SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879

Improvising the Tesla Micro-Turbine: Experimental and Performance Analysis

Muhammad Nor Ikmal Muhamad Nazri[1], Adi Azriff Basri[1,2,3,*], Mohd Na'im Abdullah[1], Faizal Mustapha[1], Farid Bajuri[1], Ernnie Illyani Basri[1], Masaaki Tamagawa[4]

[1] Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia
[2] Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, Serdang, Selangor, Malaysia
[3] Aerospace Malaysian Research Center (AMRC), Universiti Putra Malaysia,43400, Serdang, Malaysia
[4] Graduate School of Life Science and Systems Engineering Department of Biological Functions Engineering, Kyushu Institute of Technology, Fukuoka, Japan

ARTICLE INFO

Article history:
Received 24 November 2024
Received in revised form 28 February 2025
Accepted 9 March 2025
Available online 30 March 2025

Keywords:
Tesla turbine; bladeless micro-turbine; improvisation of tesla turbine; tesla turbine power generation

ABSTRACT

Present Tesla turbine presented a distinct approach to conventional turbine technology by utilizing frictional and viscous forces acting on stacked discs, deviating from the traditional use of blades. Characterized by its efficient energy extraction through boundary layer adhesion and cohesion, the Tesla turbine can achieve exceptional rotational speeds. However, its limited torque output remains a significant challenge, particularly for applications demanding high torque. Hence, the objective of this manuscript is to improvise the design of the Tesla turbine and analyze the impact of the new design's rotational speed, voltage, current and electrical power generation with increasing inlet pressure. The research methodology employed in this study involves the design of the Tesla turbine discs, then proceeded with experimental work from fabrication of the designed discs and conducting performance tests. It aims to gather quantitative data through controlled experiments to assess the best design of the turbine and test the performance and feasibility of the improvised Tesla turbine. The model comprises of bladed design around the disc performed the best at producing electrical power up to 19.08 W at 50 psi inlet pressure.

1. Introduction

Growing concerns about the environment have led to growing interest in eco-friendly technologies, particularly those that utilize renewable energy sources [1]. Researchers have designed and analyzed various wind turbine configurations to maximize wind energy extraction. Tesla turbine, patented by Nikola Tesla, is a unique turbine that is made up of a series of flat discs with nozzle on the side [2]. As the fluid spirals inward towards the central exhaust, it interacts with the discs, transferring energy through friction and viscous forces within the boundary layer. Unlike traditional

* *Corresponding author.*
E-mail address: adiazriff@upm.edu.my

https://doi.org/10.37934/arfmts.129.1.5868

turbines, it relies on utilizing the boundary layer of the fluid for momentum transfer. There are many studies on the Tesla turbine including numerical analysis, simulation works, and experimental investigation done by the researchers for many years. In terms of experimental works, most literature focuses on finding the best parameters of Tesla turbines like disc sizes, spacings, and the nozzle designs [3-5]. In terms of experimental works, most literature focuses on finding the best parameters of Tesla turbines like disc sizes, spacings, and the nozzle designs [6-8].

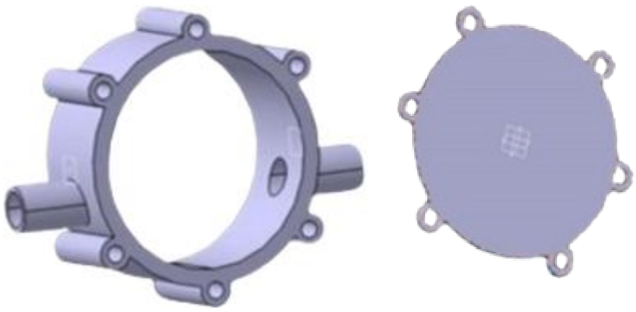
While the Tesla turbine offers a simpler design compared to bladed turbines, its operational efficiency needs further research and development. The resurging interest in Tesla turbines comes from their potential as a source of energy-efficient, low-power generation. Early research in Tesla turbines technology established their potential for low-power applications, paving the way for smaller-scale turbine development [9,10]. The Tesla turbine presents itself as a valuable option for diverse energy recovery projects, including: (i) low-capacity Organic Rankine Cycle (ORC) systems, (ii) extraction of energy from various sources, and (iii) integration of low-enthalpy gaseous or fluid streams within micro combined heat and power (mCHP) systems [8,11-14]. One noted challenge associated with Tesla turbines is the difficulty in initiating rotation [15]. This issue arises when the initial flow velocity is insufficient to establish a strong boundary layer, hindering the turbine's ability to start at low inlet pressure. Consequently, various research efforts have explored modifications to the Tesla turbine design aimed at overcoming this initial rotation difficulty.

Anirudh and Shashank [16] conducted an experimental study comparing the performance of discs with varying dimple sizes on one side to discs without dimples. At an inlet pressure of 72 bars, the dimpled discs exhibited a rotational speed of approximately 13500 revolutions per minute (RPM), while the non-dimpled discs reached speeds of 12000 RPM. This suggests that increasing the total surface area for fluid adhesion through the incorporation of dimples may prove more effective than utilizing flat surfaces during boundary layer flow. Additional studies explore enhancing the torque and power output in Tesla turbines. Basri *et al.,* [17,18] uses CFD to investigate the impact of inlet nozzle configuration on turbine performance. Their findings reveal that the 4-inlet, 4 outlet (4i4o) configuration significantly outperforms the 4 inlet, 1-outlet (4i1o) setup in terms of torque and power output, with a tenfold increase. Additionally, the 4i4o design exhibits superior thrust (33.69% improvement) and efficiency (34.30% improvement) compared to the 4i1o configuration. Notably, the 4i4o configuration achieves a much higher efficiency (34.30%) than the 4i1o configuration (3.11%).

In terms of power output, an increase of RPM of Tesla turbine results in a corresponding increase in voltage, current, and power. Study suggests that to achieve greater power generation, a Tesla turbine design with an enhanced RPM capacity is necessary [4]. Rice recorded the top experimental power output, which was achieved using a 4-kW bench setup [9]. These discoveries support the idea of using Tesla turbine as a small turbine and show that it's becoming more common to use it for capturing very low levels of energy. This study investigated the impact of disc design on the rotational speed, voltage, current, and power output of an improvised Tesla turbine. The discs, fabricated using stereolithography (SLA) 3D printing, were tested with compressed air. The performance of the most effective design is then compared to the original bladeless turbine design.

2. Methodology

Experiments were conducted to measure the RPM of the turbine with increasing inlet pressure. The design parameter is shown in Table 1. This design parameter was kept constants for all models. All Tesla turbine blade models and the casing were designed using CATIA V5 as shown in Figure 1 to Figure 4. The models were fabricated using 3D printing method because compared to traditional methods like machining, 3D printing allows for quick and affordable creation of multiple iterations of the turbine designs. 3D printing was conducted using the Eleagoo Saturn 3 Ultra resin 3D printer for its capability in producing high accuracy model.



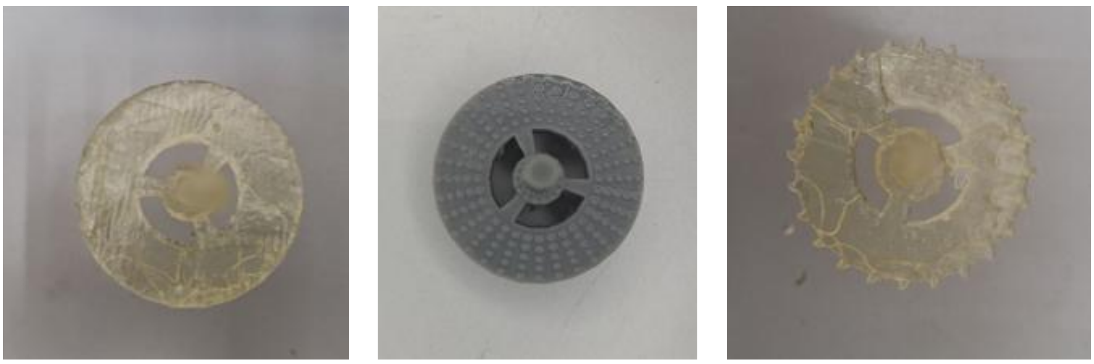
(a) (b)

Fig. 1. 3D drawing of a (a) body casing (b) top casing

Table 1
Constant parameter of all turbine model

Parameters	Measurement
Disc Spacings (mm)	0.9
Disc Thickness (mm)	1.1
Disc Diameter	24.85
Number of Disc	4
Shaft Diameter (mm)	2.8
Diameter of Turbine Casing (mm)	71.5 x 21 x 53.8
Inlet Nozzle Diameter (mm)	5

Three models of different Tesla turbines were designed in CATIA V5. Model 1 was comprised of normal disc pure Tesla Turbine. Model 2 was comprised of roughened disc of pure Tesla model. The aim is to maximize the adhesive and cohesive force that will drive the turbine. Model 3 comprises of added blade around the discs to improve the turbine's capacity to capture and transform the kinetic energy of air (or other working fluids), as opposed to depending exclusively on the boundary layer effect. The disc spacing, diameter and thickness were kept constants for all models. Prior to printing the 3D model was sliced using Chitubox slicing software. The material used for printing was water-washable resin which is ABS-like UV sensitive resin by Sunlu. Figure 2 shows the three printed models of the turbines. All models were exposed to sunlight for 4 hours for further curing.



(a) (b) (c)

Fig. 2. Fabricated 3D printed model of (a) Pure Tesla Turbine Disc (Model 1) (b) Roughened Surface Disc (Model 2) (c) Bladed Disc (Model 3)

As shown in Figure 3, the experimental setup was used to obtain RPM of each turbine without load (without generator). The Tesla turbine was connected to the air compressor to supply the compressed air, and a pressure gauge was placed between them to monitor the input pressure. The pressure gauge was shown in Figure 4. The tachometer, on the other hand, was placed perpendicular to the turbine to measure the RPM of the rotor starting from 10 psi inlet pressure with subsequent data collection at pressure increments of 10 psi until 50 psi. The tachometer readings were monitored until they stabilized before recording the value. Each measurement was repeated three times to obtain an average rpm reading for improved accuracy.

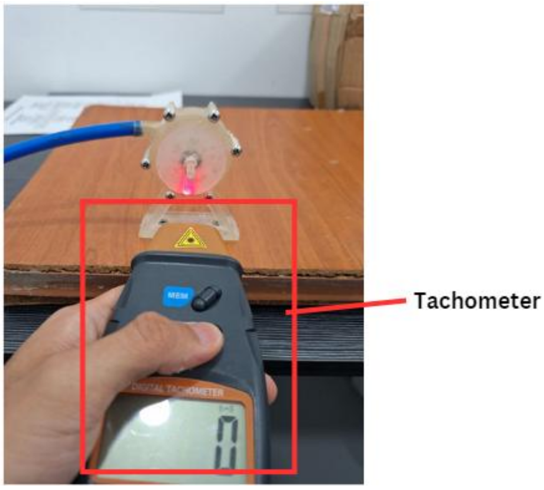


Fig. 3. Unloaded turbine rotational speed test set up

Fig. 4. Pressure gauge of the air compressor to control inlet pressure

In addition to unloaded testing, loaded testing was performed by connecting the turbine shaft to a generator to measure the voltage, current, and electrical power output for each turbine model. The RS-500 DC motor was used as the generator in this experiment as shown in Figure 5. The rotational speed of the turbine was also recorded to assess its performance under loaded conditions. The setup of the experiment can be this creates a single device capable of both generating electricity and driving the compression process [8,19]. The rotational motion of the shaft is transformed into electrical energy. This electrical energy can be quantified by measuring the voltage and current produced. The value of voltage and current output of all turbines were obtained using a voltmeter and an ammeter, respectively. Likewise, an average data collection of three times for each inlet pressure was made. By obtaining the voltage and current value, the useful electrical power obtained can be calculated using the electrical power law equation as shown in Eq. (1).

$$P = IV \tag{1}$$

where P is the electrical power generated, I is the current produced and V is the output voltage.

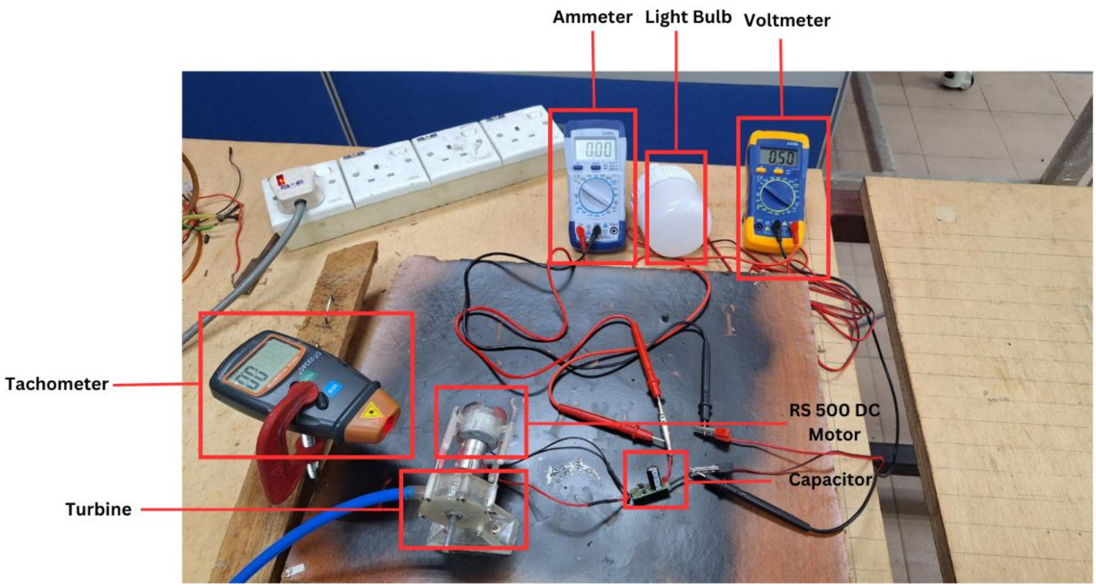


Fig. 5. Loaded experimental setup

3. Results

3.1 Unloaded Rotational Speed

Figure 6 shows the unloaded rotational speed of all model turbine. The trend shows that as inlet pressure increases, rotational speed rises for all turbine models until reaching a saturation point, where the speed remains constant, indicating the maximum achievable speed. At 10 psi, noticeable differences in speed were observed. The pure Tesla disc had the lowest speed at 3926 rpm, followed by the bladed disc at 4846 rpm. The roughened disc reached 6027 rpm, while the roughened bladed disc recorded the highest speed at 7315 rpm. This suggests that roughened surfaces enhance boundary layer interaction and momentum transfer, leading to higher speeds at lower pressures. In contrast, smooth discs experience less surface friction, limiting momentum transfer [13]. At 30 psi, all models plateaued, with the roughened disc achieving the highest speed of 17653 rpm at 50 psi, likely due to its combined roughened, which optimizes energy transfer from the fluid due to its optimized adhesion forces.

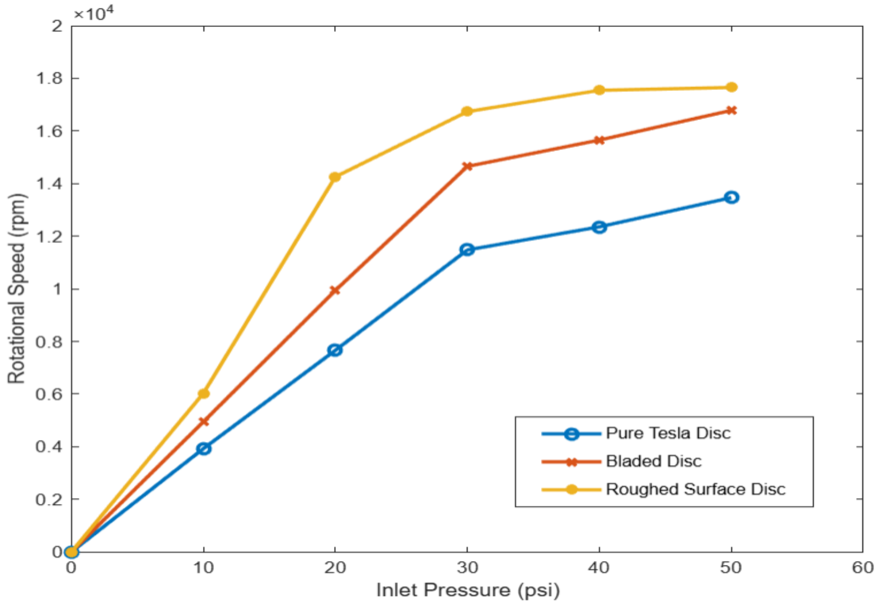


Fig. 6. Unloaded Rotational Speed vs Inlet Pressure (Psi) Testing Result

3.2 Loaded Testing Results

After testing the models without load, the next phase involved rotational speed testing with a load by connecting the turbine to the RS-500 DC Motor generator. The goal was to assess how well the three models performed in generating useful electrical power. The results, shown in Figure 7, mirror those in Figure 6. At a lower inlet pressure of 10 psi, roughened disc performed best, reaching around 3300 rpm, while Models 1 and 3 spinned at 2607 and 1500 rpm respectively. The roughened disc was performed the best at lower inlet pressure (10-30 Psi). However, at 40 psi, the bladed disc was starting to surpass and at higher inlet pressure (50 Psi) the bladed disc outperformed the roughned disc by around 3000 rpm, spinned at around 15648 rpm. The pure Tesla on the other hand spinned at the lowest speed among the three, at around only 8453 rpm.

Like the behavior observed during unloaded rotations, the turbine with a roughened surface disc was able to generate revolutions at lower inlet pressures, even under load. This demonstrates the turbine's ability to maximize adhesion forces by increasing surface friction, which helps drive the turbine to higher speeds at lower pressures. The roughened surface enhances the boundary layer interaction, allowing the turbine to transfer more of the fluid's kinetic energy into rotational motion. However, this concept holds true only at lower inlet pressures. At higher pressures, the turbine with blades began to outperform the roughened disc model without blades. This indicates that at elevated pressures, adhesion forces become less effective in driving the turbine. Instead, the blades play a crucial role by capturing the energy from the fluid flow more efficiently and converting it into rotational movement.

The shift in dominance from surface adhesion to blade-driven energy capture highlights the importance of blade design in enhancing turbine performance, particularly at higher pressures. It suggests that while roughened surfaces are beneficial at lower pressures, blades are essential for maximizing turbine speed and efficiency when dealing with stronger fluid flows.

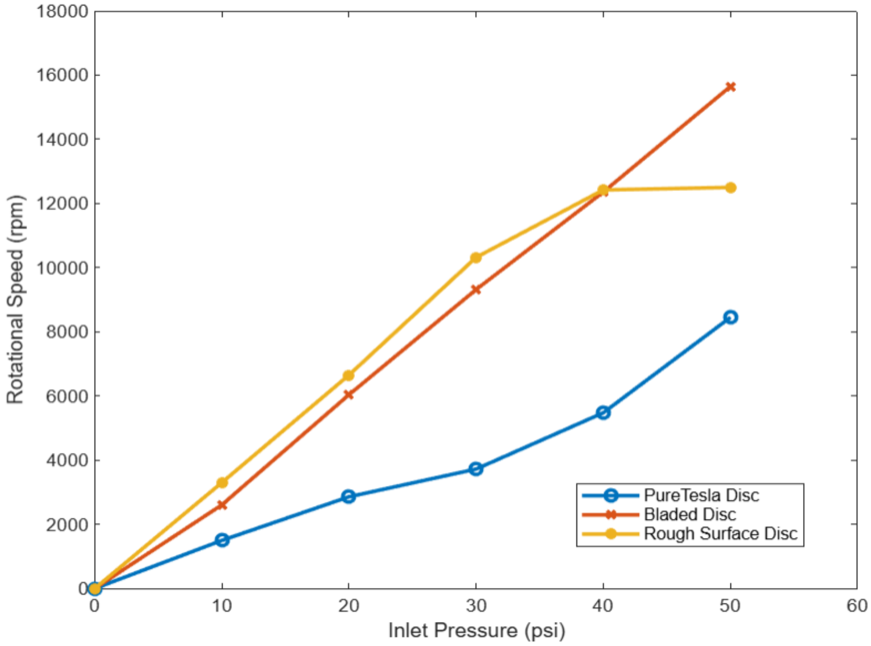


Fig. 7. Loaded Rotational Speed Result vs Inlet Pressure (Psi) Testing Result

The voltage generation in Figure 8 follows a similar trend to the RPM data presented in Figure 7. This is due to the direct linear relationship between the rotational speed of a DC motor's shaft and the voltage it generates. Simply put, as the shaft rotates faster, the generated voltage increases proportionally [4,20]. Since the turbine shaft is connected to the generator motor, both the turbine and generator motor share the same RPM. At a lower inlet pressure of 10 psi, the roughened disc outperformed the other designs, generating approximately 6.6 V, while the pure disc and bladed disc produced around 3 V and 5.214 V, respectively. This advantage of the roughened disc continued until the inlet pressure reached 40 psi. However, similar to the RPM trend in Figure 7, the bladed disc began to outperform the roughened disc in voltage generation as the rotational speed of the roughened disc slowed down relative to the bladed one. This emphasizes the superior ability of the bladed design to capture flow at higher inlet pressures, even when under load. At 50 psi, the bladed disc turbine achieved the highest voltage output of 26.426 V, surpassing both the pure and roughened disc designs. Although the RPM in Figure 7 was higher at this point, the voltage output plateaued due to the motor reaching its maximum voltage capacity.

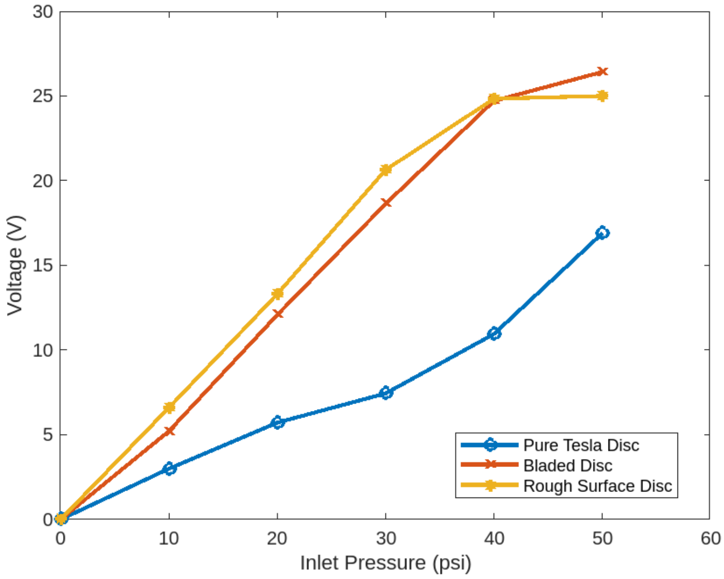


Fig. 8. Voltage (V) vs Inlet Pressure (Psi)

As shown in Figure 9, the current produced by all turbine models increased with higher inlet pressure. At a low inlet pressure of 10 psi, the bladed disc turbine generated the highest current at approximately 0.054 A, while the pure Tesla disc produced about 0.005 A—ten times lower than the bladed disc. This trend of the bladed disc producing the highest current continued at higher inlet pressures. The reason for this lies in the relationship between current and the torque produced by the turbine. The bladed disc generated more torque because it was better at capturing the kinetic energy of the fluid flow, resulting in significantly more torque and, consequently, higher current production compared to the pure Tesla and roughened discs, which produced lower torque and, therefore, lower current.

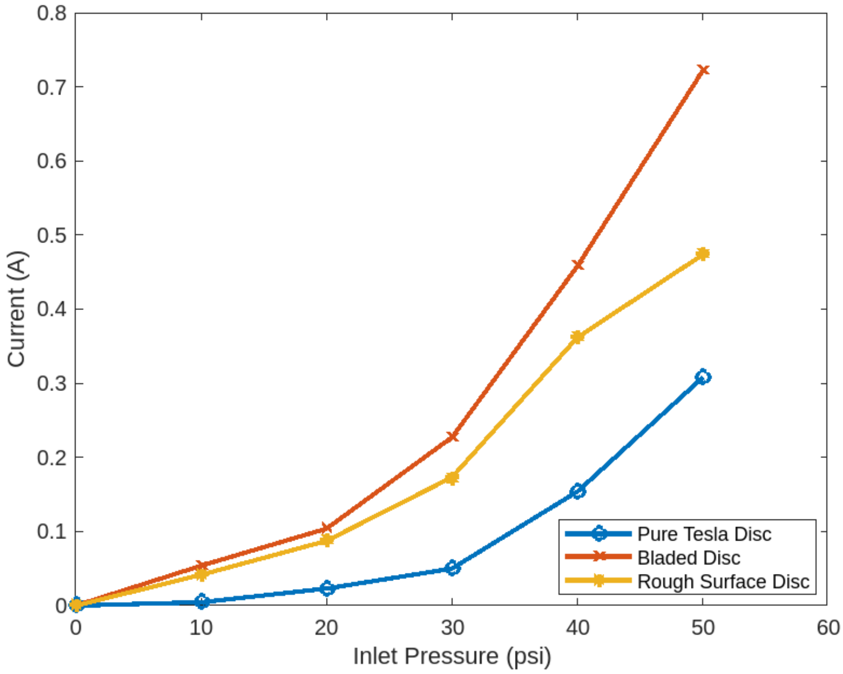


Fig. 9. Current (A) vs Inlet Pressure (Psi)

Figure 10 illustrates the output power generated by all turbine models and their corresponding generators. This power is the product of the voltage and current produced by the turbines. Since the measurements were taken directly from the motor, the recorded power includes frictional losses from the turbine shaft bearings and the generator itself [20]. The bladed disc produced the highest power, reaching 19.08 W at maximum inlet pressure. By optimizing both speed and torque, the bladed disc turbine generated significantly more power than the roughened disc (11.85 W) and Model 1 (5.21 W). At low inlet pressures, such as 10 psi, there was little difference in power output between the three models. However, at 20 psi, the performance gap between the modified turbines and the original pure Tesla disc became evident, demonstrating the superiority of the modified designs. As the inlet pressure increased further, the bladed disc consistently outperformed the other models. This highlights the effectiveness of the added blades around the disc, which significantly improved torque and current production, both critical factors in maximizing power output.

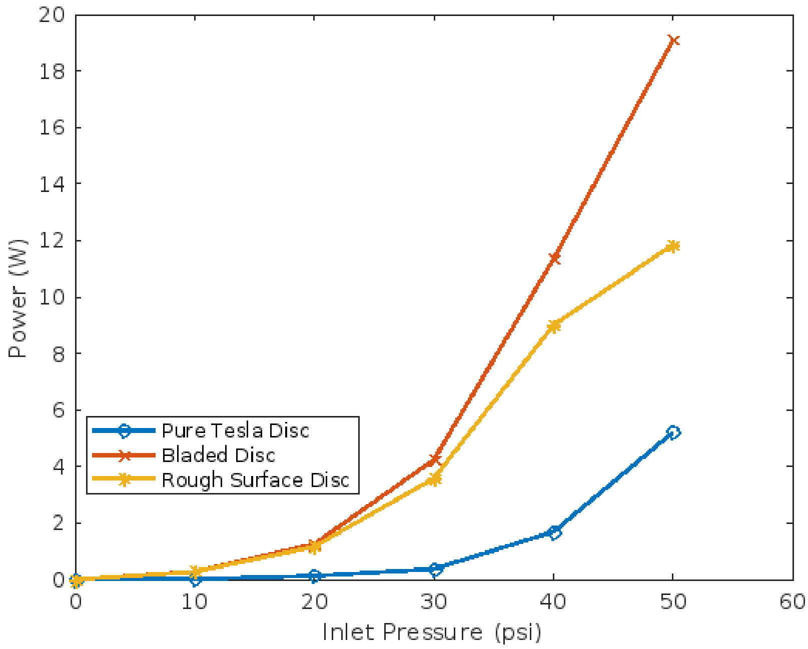


Fig. 10. Electrical power output (W) vs Inlet Pressure (Psi)

The inclusion of a blades design in the Tesla microturbine has demonstrated significant improvements in capturing fluid flow, thereby enhancing torque generation. This increased torque is directly proportional to the current produced, highlighting the efficiency gains from the modified design. Studies have shown that optimizing blade or disc designs to better capture and direct flow can lead to substantial performance improvements in turbine systems. For instance, Gümüş *et al.,* (2016) found that modifications to the geometry of turbine blades could significantly improve energy conversion efficiency. In the context of microturbines, where compact and efficient designs are crucial, the blades offer a promising avenue for maximizing energy conversion from fluid dynamics. Additionally, the work by Li and Wang (2018) supports the notion that intricate design features can enhance the interaction between fluid flow and turbine components, leading to higher performance metrics.

Further CFD simulations shall provide detailed insights into the behavior of fluid interactions with turbine components, enabling precise adjustments to optimize performance. In the realm of microturbines, CFD has been effectively used to model and predict performance outcomes [21]. Different turbulence models available in commercial CFD software offer distinct advantages that can be leveraged to extend microturbine studies. The Shear Stress Transport (SST) model and its variants have been extensively tested across various applications including turbines, machinery, and medical devices [22,23]. By applying CFD to the Tesla microturbine, researchers can identify areas of potential improvement and further refine the teeth-like design to achieve higher efficiency and power output. This approach not only advances the theoretical understanding of microturbine operation but also offers practical benefits in the development of more efficient renewable energy technologies.

4. Conclusions

In conclusion, for both without load and loaded test, the highest RPM was achieved by Model 3 at highest inlet pressure (50 psi). However, at low inlet pressure (10-30 psi), Model 2 performed better in terms of RPM. For power production, Model 2 has the best performance compared to Model 1 (pure disc) and Model 3 due to Model 2 producing more current hence increasing the power production. This shows that the added blades design help in capturing the flow, producing more torque, which is proportional to the current produced. The next step in this research would be employing CFD simulations to analyze the flow patterns across the disc design. Future research on this improvised model could concentrate on assessing the turbines' torque using various motors with varying rotational torques. This information can then be used to further optimize the design for improved performance. In the future, the modified Tesla turbine could potentially be utilized to power applications such as a quadcopter [24].

Acknowledgement
This research was funded by a grant from Universiti Putra Malaysia (GP-IPS/2024/9786500).

References

[1] Yu, Chia-Wei, and Wen-Bin Young. "Study of radiation heating and heat transfer of a concentrating solar power system with cavity receiver." *Journal of Aeronautics, Astronautics and Aviation* 50, no. 1 (2018): 81-94.

[2] Zuber, Mohammad, Adithya Ramesh, and Darpan Bansal. "The Tesla Turbine–A Comprehensive Review." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 62, no. 1 (2019): 122-137.

[3] Shaw, Dein, Feng Ting Liu, and Jyun Jhe Yu. "Experiment of a Tesla Engine for Wind Energy Capture." *Applied Mechanics and Materials* 284 (2013): 1051-1056. https://doi.org/10.4028/www.scientific.net/AMM.284-287.1051

[4] Akele, S. M. G., M. Ejededawe, G. A. Udoekong, A. Uwadiae, M. E. Oviawe, and B. O. Ayewa. "Design, construction and simulation of tesla turbine." *International Journal of Engineering and Management Research (IJEMR)* 11, no. 1 (2021): 84-92. https://doi.org/10.31033/ijemr.11.1.13

[5] Umar, Hamdani, Teuku Muhammad Kashogi, Sarwo Edhy Sofyan, Razali Thaib, and Akram Akram. "CFD Simulation of Tesla Turbines Performance Driven by Flue Gas of Internal Combustion Engine." *Journal of Advanced Research in Applied Mechanics* 98, no. 1 (2022): 1-11. https://doi.org/10.37934/aram.98.1.111

[6] Qi, Wenjiao, Qinghua Deng, Yu Jiang, Qi Yuan, and Zhenping Feng. "Disc Thickness and spacing distance impacts on flow characteristics of multichannel Tesla turbines." *Energies* 12, no. 1 (2018): 44. https://doi.org/10.3390/en12010044

[7] Qi, Wenjiao, Qinghua Deng, Zhenping Feng, and Qi Yuan. "Influence of disc spacing distance on the aerodynamic performance and flow field of Tesla turbines." In *Turbo Expo: Power for Land, Sea, and Air*, vol. 49866, p. V008T23A035. American Society of Mechanical Engineers, 2016. https://doi.org/10.1115/GT2016-57971

[8] Thomazoni, André Luis Ribeiro, Conrado Ermel, Paulo Smith Schneider, Lara Werncke Vieira, Julian David Hunt, Sandro Barros Ferreira, Charles Rech, and Vinicius Santorum Gouvêa. "Influence of operational parameters on the performance of Tesla turbines: Experimental investigation of a small-scale turbine." *Energy* 261 (2022): 125159. https://doi.org/10.1016/j.energy.2022.125159

[9] Rice, Warren. "An analytical and experimental investigation of multiple-disk turbines." *Journal of Engineering for Gas Turbines and Power* 87, no. 1 (1965): 29-36. https://doi.org/10.1115/1.3678134

[10] Truman, C. R., W. Rice, and D. F. Jankowski. "Laminar throughflow of varying-quality steam between corotating disks." *Journal of Fluids Engineering* 100, no. 2 (1978): 194-200. https://doi.org/10.1115/1.3448629

[11] Manfrida, G., L. Pacini, and L. Talluri. "An upgraded Tesla turbine concept for ORC applications." *Energy* 158 (2018): 33-40. https://doi.org/10.1016/j.energy.2018.05.181

[12] Talluri, Lorenzo, Olivier Dumont, Giampaolo Manfrida, Vincent Lemort, and Daniele Fiaschi. "Experimental investigation of an Organic Rankine Cycle Tesla turbine working with R1233zd (E)." *Applied Thermal Engineering* 174 (2020): 115293. https://doi.org/10.1016/j.applthermaleng.2020.115293

[13] Romanin, Vince D., Vedavalli G. Krishnan, Van P. Carey, and Michel M. Maharbiz. "Experimental and Analytical study of sub-watt scale Tesla turbine performance." In *ASME International Mechanical Engineering Congress and Exposition*, vol. 45233, pp. 1005-1014. American Society of Mechanical Engineers, 2012. https://doi.org/10.1115/IMECE2012-89675

[14] Lu, Zhao, Xiaoling Yu, Lichuan Wei, Yalin Qiu, Liyu Zhang, Xiangzhao Meng, and Liwen Jin. "Parametric study of forced air cooling strategy for lithium-ion battery pack with staggered arrangement." *Applied Thermal Engineering* 136 (2018): 28-40. https://doi.org/10.1016/j.applthermaleng.2018.02.080

[15] Hoya, G. P., and A. Guha. "The design of a test rig and study of the performance and efficiency of a Tesla disc turbine." Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 223, no. 4 (2009): 451-465. https://doi.org/10.1243/09576509JPE664

[16] Anirudh, Palle, and Shashank D. L. "Development of a modified tesla turbine." *International Research Journal of Engineering and Technology* 6, no. 9 (2019): 1665–1668.

[17] Basri, Adi Azriff, Shah Mohammed Abdul Khader, Cherian Johny, Raghuvir Pai, Muhammad Zuber, Kamarul Arifin Ahmad, and Zanuldin Ahmad. "Numerical study of haemodynamics behaviour in normal and single stenosed renal artery using fluid–structure interaction." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 51, no. 1 (2018): 91-98.

[18] Basri, Ernnie Illyani, Adi Azriff Basri, and Farah Nur Diyana Salim. "Study on the Effects of Individual Pitot Tube Inlet of a Bladeless Tesla Microturbine using Numerical Analysis." *CFD Letters* 15, no. 7 (2023): 14-30. https://doi.org/10.37934/cfdl.15.7.1430

[19] Pandey, Raunak Jung, Sanam Pudasaini, Saurav Dhakal, Rangeet Ballav Uprety, and Hari Prasad Neopane. "Design and computational analysis of 1 kW Tesla turbine." *International Journal of Scientific and Research Publications* 4, no. 11 (2014): 1.

[20] Guha, Abhijit, and Sayantan Sengupta. "The fluid dynamics of the rotating flow in a Tesla disc turbine." *European Journal of Mechanics-B/Fluids* 37 (2013): 112-123. https://doi.org/10.1016/j.euromechflu.2012.08.001

[21] Chen, Jianchong, Qiwei Zhou, Chenbing Zhu, and Xuelong Yang. "Effect of different blade number and thickness on performance of micro-turbine." In *Journal of Physics: Conference Series*, vol. 2707, no. 1, p. 012065. IOP Publishing, 2024. https://doi.org/10.1088/1742-6596/2707/1/012065

[22] Johari, Nasrul Hadi, Jegatis Balaiyah, and Zulkifli Ahmad. "Effect of chronic obstructive pulmonary disease on airflow motion using computational fluid dynamics analysis." In *2014 International Conference on Computer, Communications, and Control Technology (I4CT)*, pp. 249-254. IEEE, 2014. https://doi.org/10.1109/I4CT.2014.6914184

[23] Johari, Nasrul Hadi, Kahar Osman, Zuliazura Mohd Salleh, Juhara Haron, and Mohammed Rafiq Abdul Kadir. "The effect of different locations of tracheal stenosis to the flow characteristics using reconstructed CT-scanned image." *Journal of Mechanics in Medicine and Biology* 12, no. 04 (2012): 1250066. https://doi.org/10.1142/S0219519412500662

[24] Nazri, Muhammad Nor Ikmal Muhamad, Adi Azriff Basri, Ernnie Illyani Basri, and Spoorthi Singh. "Implementation of Control Valves System on Microturbine Drone's Rotational Motion." *Journal of Advanced Research Design* 122, no. 1 (2024): 46-59. https://doi.org/10.37934/ard.122.1.4659