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# Comparative Study of Gravitational Water Vortex Turbine(GWVT) with Fibonaccian and Conical Casing

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***Abstract: A gravitational vortex turbine is an eco-friendly micro hydropower generation turbine that operates in ultra-low heads to provide energy in rural areas. Nowadays, the challenging aspects of conical casing vortex turbines are low efficiency and poor vortex dynamics. This paper focuses on a conceptual idea study that serves as a comparison of the results of a self-developed golden ratio spiral-based casing for an ultra-low head vortex turbine to a conical gravitational turbine using SolidWorks flow simulation. A six-blade rear turbine is used for the overall simulation. The turbine is placed at the outlet of the casing, and the values of force acting on the turbine blades are simulated. The torque at the turbine blade is also determined for the generic conical casing and the Fibonaccian casing, which are compared for the results. The relative pressure contour acting on the blades of the turbine is represented in a pictorial form. The torque is compared at each axis and plotted in a graphical format. The results encourage further development of GWVT, as there is an increase in the overall torque and efficiency.***
***Keywords: GWVT-Gravitation water vortex turbine, golden ratio spiral, Fibonaccian casing, ultra-low head-ULH, Conical casing***

## I. INTRODUCTION

Electricity is the most important carrier of energy, which is readily usable in a variety of equipment. Green and renewable energy are going to play a vital role in the generation of electricity in the future. Gravitational Water Vortex Turbine (GWVT) is an ultra-low head, cost-effective green source of energy. As it operates at a low head of 0.7 meters to 3 meters, it can be harnessed in most rivers in hilly regions (where it is most efficient) and even in plains. Harnessing electrical energy from small, year-round, free-flowing water sources offers a viable alternative for generating clean energy.

Presently, there are two primary methods to produce electricity from such water sources: the bypass method and the open canal method. The bypass method involves diverting water from an irrigation canal into a power generation system, while the open canal method entails installing a power generation system directly within the canal. Free vortex flow, a natural phenomenon driven by gravitational force, occurs when fluid is introduced into the inlet of a cylindrical or conical casing at a specific angle.A free vortex is formed, which can be used to generate electricity using a turbine and an alternator.

Generating a stable water vortex drives a water turbine, which is positioned at a suitable height. Therefore, this system can convert the energy of a moving flow into rotational energy. There are several studies focused on discerning or developing the most suitable runner for a GWVT that have researched the influence of the variation in the number of blades, but the studies based on the alteration of the casing of GWVT are relatively less. The research conducted on GWVT reports efficiencies of around 30-50% in practical applications. The incorporation of the Fibonaccian spiral design for the casing of GWVT is a significant aspect of this paper. Hurricanes and tornadoes majorly follow the Fibonacci sequence. As nature follows the Fibonacci sequence, it is intriguing to incorporate it into this blooming technology. Designing a casing inspired by a Fibonaccian spiral and comparing it with a generic conical casing of the same volume and head will give the proper idea of the functioning of the newly designed casing. The past and recent developments are discussed in the section below.

## II. LITERATURE REVIEW

Gravitational vortex turbines are not the onlyultra-low-head water turbines but are one of the most efficient turbines among them. The comparison of the efficiency of the two types of electricity generators leads to the following conclusions. The free water vortex turbine performed better than the small undershot water wheel. The rotational speed of the vortex turbine was higher because of the acceleration of water in the free vortex.

The maximum power it generated was 14.5 watts with an efficiency of 35.92%, whereas that of the undershot wheel was 7.51 watts with an efficiency of 13.96%. Under the head of 0.5 meters and a rate of flow equal to 950 liters per minute, the water-free vortex turbine is more economical and appropriate as compared to the undershot wheelas mentioned in[1].

The 5-blade turbine offers the greatest torque, as proven by Wanchat et al., because it has the greatest surface area to impact water. Adding blades to 6 or 7 results in less space between them, leading to water flow interference, eddies, elevated resistance, and hence decreased torque. Studies confirm the significance of blade number, angle, and baffles towards turbine efficiency. Therefore, 5 blades have the optimal blend of surface area and flow characteristics for maximum functionality,as mentioned in[2]. Theeffect ofboosters plays an important role. The energy of water that falls to a certain height after leaving the main runner was utilized by designing suitable booster runners for the necessary conditions. The increase in efficiency is about 6% more than that of a single main runner, as mentioned in[3].

The multistage vortex turbine research is also significant in GWVT and future growth. A conical basin multi-stage GWVT improves performance by increasing flow parameters through interactions between runners in different stages. Although multi-staging can decrease rotational speed in lower runners because of distortion of the vortex from higher stages, torque is made up of water load. Performance is maximum in the middle stages but decreases towards the bottom because of disruption of the vortex by the higher stagesas mentioned in [4].There are fewer blades and greater efficiency, and more blades distort the vortex at even lower loads. The radius of the blades is increased by, which efficiency is reduced by friction on the basin's inner surface. Conical basins work better than cylindrical basins and enhance the vortex's strength and formation, for which a test gives a maximum efficiency of 29.63%from [5].The test conducted indicates the process of performance analysis and validation study. An efficiency of 82% was realized with a curved profile blade of 44° as well as with a turbine output power of 6.91 kWreferred from[6].

Research indicates optimal turbine placement at 0.65 to 0.75 of the basin's height, with efficiency ranging from 30% to 50%, depending on blade size and number. Conical basins outperform cylindrical ones, and efficiency increases with higher inlet flow rates as from paper.[7]. The development of a new 3D runner with results in maximum efficiency reaches a velocity of 90 to 120 rpm,the maximum efficiency reaches a flow rate of 23.8 to 4.07 kg/s. It could rotate from a low speed of 40 rpm, to a maximum speed of 192 rpm as shown in [8].

A small water vortex turbine with straight blades produces results indicating that the flow rate increase increased the rpm, output power, and efficiency. At 264 rpm, the turbine produced 12.3W of power with an efficiency of 52.67%from [9]. The best runner design had a rotation angle of 55°, six blades, and upper/lower diameters of 250 mm and 120 mm, respectively. The experimental efficiencies had differences of 5.1% asreferredto from [10]. The simulation of horizontal axis water turbines (HAWT) by SolidWorks flow simulation indicates that the best turbine design, which generates the maximum torque of 8.464 Nm, has 6 blades, a 65° blade curvature angle, a 10° bucket angle, and a 40° blocking system angle as mentioned in [11].

An eight-blade turbine achieved the highest hydraulic efficiency of 57%, balancing vortex exposure and stable air core propagation. Fewer blades caused water splashes, while more blades blocked the outflow, creating back pressure. Adding a smaller draft tubeincreases efficiency to 60% by recovering the low-pressure region from the drain outlet from [12]. The GWVT test on the conical basin demonstrates that the power coefficient rose to 0.64 in simulations and 0.478 in experiments. For a runner design in GWVPP with conical basins, major recommendations are a height ratio of the runner to the basin of 0.31–0.32, a taper angle equal to the cone of the basin, and an impact angle of 20°, curved blades with 50°–60° angles, and a cut ratio less than 15%from[13].

Using lightweight aluminum instead of steel for turbines improves efficiency, with experiments showing 34.79% efficiency for aluminum compared to 33.56% for steel. The aluminum turbine produced 8.4% higher torque and 8.14% greater efficiency on average while reaching top speed faster. Lightweight materials enhance electricity production efficiency without altering the size or design as mentioned from [14].The maximum torque produced from turbines with 50% baffles and 5 blades; so, that it increases efficiency as mentioned in [15]. The test on the relation between RPM and efficiency shows the maximum efficiency of 40 % is obtained at the speed of range between 28 and 38 rpm mentionedfrom[16].A 5-blade propeller-type turbine (0.4 m diameter, 0.7 m height) attained 13.92% efficiency at 0.02 $m^3/s$, whereas an 18-blade crossflow turbine (0.3 m height, 0.4 m diameter) obtained 23.01% efficiency at 0.02 $m^3/s$ flow rate, demonstrating a 9.09% higher efficiency from the results of [17].

Where increased rotational speed exists at the inlet to the runner, forward flow areas and also backward flow areas both increase by minimized air space, with the central flow rate showing a constant pattern. The fluid in the tank of the turbine veers off the free-vortex pattern owing to the prominent impact of runner rotation close to the inletas referred to in[18].

Similarly, the test for 2 different casingsdone using SolidWorks flow simulation is described in this paper, and the way the design is formed and meshed is discussed in the next section.

## III. METHODOLOGY

Fibonaccian spiral is one of the major patternsthat is observed across various natural phenomenalike tornadoes and storms. So,the inclusion of the spiral pattern in the casing of the free vortex gravitational vortex turbine is the primary base of this paper. This casing is modeled using SolidWorks 2023 modeling software with a head of 1.01 m and a volume of 0.35 $m^3$.Fibonaccian casing has an inlet area of 0.16 $m^2$ and an outlet area of 0.14 $m^2$ while the conical casing has the same inlet area but an outlet area of0.2$m^2$. The Fibonaccian or golden ratio spiral design is done using the equation-driven spline option with the parametric equation of

$$X = \sin(t) * 1.6180339875^{\left(\frac{t}{\pi}\right)} \text{----------------------} (1)$$

$$Y = \cos(t) * 1.6180339875^{\left(\frac{t}{\pi}\right)} \text{-------------------------} (2)$$

$$Z = 4 * t \text{---------------------------} (3)$$

With the parameters 10<= t <=25 where “1.61803398875” is the golden ratio.A similar conical-cased GWVT is used with the same head and volume designed to compare the torque generated in the turbines. Figure 1 shows the image of the Fibonaccian casing, and Figure2 shows the image of the conical casing. The Computational Fluid Dynamics (CFD) simulation is done using the SolidWorks Flow Simulation 2023 version, the initial boundary condition is defined with the velocity in the z-axis as 1 m/s, and gravity is defined. There are 2 pressure outlets with atmospheric pressure and 5 various mass flow rates of 0.02 $m^3$/s,0.03 $m^3$/s, 0.04 $m^3$/s,0.05 $m^3$/s, and 0.06 $m^3$/s are given at the inlet. The meshing is done with the automatic meshing of the fine mesh level structure of “6”.

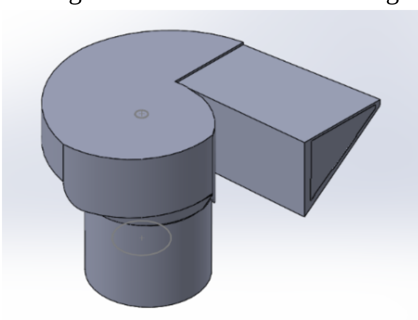

Figure 1:Fibonaccian casing

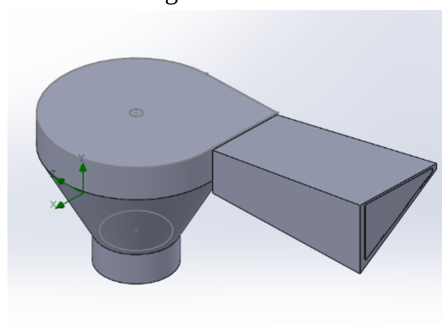

Figure 2:Conical casing

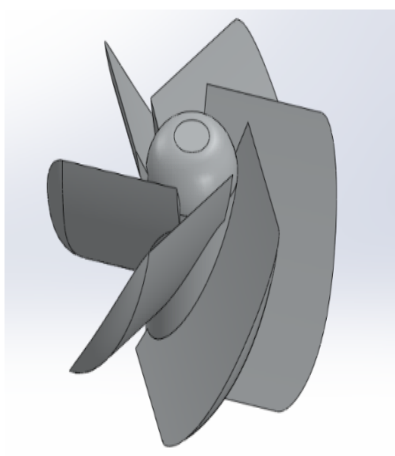

Figure 3: 6 Blade Impeller

The impeller that is used for simulation, as shown in Figure 3, is a mixed flow, reaction turbine with a 6-blade design as from results from [17]. The 6-blade design shows maximum efficiency. The blades are angled at $40^0$ from the axis, and it is placed at the base outlet of both the casings. The casings along with the impeller are used in the assembly in which the analysis is done at various volume flow rates, and the results of the relative pressure plotand torque acting on the blades are shown in images and graphs.

## IV. RESULTS & DISCUSSIONS

This section describes results from simulation analysis; it predominantly shows the relative pressure acting on the blades of the turbine, and the torque generated in the turbine is also tabulated. Figures4(a) and 4(b)show the relative pressure acting on the blade at a volume flow rate of 0.02 $m^3/s$ for both casings.

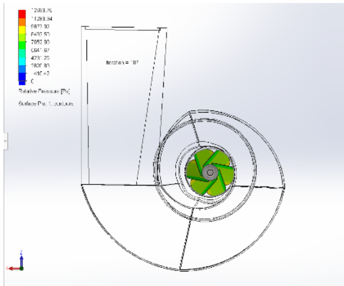

Figure 4(a): Relative pressure contour at 0.02 $m^3/s$ of Fibonaccian casing

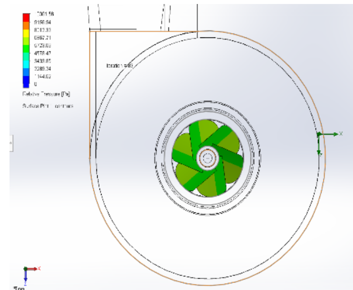

Figure 4(b): Relative pressure contour at 0.02 $m^3/s$ of Conicalcasing

The relative pressure contour shown in figure 4(a) for the Fibonaccian casing shows the maximum average pressure of 9500 Pa in the lower part and the minimum average pressure of 7000 Pa in the upper part from the contour.Figure 4(b) for the conical casing shows the maximum average pressure of 6800 Pa in the lower part and the minimum average pressure of 5500 Pa in the upper part of the contour.

Figures 5(a)and 5(b) show the relative pressure acting on the blade at a volume flow rate of 0.03 $m^3/s$for both casings.

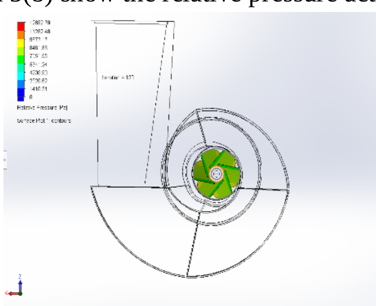

Figure 5(a): Relative pressure contour at 0.03 $m^3/s$ of Fibonaccian casing

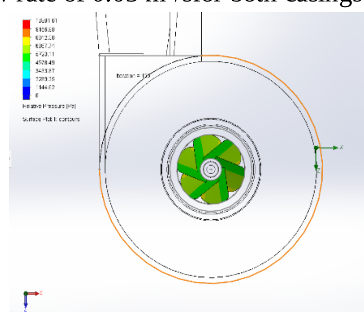

Figure 5(b): Relative pressure contour at 0.03 $m^3/s$ of Conicalcasing

Figure 5(a) for the Fibonaccian casing shows the maximum average pressure of 9800 Pa in the lower part and the minimum average pressure of 7200 Pa in the upper part of the contour.Figure 5(b) for the conical casing shows the maximum average pressure of 7300 Pa in the lower part and the minimum average pressure of 5600 Pa in the upper part of the contour.

Figures 6(a)and 6(b) show the relative pressure acting on the blade at a volume flow rate of 0.04 $m^3/s$for both casings.

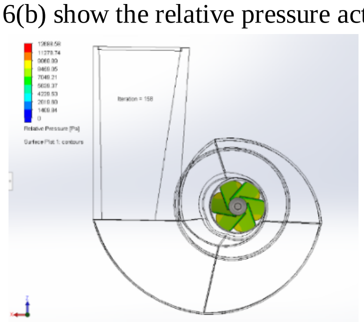

Figure 6(a): Relative pressure contour at 0.04 $m^3/s$ ofFibonaccian casing

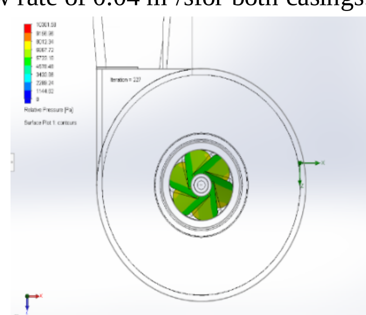

Figure 6(b): Relative pressure contour at 0.04 $m^3/s$ of Conicalcasing

Figure 6(a) for the Fibonaccian casing shows the maximum average pressure of 9800 Pa in the lower part and the minimum average pressure of 7500 in the upper part of the contour.Figure 6(b) for the conical casing shows the maximum average pressure of 7500 Pa in the lower part and the minimum average pressure of 5800 Pa in the upper part of the contour.

Figures 7(a) and 7(b) show the relative pressure acting on the blade at a volume flow rate of 0.05 $m^3$/sfor both casings.

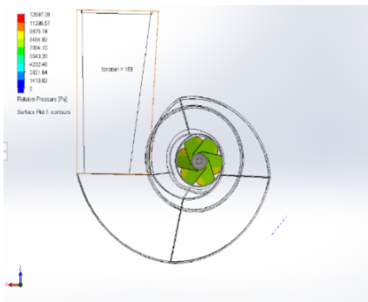

Figure 7(a): Relative pressure contour at 0.05 $m^3$/s of Fibonaccian casing

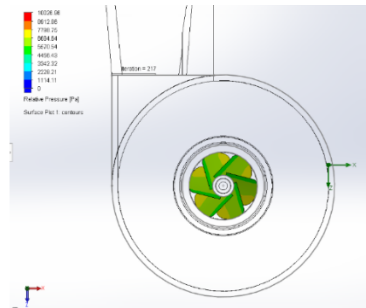

Figure 7(b): Relative pressure contour at 0.05 $m^3$/s of Conicalcasing

Figure 7(a) for the Fibonaccian casing shows the maximum average pressure of 9900 Pa in the lower part and the minimum average pressure of 7800 Pa in the upper part of the contour.Figure 7(b) for the conical casing shows the maximum average pressure of 7800 Pa in the lower part and the minimum average pressure of 5800 Pa in the upper part of the contour.Figure 8(a) for the Fibonaccian casing shows the maximum average pressure of 9900 Pa in the lower part and the minimum average pressure of 8000 Pa in the upper part from the contour.

Figures 8(a)and 8(b) show the relative pressure acting on the blade at a volume flow rate of 0.06 $m^3$/sfor both casings.

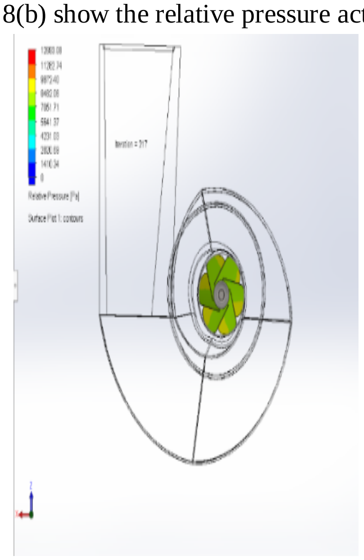

Figure 8(a): Relative pressure contour at 0.06 $m^3$/s of Fibonaccian casing

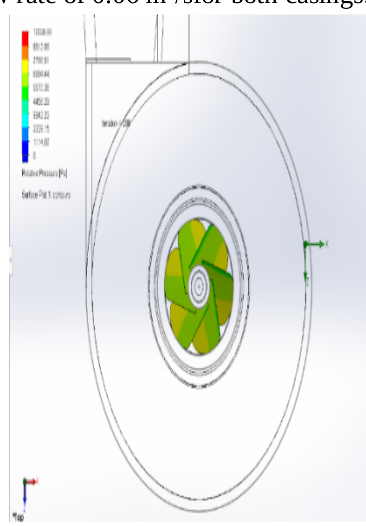

Figure 8(b): Relative pressure contour at 0.06 $m^3$/s of Conicalcasing

Figure 8(b) for the conical casing shows the maximum average pressure of 8100 Pain the lower part and the minimum average pressure of 6000 Pa in the upper part of the contour. The average relative pressure is relatively higher in the Fibonaccian casing due to the guided structure of the turbine. The higher-pressure contour gradually increases with the increase in the inlet volume due to increase in the amount of water in contact.

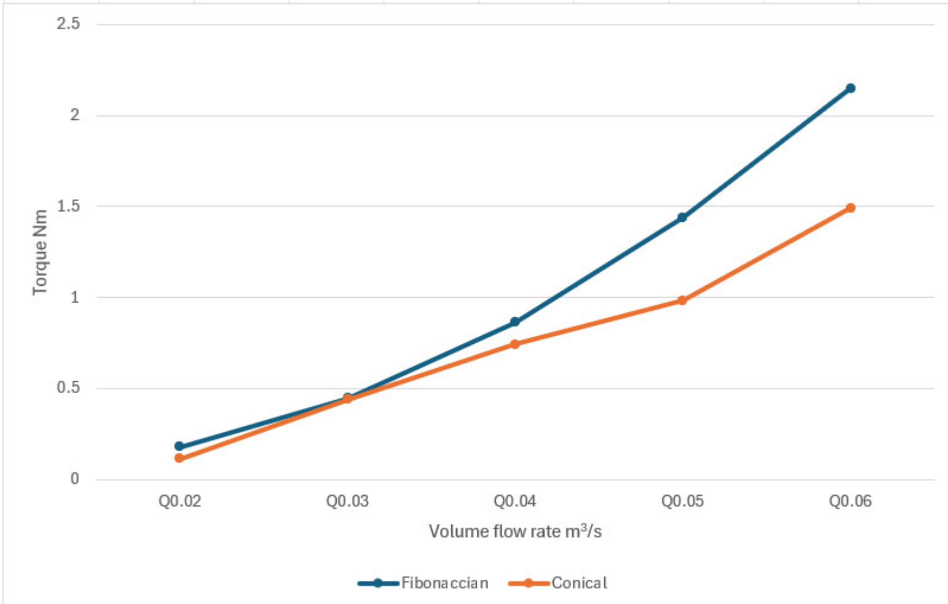


Figure 9:Torque-volume flow rate curves in X-axis

ConcerningFigure 9, the torque acting on the X axis increases with the increase in volume flow rate as 0.1761Nm at 0.02 $m^3$/s,0.4441 Nm at 0.03 $m^3$/s, 0.8617 Nm at 0.04 $m^3$/s,1.4397Nm at 0.05 $m^3$/s and 2.1484 Nm at 0.06 $m^3$/s in Fibonaccian casing and 0.1114 Nm at 0.02 $m^3$/s,0.4382Nm at 0.03 $m^3$/s,0.7410 Nm at 0.04 $m^3$/s,0.9821 Nm at 0.05 $m^3$/s and 1.4897 Nm at 0.06 $m^3$/s in conical casing.

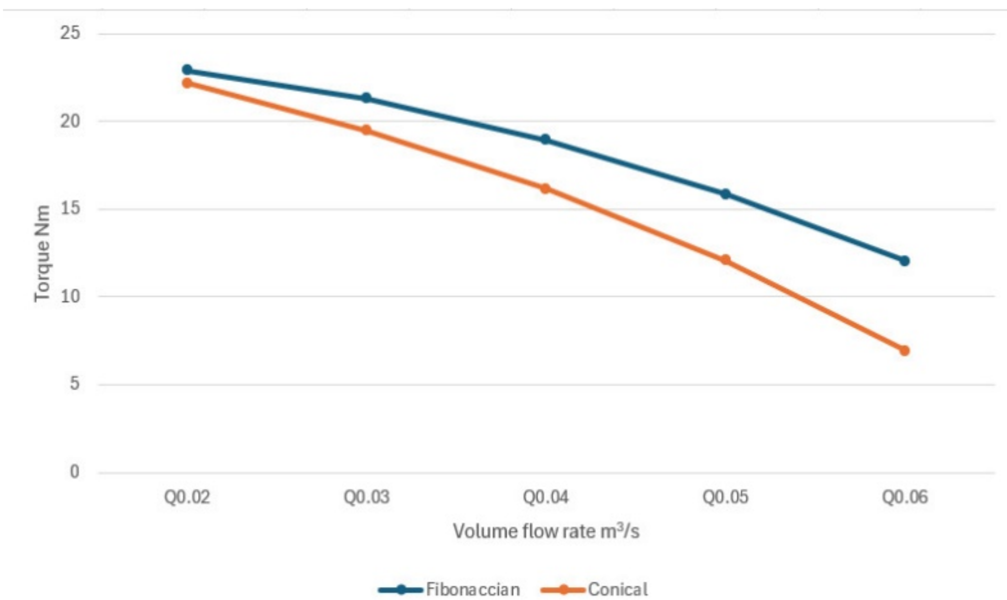


Figure 10:Torque-volume flow rate curves in theY-axis

From the above Figure 10, it is observed that the torque in the Y axis rapidly decreases with the increase in volume flow rate:22.9153 Nm at 0.02 $m^3$/s, 21.2948Nm at 0.03 $m^3$/s,18.9558 Nm at 0.04 $m^3$/s,15.8506 Nm at 0.05 $m^3$/s and 12.0356 Nm at 0.06 $m^3$/s in Fibonaccian casing and 22.1731 Nm at 0.02 $m^3$/s,19.4575Nm at 0.03 $m^3$/s,16.1459 Nm at 0.04 $m^3$/s,12.0812Nm at 0.05 $m^3$/sand 6.9107 Nm at 0.06 $m^3$/s in conical casing.

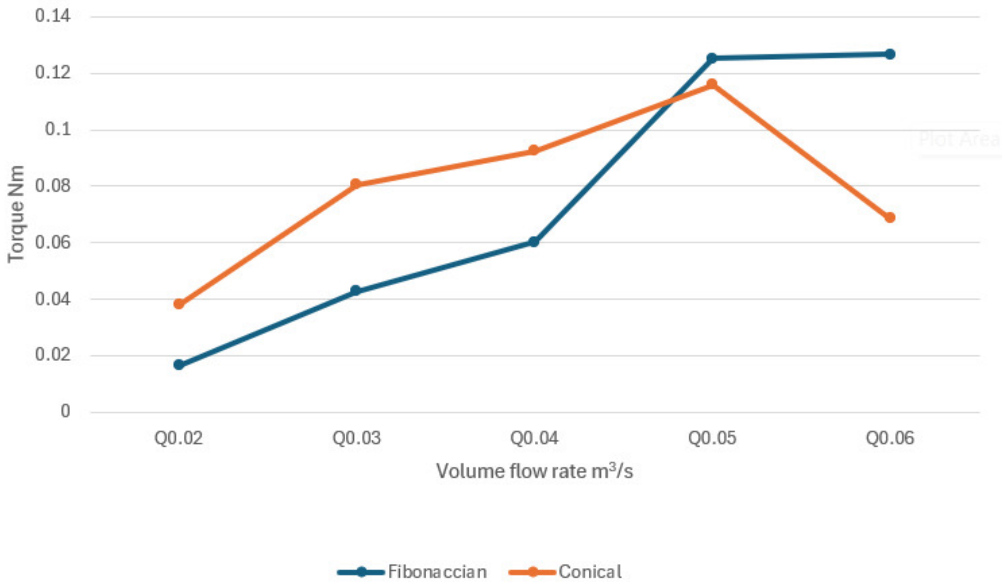


Figure 11:Torque-volume flow rate curves in the Z-axis

From the above figure 11, the torque acting along the z-axis is significantly small, that is,<<0.2 Nm. It ranges from a minimum of 0.0165 Nm at a flow rate of 0.02 $m^3/s$ to a maximum of 0.1267 Nm at 0.06 $m^3/s$.

The decrease in the torque at the Y axis is due to the volume flow, which increases the velocity in the X and Z axes which reduces the direct fall of water and forms a stronger vortex, which reduces the torque in the Y axis. Similarly, the torque onthe X and Z axes increases due to the increase in velocity in the X and Z axes. From the graphs, the torque inthe Fibonaccian casing is higher than the conical casing in all axes due to the guided flow of the casing of the Fibonaccian casing.

## V. CONCLUSIONS

The discussion above reveals various concepts about the comparison between Fibonaccian casing and conical casing while used in gravitational watervortex turbines. Theaverage relative pressure of the Fibonaccian casing is higher due to the guided structure present in the Fibonacciancasingsattaining a maximum average relative pressure of 8950 Paat a volume rate of 0.06 $m^3/s$ while the maximum average relative pressureat a volume flow of 0.06 $m^3/s$ is 7050 Pa in the conical casing;thus, it shows 21% higher relative pressure is achieved in the Fibonaccian casing. The torque inthe Y axis does not contribute to the rotation of the turbine. The torque in the X axis is higher in the Fibonaccian casing than in the conical casing, as the maximum value of X torque in the Fibonaccian casing is2.1484 Nm and in the conical casing is 1.4897Nm which is 30% higher. The difference in the torque generated in the Z direction between the 2 casings is relatively very small the Fibonaccian casing which has a small increase in net torque when compared to the conical casing as the maximum value ofZ torque in the Fibonaccian casing is 0.1267Nm and in the conical casing is 0.0686 Nm, which is 45% higher.

The relative pressure and the torque acting on the turbine directly affect the angular velocity of the impeller and the torque generated by the turbine which is directly proportional to the efficiency of the turbine.With higher pressure, optimized flow guidance, and greater torque, the Fibonaccian casing achieves an efficiency of 8.47%, whereas the conical casing reaches 7.37 %. This increase in efficiency demonstrates the enhanced energy conversion efficiency of the Fibonaccian casing than the conical casing. The manufacturing process of Fibonaccian casing is a bittricky, the complex structure makes it only manufacturable using 3D printing or printing a Mold using 3D printing and casting the cement into it.

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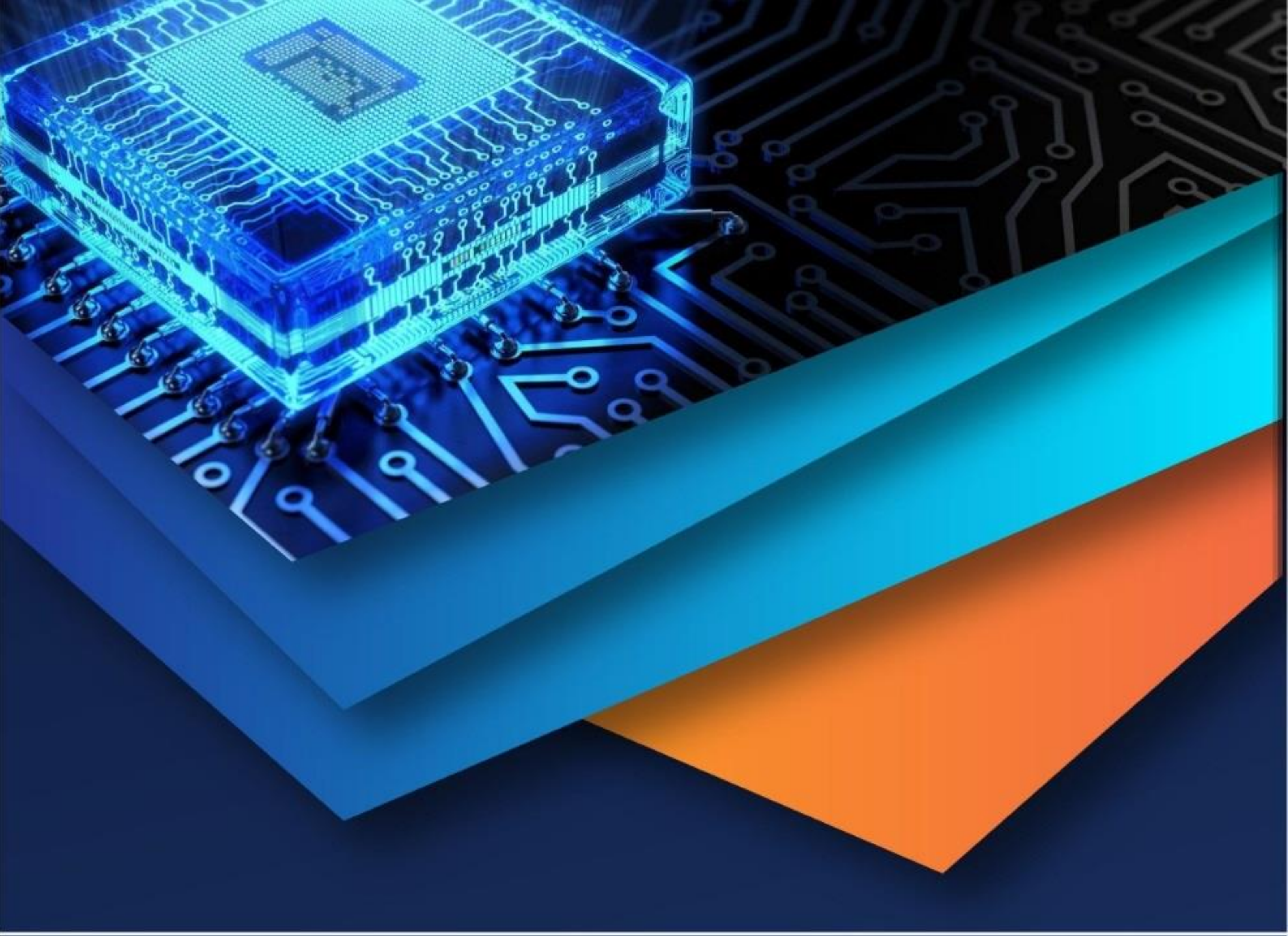


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