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Design Of Gorlov Helical Turbine And Open Channel Water Flow Apparatus For Hydroelectric Energy Harvesting

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***Abstract*—In this work, the design of Gorlov Helical Turbine (GHT) and open channel water flow apparatus for application in laboratory demonstration of hydroelectric energy harvesting using rotating engine is presented. The essence of the design of the two items is to provide tools for laboratory demonstration of electric energy generation from a flowing water using rotating engine. Key design calculations are presented and the designed items are printed using 3D printer. The design calculation results of the GHT showed that the power output of the designed GHT is 74.6W. When the turbine efficiency of 35% was considered, the output power output dropped to 26.11W. Furthermore, when the combined efficiency of the electric generators (including loses in electric circuits) was considered, the power output further dropped to 22.2W. The ideas presented in this study is essential for laboratory demonstration of energy harvesting setup using GHT and open channel water flow apparatus.**

Keywords*— Gorlov Helical Turbine, Open Channel Water Flow Apparatus, SolidWorks CAD package, Energy Harvesting Mechanism, Hydro Power Plant, Hydroelectric Energy

1. Introduction

Nowadays, as technology continues to improve and permeate every area of our live electric energy becomes increasingly important and the demand keep rising endlessly [1,2,3]. The emergence of electric vehicle has added to the increasing demand for electric energy [4,5,6]. Also, the quest for environmentally friendly energy generation has also brought about the rise in green and renewable energy system [7,8]. In this wise, there is growing study of renewable energy generation systems such as hydroelectricity power and solar power systems [9,10].

Accordingly, in this work, the focus is the design of Gorlov Helical Turbine (GHT) [11,12] and open channel water flow apparatus [13,14] for application in laboratory demonstration of hydroelectric energy harvesting using rotating engine. This study has become essential given that the cost of setting up hydro power plants are very high. Hence, a small scale equipment that can facilitate the study of the design and implementation of functional solar hydro power plant is in high demand in various institutions across Nigeria. The detailed design calculations and the approach used for the 3D printing of the designed equipment are presented.

2. Methodology

The focus in this work, is the Gorlov Helical turbine and open channel water flow apparatus using SolidWorks CAD package [15,16]. The two items are applicable demonstrating how water flow can be harnessed to produce electricity through a rotary engine.

2.1 Design Calculation for the Gorlov Helical Turbine

The principle of operation for the Gorlov Helical turbine (GHT) is that the energy conversion is achieved by harnessing lift force on the blade (Figure 1). This approach enables the GHT to attain rotational speed that is higher than the natural velocity of the stream. The design parameters for developing GHT includes; the helical angle, twisting angle, solidity ratio of the turbine, height of the turbine, the turbine thickness, chord the length of the turbine blade and the turbine end plates diameter x.

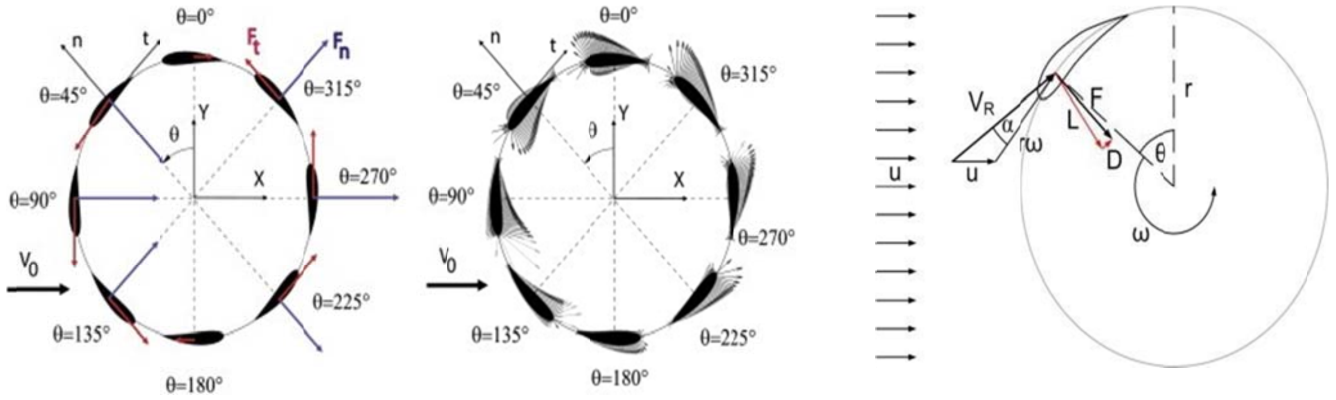

Figure 1 Schematics showing the various forces that are acting on the foil. Source: Anderson et al, 2011

The efficiency of a turbine to produce power is directly related to this relative speed, the torque (T), angular velocity (ω), fluid density(ρ) and free stream velocity (V) as follows;

$$\eta = \frac{T.\ \omega}{\frac{1}{2}\rho A V^3} \qquad (1)$$

The turbine helix angle **(φ)** is computed as follows;

$$\varphi = \tan^{-1}\left(\frac{(N)(H)}{\pi(D)}\right) \qquad (2)$$

Where; N is used to denote the number of blades; H is used to denote the height of the turbine blade; D is used to denote the diameter of the turbine. For the following values, (N =3, H =0.25 and D =0.075) the helix angle (φ) is computed as;

$$\varphi = \tan^{-1} \frac{3\times 0.25}{\pi\times 0.075} = 72.56°$$

The expected torque (T) of the turbine is computed as follows;

$$T = \frac{C_P\ \rho A V^3}{\omega} \qquad (3)$$

For the following values CP=1/2, $\rho = 1000\frac{Kg}{m^3}$, A= $0.04\ m^2$, ω=15.8, and $V = 0.7\frac{m}{s}$ the expected torque (T) is computed as;

$$T = \frac{(C_P)\ (\rho)(A)(V)^3}{\omega} = \frac{\frac{1}{2}(0.1)(1000\frac{Kg}{m^3})(0.04m^2)(0.7\frac{m}{s})^3}{15.8} = 0.04\ Nm$$

The solidity ratio is the ratio of the area of the blades to the area of the disc, where;

$$\sigma = \frac{N(c)}{\pi(d)} \qquad (4)$$

Where number of blades (N), propeller diameter (d) and blade chord length (c). Again, the chord length of the blade is the distance from the front edge of the blade to the back edge of the blade and it is determine with respect to the solidity ratio, where

$$c = \frac{(\sigma)(\pi)(d)}{N} \qquad (5)$$

Assuming a solidity ratio (σ) of 0.5, then,

$$c = \frac{0.5\times\pi\times 0.075}{3} = 0.039\ m\ = 39\ mm$$

The maximum thickness of the blade is assumed to be 20% of 39 mm which is 7.8mm. In this work, a *NACA 0020* airfoil/hydrofoil is used in the turbine. The turbine output power (Pw) can be expressed as;

$$P_w = \frac{1}{2}\rho A v^2 \qquad (6)$$

Where, A denotes the frontal area of the turbine, given as;

$$A = h \times D \qquad (7)$$

Then, given that h= 0.25 and D = 0.75, then;

$A = 0.25\times 0.075 = 0.01875m^2$ and $P_w = \frac{1}{2}\rho A v^2 = 74.6W$

The power of one turbine with the efficiency (η_t) of 35% can be calculated as;

$$P_t = \eta_t\ (P_w) \qquad (8)$$

Then,

$$P_t = 0.35(P_w) = 26.11W$$

Taking into account the combined efficiency of the electric generators (including loses in electric circuits) as ηh where η_h = 85%. Then;

$$P_h = \eta_h\ (P_t) \qquad (9)$$

$P_h = \eta_h\ (P_t) = 0.85\ (26.11) = 22.2W.$

2.2 Design Calculation for the Transmission

The spur gear was used for the transmission and the speed increase specification ratio used is 3:1. The driving gear has a diameter of 123mm and 36 teeth, while the driven gear that powers the generator has a diameter of 43mm with 12 teeth. The pitch for the driving gear and the driven gear is given as;

$$Pitch = \frac{\pi(d)}{t} \qquad (10)$$

For driving gear; pitch = $\frac{\pi\times 123}{36}$ = 16.80 mm

For driven gear; pitch = $\frac{\pi\times 41}{12}$ = 10.73 mm

Finally, a DC generator which electrical load is connected to its terminals is connected to a spur gear which is driven by wheel gear component. The rating of the generator is 15W, 12V-24V, 30,000 rpm.

2.3 Construction of the water flow apparatus

The water flow apparatus (Figure 2) consists of the frame, pipe, open channel, pump, supports and the storage tank. It is made up of steel bars (angle and box profile), welded to produce a jointed connection. Angle bars when welded together provides the necessary support for the acrylic open channels that allows for the stability of the system such that the channel is not necessarily affected by the vibrations from the pump. The pump and the storage tanks are fitted opposite each other at the ends of the apparatus. The network of the piping system requires the use of a PVC pipe of an outer diameter of 254mm and an internal diameter of 250mm, the outlet of the pipe is connected to the pump which drains to the open channel in a tap. In other to generate hydrokinetic energy from the flow, the runner (bucket) is positioned beneath the pipe. The system discharges at an outlet, which is connected to a storage tank from which is recirculated by the pump.

2.4 Processes Utilized in creating the design model on 3D printer

The Ender5 plus and the davinci XYZ Pro printer were used for 3D printing of the Gorlov helical turbine, along with the other components. We purchased a Polylactic Acid (PLA) filament for the printing. This filament was loaded into the 3D printer spool which is then connected to the heater nozzle through an extruder. The extruder works like a forming device that enables the heated filament to form a simple thin shape which is built up in stacks to form the final object on the bed.

3. Results and Discussion

The designed Gorlov Helical Turbine (GHT) is presented in Figure 2 and Figure 3 and while the designed open channel water flow apparatus assembly is presented in Figure 2 and Figure 3. The key input parameters used for the Gorlov Helical Turbine (GHT) design are presented in Table 1. Also, some of the computed parameters of the Gorlov Helical Turbine (GHT) and transmission gear design are presented as the results in Table 2. According to the results in Table 2, the power output of the designed GHT is 74.6W. When the turbine efficiency of 35% was considered, the output power drops to 26.11W. Furthermore, when the combined efficiency of the electric generators (including loses in electric circuits) was considered, the power output further drops to 22.2W.

Table 1: The key input parameters used for the Gorlov Helical Turbine (GHT) design

SN	Description of Parameter	Parameter Value and Unit
1	Height of turbine	0.25m
2	Diameter of turbine	0.075m
3	Velocity of flow	2.8m/s
4	Frontal area of turbine	$0.01875m^2$
5	Helix angle of turbine	72.56°
6	Chord length of turbine	39mm
7	Thickness of the turbine	7.8mm
8	Efficiency of the turbine	35%

Table 2: The key design parameters computed for the Gorlov Helical Turbine (GHT) and transmission gear design

SN	Description of Parameter	Parameter Value and Unit
1	Turbine helix angle (φ)	72.56°
2	The torque (T)	0.04 Nm
3	Solidity ratio	0.039 m = 39 mm
4	The frontal area of the turbine	$0.01875m^2$
5	The power output (Pw) of the turbine	74.6W
6	The power of one turbine with the efficiency (ηt) of 35%	26.11W
7	The power output taking into account the combined efficiency of the electric generators (including loses in electric circuits)	22.2W
8	The pitch for the driving gear	16.80 mm
9	The pitch for the driven gear	10.73mm

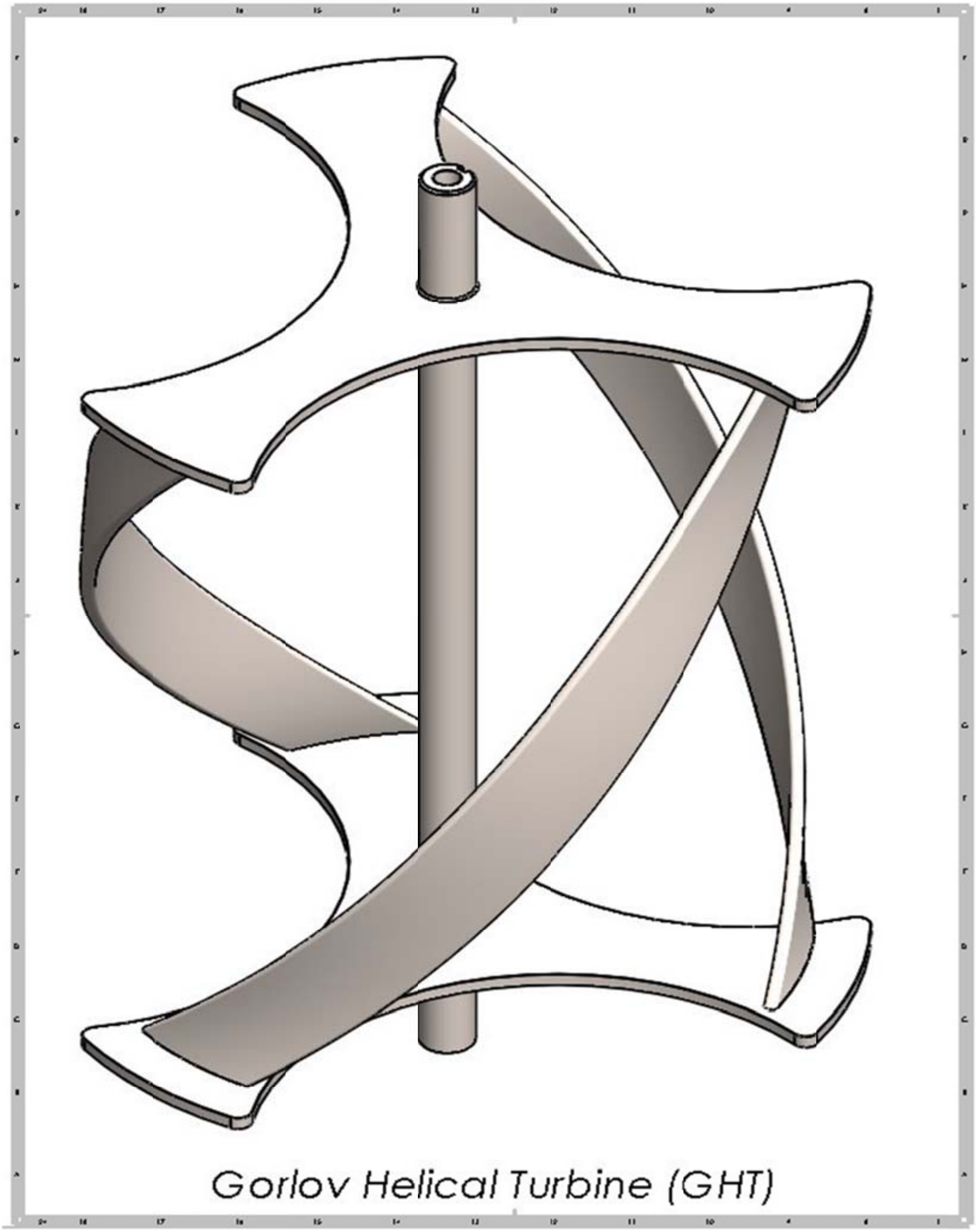

Figure 2 The Gorlov Helical Turbine (GHT)

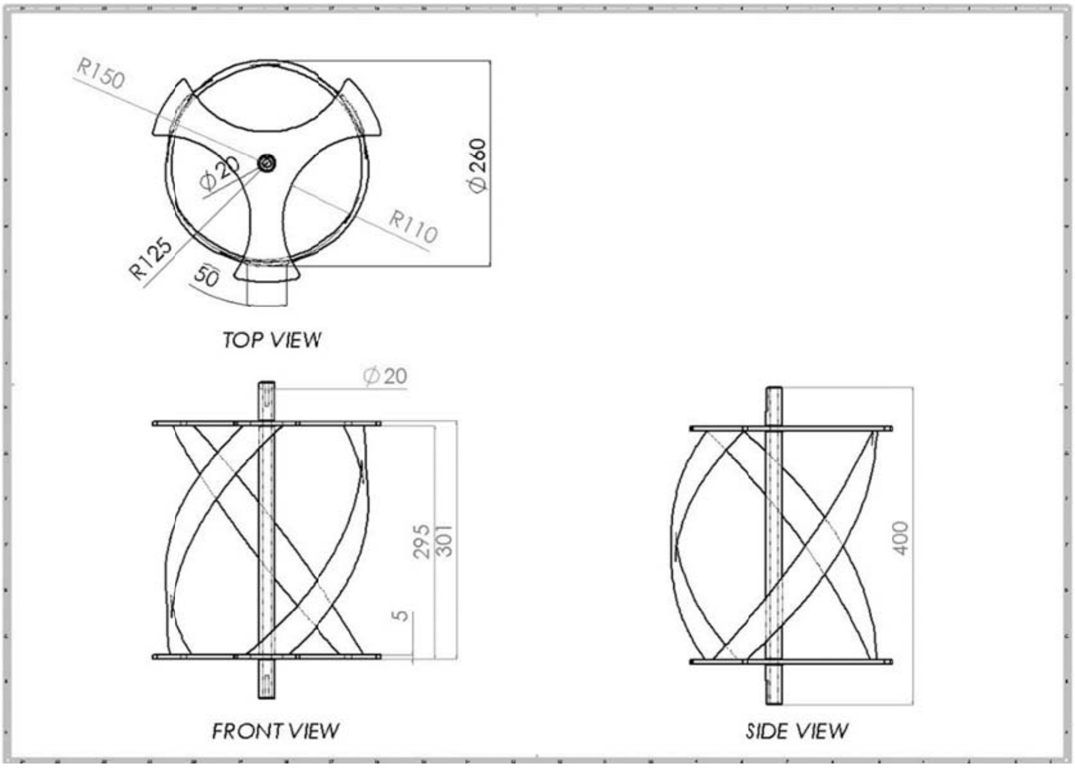

Figure 3: Isometric view of the designed Gorlov Helical Turbine (GHT)

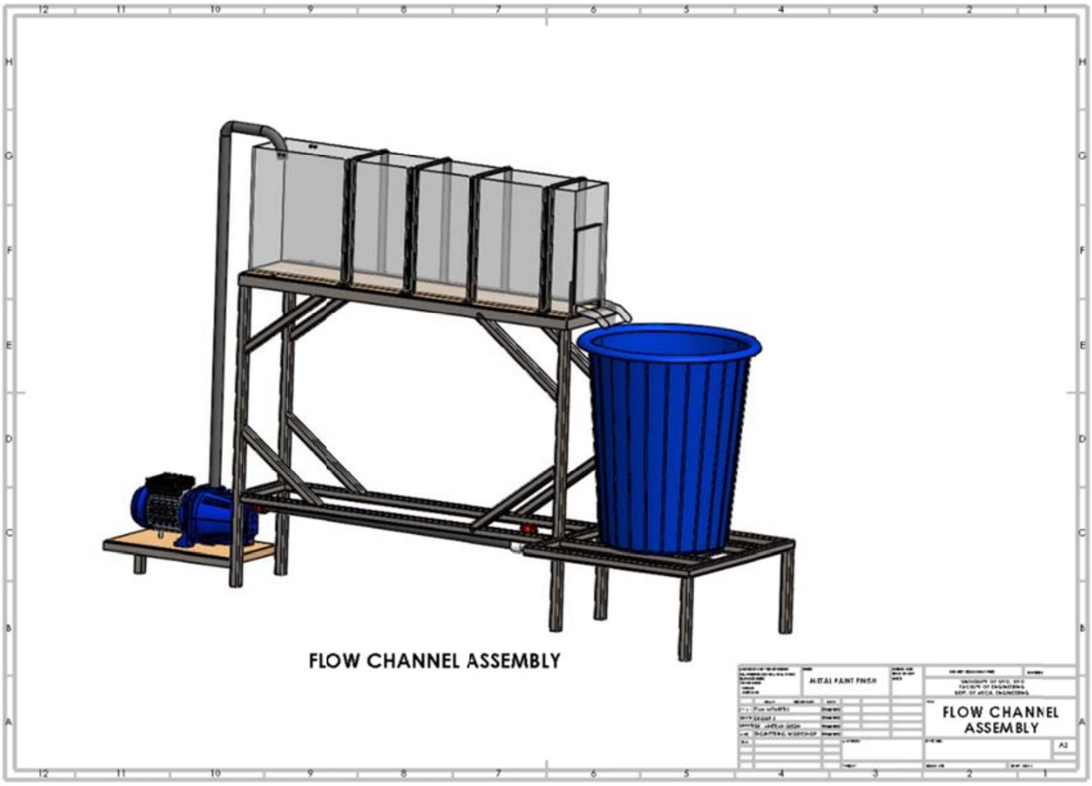

Figure 4 The designed open channel water flow apparatus assembly

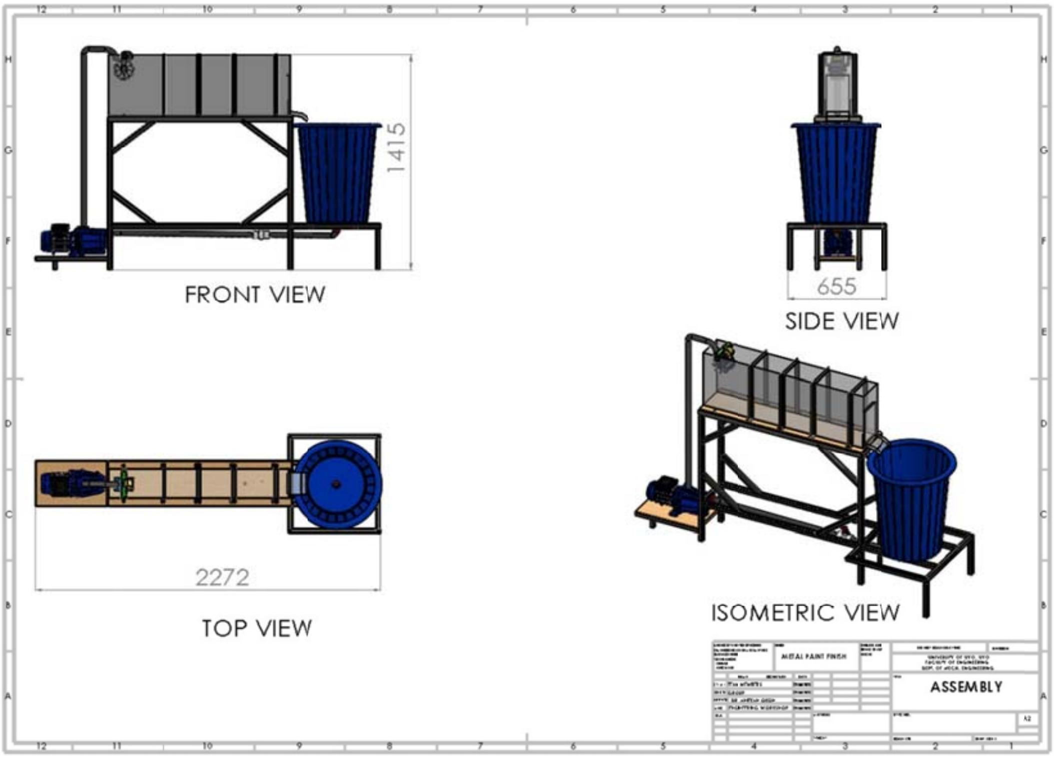

Figure 5 The isometric view of the open channel water flow apparatus assembly

4. Conclusion

The design of a Gorlov Helical Turbine (GHT) and open channel water flow apparatus, using SolidWorks CAD package is presented. The design key calculations are presented. The designed items are printed using 3D printer. The two GHT and open channel water flow apparatus are designed with focus on providing tools for laboratory demonstration of electric energy generation from a flowing water using rotating engine.

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