the turbine model with three blades, PLA+ as the modeling material, and water velocity.

The method employed in this research is experimental, involving direct field testing simulated in an artificial water channel. Figure 3 illustrates the schematic design of the artificial water channel used in the study.

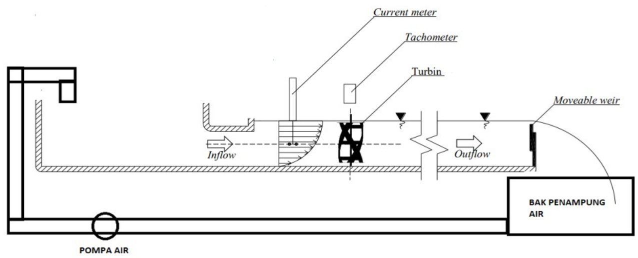


Figure 3. Scheme of artificial water channel test equipment

The research data was obtained from direct field testing. The collected data included turbine rotation speed (rpm), load (kg), and spring balance load (kg). Several activities during the data collection process are depicted in Figure 4. Subsequently, the collected data underwent processing to determine the performance of the modified turbine, including angular speed (ω), torque coefficient (Ct), and power coefficient (Cp).

Figure 4. Experiment Setup

The equations used to calculate the performance of the turbine are as follows. The equation to calculate the Tip Speed Ratio (TSR) is:

$$TSR = \frac{\omega . D}{2.U} \quad (1)$$

$$\omega = \frac{2.\pi . n}{60}$$

Where:

n = Turbine rotation speed

D = Turbine Diameter

U = Fluid Flow Velocity

The equation to obtain the torque value (T) is as follows:

$$T = (M - S)(r_{Shaft+d_r})g \quad (2)$$

Where:

M = Load (kg)
S = Spring Balance Load
r_{Shaft} = pully/shaft radius
d_r = Nylon Diameter
g = Gravity

The equation to obtain the torque coefficient value (Cm) is as follows:

$$Cm = \frac{4T}{\rho . U^2 . D^2 . H} \quad (3)$$

Where:

T = Torsi
ρ = density water
U = Fluid flow speed
D = Turbine rotor diameter
H = Turbine rotor height

The equation to obtain the power coefficient (Cp) value is as follows:

$$Cp = TSR.Cm \quad (4)$$

Where:

Tsr = Tips Speed Ratio
Cm = Torque Coefficient

To evaluate the experimental results and strengthen the reliability of the findings, correlation regression analysis was employed.

3. Results and Discussion

To compare the performance of conventional Gorlov turbines and modified Gorlov turbines, data processing must be conducted. The following is an example of the calculations for the performance of a conventional Gorlov turbine with a flow speed of 0.185 m/s and a turbine rotation speed of 26.2 rpm:

Table 1. Conventional Gorlov Turbine Test Data

U (m/s)	M (kg)	S (kg)	N (rpm)
0.185	0.2	0.151	30.1
0.195	0.2	0.143	32.1
0.205	0.2	0.131	34.2
0.215	0.2	0.122	36.1
0.225	0.2	0.112	38.1

Table 2. Modified Gorlov Turbine Test Data

U (m/s)	M (kg)	S (kg)	N (rpm)
0.185	0.2	0.14	26.2
0.195	0.2	0.131	28
0.205	0.2	0.122	30.1
0.215	0.2	0.111	32
0.225	0.2	0.12	34.1

The Tip Speed Ratio is calculated using equation 1:

$$TSR = \frac{\omega . D}{2.U}$$

$$\omega = \frac{2.\pi.n}{60}$$

$$\omega = \frac{(2)x(3.14)x(30}{60} = 3.14 \text{ Rad/s}$$

Where:

n = Turbine Rotation Speed = 30 rpm
D = Turbine Diameter = 0.18 m
U = Fluid Flow Velocity = 0.185 m/s

So we get the TSR value:

$$TSR = \frac{(3.14).(0.18)}{2.(0.185)} = 1.52$$

Torque (T) is calculated using equation 2:

$$T = (M - S)(r_{Shaft+d_r})g$$

Where:

M = Load (kg) = 0.2 kg
S = Spring Balance Load = 0.15 kg
r_{Shaft} = pully/shaft radius = 0.02 m
d_r = Nylon Diameter = 0.001 m
g = Gravity = 9.81 m/s^2

So we get the T value:

$T = (0.2 - 0.15)(0.02 + 0.001).(9.81) = 0.01030\ Nm$

Torque coefficient (Cm) is calculated using equation 3:

$$Cm = \frac{4T}{\rho U^2.D^2.H}$$

Where:

T = Torsi = 0.01030 N.m

ρ = The density of water is 999 kg/m3 when the water temperature reaches 30 °C

U = Fluid flow speed = 0.185 m/s

D = Turbine rotor diameter = 0.18 m

H = Turbine rotor height = 0.20 m

So we get the CM value:

$$Cm = \frac{4(0.01030)}{(999).(0.185^2).(0.18^2).(0.20)} = 0.185$$

Power coefficient (Cp) is calculated using equation 4:

$Cp = TSR.Cm$

Where:

Tsr = Tips Speed Ratio = 1.52

Cm = Torque Coefficient = 0.185

So we get the Cp value:

$Cp = (1.52).(0.185) = 0.284$

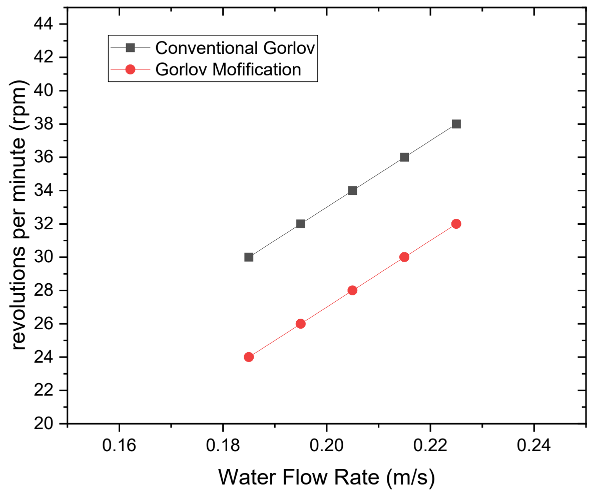
Table 3. Gorlov Turbine Performance Calculation Data

U (m/s)	N (rpm)	Torque (N.m)	Cm	Cp
0.185	30.1	0.0103	0.185	0.284
0.195	32.1	0.0123	0.200	0.310
0.205	34.2	0.0144	0.212	0.331
0.215	36.1	0.0164	0.220	0.340
0.225	38.1	0.0185	0.226	0.345

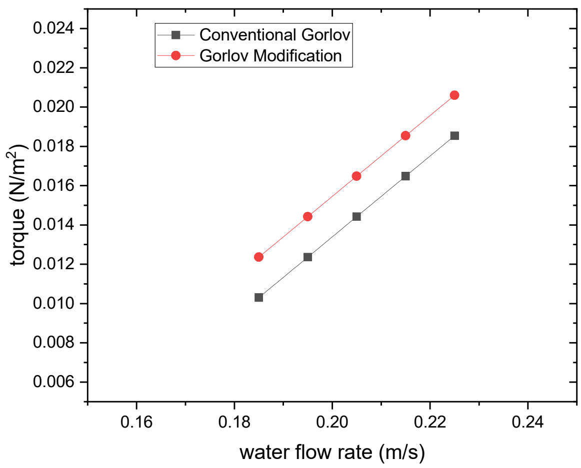
Table 4. Calculation Data for Modified Gorlov Turbine Performance

U (m/s)	N (rpm)	Torsi (N.m)	Cm	Cp
0.185	26.2	0.0123	0.223	0.272
0.195	28	0.0144	0.234	0.294
0.205	30.1	0.0164	0.424	0.313
0.215	32	0.0185	0.247	0.325
0.225	34.1	0.0200	0.251	0.336

Figure 5 is a comparative graph illustrating turbine rotation speed (rpm) and turbine torque as functions of various water flow speed variations for both the conventional Gorlov turbine model and the modified Gorlov turbine model.



(a)



(b)

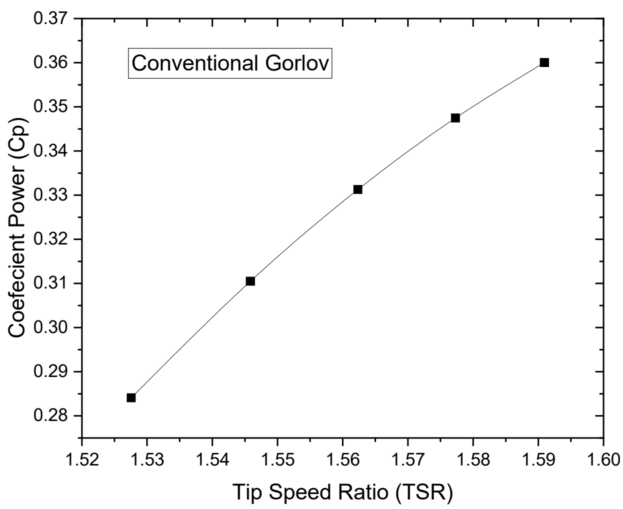
Figure 5. Presents a comparison graph of turbine rotation speed (Figure 5a) and turbine torque (Figure 5b).

Figure 5a and Figure 5b display the testing results of hydrokinetic turbines at various water flow speeds. The comparative analysis between the Gorlov turbine and the modified Gorlov turbine reveals several interesting findings.

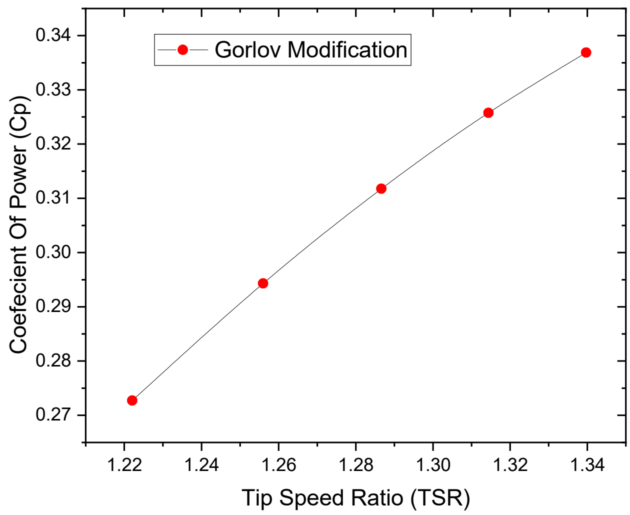
Figure 5a illustrates the revolutions per minute (rpm) of both turbine types. The results indicate that the Gorlov turbine has a rotation speed ranging from 30 rpm to 38 rpm, while the modified Gorlov turbine exhibits values between 24 rpm and 32 rpm. Notably, both turbine types show a tendency for increasing revolutions per minute proportionally with the increase in water flow speed. In other words, the faster the water flow, the higher the revolutions per minute produced by both turbines.

Figure 5b shows that the conventional Gorlov turbine produces torque values ranging from 0.010301 to 0.018541 Nm, while the modified Gorlov turbine generates torque values between 0.012361 and 0.020601 Nm. This data indicates that the modified Gorlov turbine consistently outperforms the conventional Gorlov turbine in terms of torque, particularly at higher water flow speeds. Consequently, the modified Gorlov turbine has the potential to generate greater mechanical power compared to the conventional Gorlov turbine.

Although the conventional Gorlov turbine exhibits a higher revolutions per minute (rpm) than the modified Gorlov turbine, it is crucial to consider this comparison alongside the torque values produced by each turbine. Despite the higher rotation speed of the conventional Gorlov turbine, the modified Gorlov turbine's superior torque is a more critical parameter for evaluating hydrokinetic turbine performance. Overall, this analysis reveals that while the conventional Gorlov turbine and the modified Gorlov turbine exhibit different characteristics, the modified Gorlov turbine has an advantage in terms of torque, whereas the conventional Gorlov turbine has a higher rpm.



(a)



(b)

Figure 6. Illustrates the turbine performance results, showing the relationship between the power coefficient and the tip-speed ratio.

Figure 6 visualizes the performance testing results for the conventional Gorlov turbine and the modified Gorlov turbine across various water speed ranges from 0.185 to 0.225 m/s. The analysis utilizes two key parameters: the tip-speed ratio and the power coefficient.

The tip-speed ratio measures the ratio of the turbine blade tip speed to the water flow speed impacting the turbine. The conventional Gorlov turbine exhibits a tip-speed ratio ranging from 1.52 to 1.59, while the modified Gorlov turbine shows lower tip-speed ratio values, ranging from 1.22 to 1.33. This difference indicates that the conventional Gorlov turbine is more effective at maximizing the conversion of kinetic energy from high-flow-speed water. Conversely, the modified Gorlov turbine demonstrates better energy conversion at lower flow speeds but is less efficient at higher speeds. This suggests that the design of the conventional Gorlov turbine and the modified Gorlov turbine each excels at specific operational speeds, with the conventional turbine being optimized for high-speed conditions and the modified turbine for low-speed conditions.

The power coefficient is a parameter that reflects the efficiency of the turbine in converting the kinetic energy of water flow into mechanical power. The conventional Gorlov turbine has a power coefficient ranging from 0.28 to 0.36, while the modified Gorlov turbine exhibits a similar range, between 0.27 and 0.36. This indicates that both turbines have comparable power conversion efficiencies. However, it is important to note that the conventional Gorlov turbine achieves a higher tip-speed ratio.

4. Conclusion

Based on the discussion, it can be concluded that there is a correlation between changes in water flow rate and increases in turbine rotation speed, torque, torque coefficient, and power coefficient for both the conventional Gorlov turbine model and the modified Gorlov turbine model. The findings reveal that the conventional Gorlov turbine has an average torque value of 0.014 N·m, an average torque coefficient of 0.0209, and an average power coefficient of 0.32. In contrast, the modified Gorlov turbine has an average torque value of 0.016 N·m, an average torque coefficient of 0.239, and an average power coefficient of 0.308.

Additionally, the Tip-Speed Ratio (TSR) for the conventional Gorlov turbine ranges from 1.52 to 1.59, whereas the TSR for the modified Gorlov turbine varies from 1.22 to 1.33.

These findings imply that adjustments to the Gorlov turbine design could significantly enhance turbine performance. The variation in TSR values indicates that the conventional Gorlov turbine is better suited for high-flow conditions, while the modified Gorlov turbine performs more effectively in low-flow conditions.

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