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Design and Development of a Small-Capacity Tesla Turbine for Rural Applications

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ABSTRACT
Bangladesh is in great need to find renewable energy sources for its fast-developing industrial sectors. The main objectives of this research are to design and fabricate a small-scale efficient Tesla Turbine for remote areas and test it through experimental investigations. Performance analysis of the newly designed Tesla Turbine suitable for remote areas of Bangladesh will be conducted. Until now, a number of researchers have undertaken several tests and studies to evaluate the Tesla turbine's performance and efficiency. Tesla Turbine does not proficient in producing torque. The work here consists of computational analysis and an experimental campaign by fabricating the turbine. Solid Edge 2021 is employed for our 3D modeling. For modeling, the desired material is Polylactic Acid (PLA) or ABS Plastic. The proposed design consists of 51 disks with an identical spacing of 3 mm. This design has led to achieving a torque of 19.85 N-m and a staggering efficiency of 81%. It was found that stress generated on the disk edges is higher than their centre due to high centrifugal force.

Keywords: *Tesla Turbine, Pico Hydro Application, Boundary Layer, Bladeless Turbine.*

1. INTRODUCTION

In this race of technological development, electricity is a must. The most conventional power generation methods involve fossil fuels. These affect the environment adversely by causing severe environmental pollution. In line with sustainable development goal (SDG) initiatives, it shall be everybody's efforts and responsibility in employing renewable energy technology for a consistent power supply and power generation. As in many developing countries, renewable energy sources are needed to counter the great global warming threat due to human activities, especially emissions from the conventional power generating sectors [1]. Recent technology in the solar panel and power generating sectors is good news, however, large batteries are required to support the electricity demand at night, which is important for developing countries. It is a matter of great concern that Bangladeshis demand for electric power rapidly outpaces supply and this is due to the high fertility rate and strong urbanization. Every year, the demand for electricity skyrockets is increasing rapidly.

As a result, meeting this demand has proven to be a difficult task. Bangladesh has numerous natural resources for generating electricity. Natural gas, on the other hand, is the most widely used energy source. This is an unsustainable source of energy and highly damaging to the environment. In such instances, using a personal small-scale turbine might help a lot. Using the water's potential energy for power generation purposes can fulfill the need for electricity in the hilly rural areas of our country.

A small-scale hydropower facility can be used to provide uninterrupted, consistent, and clean electricity. In this article, a study has been conducted to design and develop a small-scale Tesla Turbine for Pico hydro application in the hilly rural areas of Bangladesh. Nicola Tesla invented the Tesla Turbine in 1913. It is a bladeless turbine that employs smooth circular disks instead of the blades used in traditional turbines. This is the simplest type of turbine in existence. The Turbine's principle of operation is based on adhesion and viscosity (i.e., boundary-layer effect). Tesla Turbine's working principle allows it to be proficient in moving at an astoundingly higher RPM. According to an analytical finding, when using laminar flow, the

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rotor efficiency can be quite high, even exceeding 95% [2].

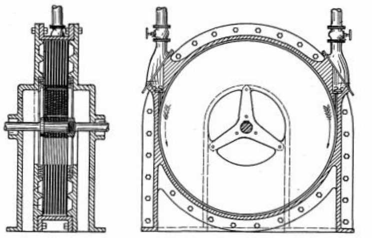

Figure 1 Tesla Turbine by Wikimedia is licensed under CC BY 4.0

Numerous researchers conducted analytical, experimental, and computational analyses to comprehend the performance of the Tesla Turbine. Rice's research was one of the first, claiming that turbines can be constructed to be 90% efficient [3]. Different nozzle styles are featured in Hoya and Guha's work. Croce's work, Roughness study, and flow through micro-channels, was published in 2007 [4]. Pandey's research focuses more on computational analysis. Sanghvi and Dave demonstrated their progress on disk assembly and surface finish. None of these studies, however, looked at the performance of a Tesla turbine built with locally available technology in a third-world country like Bangladesh where access to alternative and affordable energy is becoming increasingly difficult.

Figure 2 Tesla Turbine by Wikimedia is licensed under CC BY 4.0

Aside from testing, different computer evaluations have been performed in the past to assess the accomplishment of the Tesla turbine. Simulation studies have been utilized to gain a better understanding of different types of Tesla turbines since the introduction of high-speed computing resources. Some noteworthy research efforts are provided below. Tesla turbines, according to Rice, may theoretically achieve maximum efficiency of 90% [3]. Lawn and Rice and Ho-Yan both claimed over 70% efficiency [5]. Carey investigated the efficiency of a Tesla Turbine as an expander in a small-scale Rankine Cycle combined heat and power plant. According to Carey, if all other operating parameters are optimized, greater than 70% isentropic efficiency can be attained [6]. Krishnan et al. supplied an acceptable design study, which included criteria for the best turbine scaling. There has been enough discussion on the causes and effects of various sorts of losses, as well as the best methods for minimizing them to the greatest extent possible [7]. Their work is based on V. P. Carey's analytical solution. They also used an ANSYS simulation to confirm their findings. The disk thickness and the disk spacing influence the efficiency of a Tesla [8]. We need to keep the disk thickness and the disk spacing in the high-efficiency range to achieve the greatest output. When selecting the optimal disk spacing and disk thickness, the disk’s aerodynamic performance and mechanical stress should be balanced.

The Tesla Turbine is a promising prospect for increasing the performance of industries, particularly those that use, both compression and absorption refrigeration cycles. Cold shops, especially those with high-pressure lines, fall under this category.

The Tesla Turbine has gained widespread acceptance due to its vast range of uses. The investigation of the Thermo-hydrodynamic properties of a Tesla Turbine running on high-pressure methane shows the reduction of both pressure and temperature by removing mechanical work from natural gas. It indicates that NG will be able to absorb more heat from its surroundings. Simultaneously, mechanical power from the Tesla turbine may be used with an alternating current or direct current generator to generate electricity.

The produced direct current can be converted to alternating current or vice versa, depending on the end-use appliance and application. For local manufacturing, a system based on the usage of a battery-inverter can be connected with an electrical generator [9]. Gamrat et al. gave a thorough summary of prior investigations, as well as stating that the Poiseuille range increases with surface roughness [10]. Razak et al. and Carey et al. showed several sized turbines for micro-hydro power applications [6][11]. The main aim of this project is to promote future research works to achieve the proposed efficiency of the Tesla turbine.

2. POTENTIAL SMALL HYDRO SITES AND RESOURCES IN BANGLADESH

Bangladesh's hydropower capacity is significantly underutilized. Bangladesh is blessed with numerous rivers, which play a vital part in the livelihood of the Bangladeshi people. Due to a lack of high head and high flow rate, hydropower output is not up to par. Because resources are limited, good usage can lead to the generation of long-term power to meet the ever-increasing demand. In Bandarban, Bangladesh's first small-scale micro-hydro power plant, with a capacity of 10 kW, was built to meet the energy needs of 140 families and a temple. In Barkal Upazila, Rangamati, the government built a 50 kW micro-hydro power plant [12]. In 1981, the Bangladesh Power Development Board (BPDB) and the Bangladesh Water Development Board (BWDB) surveyed the country to identify potential hydropower sites for small-scale hydropower facilities. Hydroelectricity can be produced throughout the year except in April and May.

There is a proposal to construct a dam in Mahamaya Chara (located in Mirsharai, Chittagong) which will encompass an area of 10.5 km^2 to reserve water and provide irrigation facilities. A mini-hydro plant will be established at the foot of the dam and reservoir water will run this plant. [14]. Sufficient electricity to fulfill the demand of locals has not been provided from the mainland grid. For the prosperity of those locations, stable and consistent electricity is very important as many of those sites are tourists spots as well. These hydro-sites are very potential for pico-hydro applications. A small-scale tesla turbine can be used to utilize the potential of these hydro-sites. Moreover, Tesla turbines do not require any complex parts which makes them easily manufacturable in a short period.

Table 1. Potential Small Hydropower sites identified by BPDP and BWDB [13][14]

District	River/Stream	Potential of electrical energy (kW)
Chittagong	Faiz Lake	4
Chittagong	Choto Kumira	15
Chittagong	Hinguli Chara	12
Chittagong hilltracts	Sealock	81
Chittagong	Lungichara	10
Chittagong	Budichara	10
Sylhet	Nikhan Chara	26
Sylhet	MadhabChara	75
Sylhet	Banga Pani Gung	616
Dinajpur	Chawai	32
Dinajpur	Tangon	48
Rangpur	Bari Khora	32
Rangpur	Ful Kumar	48

3. PERFORMANCE ANALYSIS

Rice's research provides us with two different equations of motions in the dimensionless form in which the dimensionless parameters are allowable turbine operating parameters. These parameters are variables in terms of which the analytical results can be related to actual turbine conditions. In each solution, the matching *x* and *y* values were tabulated, together with a range of values of other dimensionless parameters. The equations are –

$$\frac{dx}{dy} + \frac{y}{x} - \frac{fr_0^2\Omega}{4bv_0}(\frac{v_0}{\Omega r_0}y - x)[1 + \left(\frac{2\pi br_0^2\Omega}{Q}\right)^2 \; x^2 \left(\frac{v_0}{\Omega r_0}y - x\right)^2]^{\frac{1}{2}} = 0 \quad (1)$$

$$\frac{1}{\rho\Omega^2 r_0^2}\frac{dp_r}{dx}\left(\frac{Q}{2\pi br_0^2\Omega}\right)^2\left(\frac{1}{x^3}\right)^2 - \left(\frac{v_0}{\Omega r_0}\right)^2\left(\frac{y^2}{x}\right) \; \frac{fr_0}{4b}\left(\frac{Q}{2\pi br_0^2\Omega}\right)^2\left(\frac{1}{x^2}\right)\left[1 + \left(\frac{2\pi br_0^2\Omega}{Q}\right)^2 \; x^2\left(\frac{v_0}{\Omega r_0}y - x\right)^2\right]^{\frac{1}{2}} = 0 \quad (2)$$

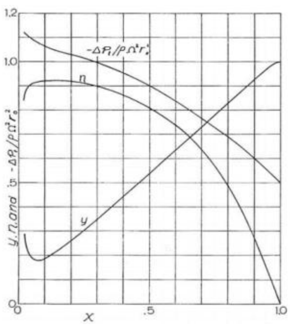

Figure 3 (a) Typical solution of equations describing turbine performance. Plotted for $f = 0.02$, $r_o/b = 50$, $\Omega r_o/v_o = 1.00$, and $Q/\Omega r_o^3 = 0.00001$ [3]

With the help of these solutions, the turbine performance parameters were developed. The relation between the performance parameters and the dimensionless parameters was plotted in graphs given in **Figure 3.**

Performance Parameters:

Table 3 provides the design parameters. The outer radius of the disks was 150 mm, and the distance between them was 3 mm, resulting in a radius to the spacing ratio of 50. This allowed us to select parameters for conducting the necessary calculation.

Table 3. Performance Parameters

Fixed Parameters	Measurement	Units
Outer radius, r_o	150	mm
Inner radius, r_i	12.500	mm
Disk spacing, b	3.00	mm
Angular velocity, Ω (Assumption)	2000	rad/s
Number of disks, N	50	
Disk thickness	1	mm
Flow rate, Q	0.00066700	m^3/s
Density of water, r	1,000.00	kg/m^3
Dynamic viscosity of water at 25 °C	0.00089000	Pa.s

Performance Calculation:

When the dimensionless radial coordinate is 0.5, the value of the dimensionless tangential velocity component (y) is 0.525, as seen in the graph provided in **Figure 3(a)** and **Figure 3(b).**

$$\frac{W}{\Omega^2 r_0^2} = \left(\frac{v_0}{\Omega r_0}\right)(i - xy) \quad (3)$$

By using the values of x & y from the graph and other design parameters, we calculated the amount of work done from equation (3). Since the amount of work done by the turbine was calculated, it was time for the calculation of efficiency. It was determined by using equation (4) which is given below.

$$\eta = \frac{\frac{W}{\Omega^2 r_o{}^2}}{\frac{\Delta pt}{\rho\Omega^2 r_o{}^2}} \quad (4)$$

On the denominator in equation (4), there is a dimensionless parameter. For the values of x & y, we got a corresponding value of the dimensionless parameter given in the denominator of the fraction in equation (4). The work done was estimated using this in conjunction with other factors. As a consequence, an efficiency of approximately 81% was attained theoretically at no-load conditions.

$$T = -(v_i r_i - v_0 r_0)\, Q\rho \quad (5)$$

Finally, by using equation (5), the torque was calculated. A table containing all the calculated results is provided in **Table 4**.

Table 4. Performance Calculation

Calculations	Results	Units
Outer velocity, v_o	300	m/s
Inner velocity, v_i	25	m/s
Dimensionless radial coordinate, x	0.50	
Dimensionless tangential velocity component, y	0.525	
Darcy friction factor, f	0.0250	
Work per unit mass, W	66,375	J
$DP_t/rW^2r_o^2$ (Dimensionless parameter from graph)	0.9	
Efficiency, η	81	%
Torque, T	19.85	N.m
Power, P	29,940	W

4. DESIGN ANALYSIS

A solid model was prepared using solid modeling software, Solid Edge 2021. An illustration of our solid model has been provided in **Figure 4** and **Figure 5.** The recommended material for disks is stainless steel. This is because stainless is much more warp-resistant than aluminium. The chance of warping in aluminium disks is higher due to the high rpm of the disks. But the body of the turbine can be made with aluminium as there is no high-speed movement or rotation.

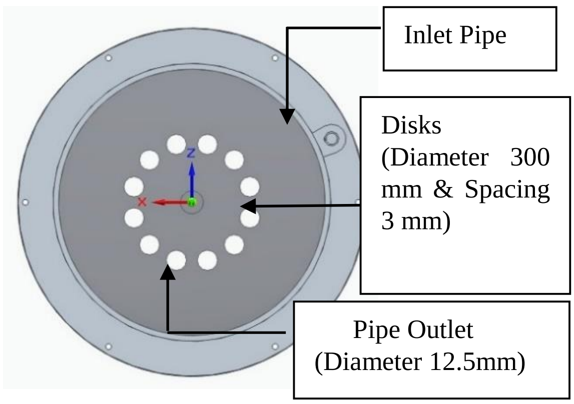

Figure 4 A Labelled Front View of the Turbine.

The selected ratio of the disk's outer diameter and the disk gaps was 50. The solid model in the current project is prepared accordingly so that further calculations to get the desired torque on a trial-and-error basis could be conducted. There are fifty disks with an identical diameter of 300 mm. Each of them has twelve outlet holes with a diameter of 12.5 mm. There is an inlet pipe to force water inside to rotate the disks.

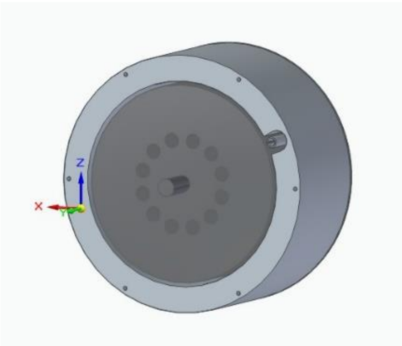

Figure 5 Isometric View of the Turbine.

Figure 5 shows an isometric view of the Tesla turbine.

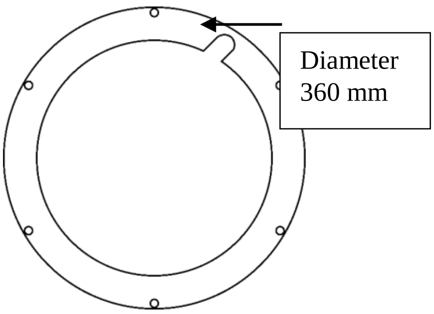

Figure 6 Housing Unit.

The shape of the case or the main housing unit is kept cylindrical. This eliminates the possibilities of residual stresses and it will take less material for fabrication. The outer diameter of the case is 360 mm and the inner diameter is 306 mm. A clearance of 3 mm is kept. This allows us to deal with the expansion of disks due to the centrifugal force caused by high rpm.

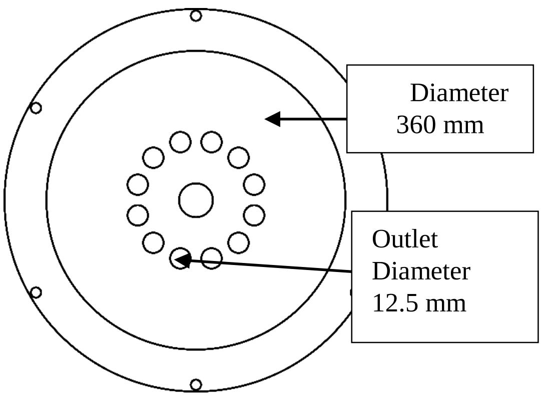

Figure 7 Outlet Cover.

What we have here is the outlet side of the turbine. What we can see here is, there are 12 outlet holes with an identical diameter of 12.5mm on the outlet cover. There are 12 holes in the disks as well as in the outlet panel to prevent backward pressure. The backward pressure can hamper the fluid's direction. The disks and shafts are kept as a whole unit. If we use the splitter, the leakage might occur. Again, the fabrication of splitters will require more material. Therefore, the design will not be cost-effective.

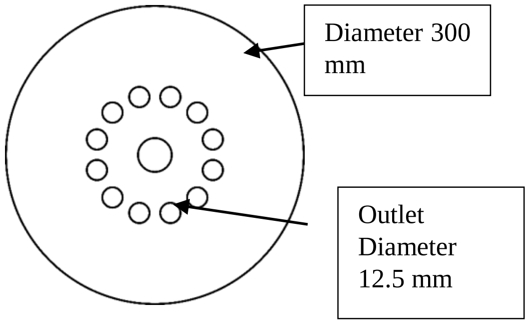

Figure 8 Disk and Shaft (Front View).

Again, the surface of the disks will be kept rough for better friction. We know that Tesla Turbine generates high speed with low torque. By making the surface rough, the torque can be increased significantly.

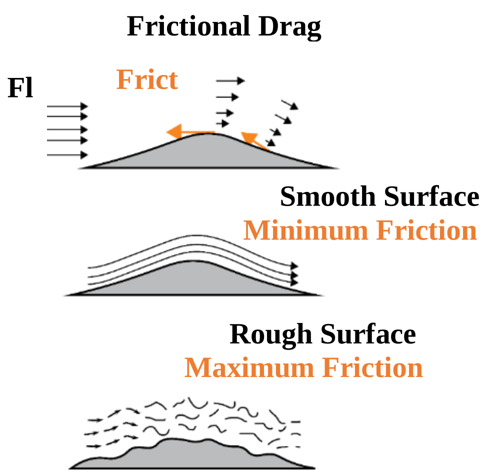

Figure 9 Frictional Drag (Using Vector Artwork Tool).

5. RESULTS & DISCUSSIONS

The outer radius of the disks was 150 mm, and the distance between them was 3 mm, resulting in a radius to the spacing ratio of 50. This enables us to take advantage of the graph's data. As seen in the graph, when the dimensionless radial coordinate (x) is 0.5, the dimensionless tangential velocity component (y) equals 0.525. These figures, together with other criteria, were used to determine the amount of work done. As a result, in no-load circumstances, a theoretical efficiency of about 81 percent was achieved. Graphical illustrations showing stress across the disk are provided below. The stress analysis was done using Solid Edge 2021. It can be seen that; stress is mostly seen on the edge areas. This is due to the centrifugal force caused by the high angular velocity (approximately 2000 rad/s) and high RPM (approximately 18,000 RPM) of the turbine disks. Again, it is seen that the stress generated on the edges of both disks increases with the increase in disk RPM. Figure 11 represents the stress across stainless steel disks and Figure 12 represents stress across ABS plastic disks.

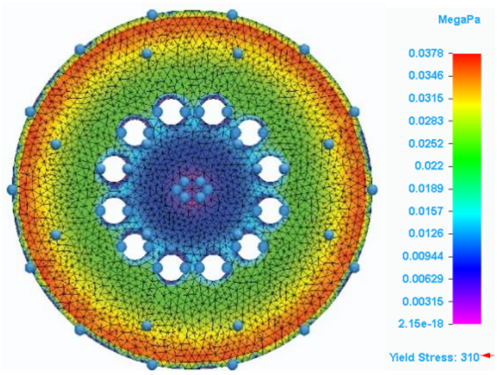

Figure 11 Stress Analysis (Stainless Steel)

The yield stress (σ_y) for stainless steel is 310 MPa. It is clear from the stress analysis that, stress generated on the edges are quite below the yield stress region.

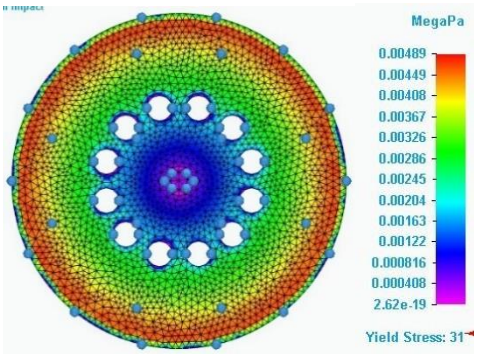

Figure 12 Stress Analysis (ABS Plastic)

Again, the yield stress (σ_y) for ABS plastic is 31 MPa. It is clear from the stress analysis that, stress generated on the edges is quite below the yield stress region. Therefore, it is suitable for using stainless steel for fabrication and ABS plastics for modeling.

6. CONCLUSION

A comparison between Rice's turbine and our turbine is illustrated in **Table 5.** It is evident from **Table 5** that an increase in the diameter and the number of disks can have a staggering increase in power. Rice's turbine could produce only 1800 W of power. On the contrary, we could achieve an astounding 29,940 W power from our turbine.

Table 5. Comparison between Rice's work and this Paper

Author	Rice	This Experiment
Inner Radius, r_i	33.5	12.5
Outer Radius, r_0	88.9	150
Number of Disks	9	51
Disk Spacing	1.6	3
RPM	11,800	18,000
Torque	N/A	19.85
Power	1800	29,940

In comparison to other prime movers, the Tesla turbine provides power at a high rotational rate and low torque. When operated with low-pressure flows and a low flow rate, Tesla turbines have high efficiency. Fluid's kinematic viscosity and density influences the energy transmission in a tesla Turbine. The flow rate controls the power output and smoothness of the flow. Tesla turbines will not be deemed competent in the general market until their efficiencies exceed those of conventional designs and their power densities are increased. This project supports SDG initiatives, e.g., "Affordable and clean energy" (SDG-7), "Responsible consumption and production" (SDG-12), "Climate action" (SDG-13). These sustainable development goals are important in building up a sustainable and reliable future especially in this region [15].

7. FUTURE SCOPE

In the future, further studies can be carried out on the surface roughness of the disks, disk thickness, and spacing between the disks. Moreover, brief research of the applications of Tesla turbines in different fields particularly in power generation at both low level and high-level generation can be conducted in the future. Due to the pandemic, we could not proceed with the fabrication. However, in the future, it can be done which will provide more information and data about the practicality of tesla turbine. Future research will reveal how a Tesla turbine can be used in the commercial sector.

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