Project report

Formation: Advanced Mechatronics (M2)

Subject: PROJ901 – Collective Project

Tesla Turbine Efficiency measurement

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I. Abstract

Tesla turbine is a bladeless turbine made by Nicola Tesla in 1913, he claimed that its efficiency can reach around 95%. This study aims to perform experimental tests using a prototyped Tesla turbine to calculate its efficiency and to show the relationship between input pressure and the outputs. The output is calculated in both mechanical and electrical methods. After comparing the results, a directly proportional relationship between the input pressure with torque and rotation speed is obtained, as well as the efficiency.

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1 Introduction

Due of the demand, researchers have been looking into new ways to provide and produce power that is more reliable, economical, and low maintenance. A bladeless turbine, invented by Nicola Tesla and patented in 1913, is made up of parallel thin discs placed closely together, held in place by spacers, and mounted on a shaft. After conducting numerous trials, Nicola came to the conclusion that it is preferable for the model to be housed so it can take advantage of the whole tangential force produced by the fluid on the discs.

A rotor working in a laminar flow can have an efficiency of more than 95%. To obtain excellent rotor efficiency, the flow rate value must be as low as possible. In other words, a large rotor and[1] numerous discs are required to achieve the aforementioned purpose [2]. According to published research, experimental results for prototype turbines show a roughly linear relationship between turbine efficiency and rotor rpm.

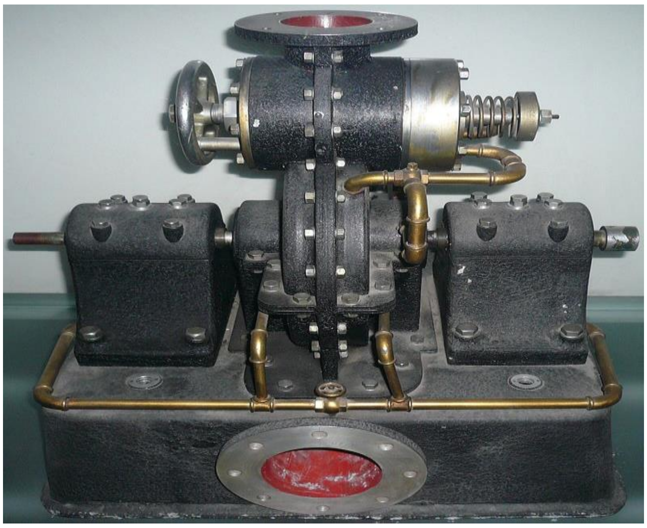


Figure 1 shows a picture of Nicola Tesla's Turbine from his museum [2]

2 Background information

In this section, we will talk about the design, the parameters and the function of the Tesla Turbine

2.1 Design

The development of the Tesla turbine was based on the idea that gradual changes in the fluid's velocity and direction result in the highest efficiency. [3]As a result, the pushing fluid in the Tesla turbine streamlines or follows its natural course with the least amount of resistance.

A flowing fluid is applied to the edges of a number of smooth discs that make up a Tesla turbine. The fluid drags on the disc as a result of its viscosity and the stickiness of its surface layer. The fluid slows down and provides the discs with greater energy as it spirals into the Center exhaust. Since it has no projections, the rotor is quite sturdy. [4]

Tesla turbines are used in a variety of applications. When using less shaft power, it operates effectively. It is lightweight and used for Pico hydropower applications. The Tesla turbine, according to Aghagoli et al., [4], is used as an expander in the heat pump cycle and increases COP by 16.3% over the traditional cycle. The rotor speed must be ideal to reach the cycle's maximum COP. Zhou et al. [5] tested a Tesla turbine as an expander to boost power output in waste recovery systems in vehicle engines. A multiple disc turbomachine performs better than a conventional turbine. Erosion and noise production can be reduced.

2.2 Its function

In a Tesla turbine, a fluid is driven through a set of closely spaced flat discs fixed on a shaft and spirals between them in the direction of a central exit. Impingement does not transfer energy. Instead, the energy of the fluid is transferred to the discs through the force of adhesion. When a disc is present, the fluid's molecules stick to it and stop moving. A portion of the fluid's energy is transmitted to the disc as the fluid pushes back against the resistance of the disc. Due to viscosity, or the adhesion between fluid molecule layers, more fluid can act on the disc than can stick to it. [5]

2.3 Design parameters

To acquire the optimum performance from a product, all design aspects and parameters must be considered and optimized during any design process. Their high efficiency and low emissions make them a great option for power generation. Here are some of the Tesla turbine parameters that you may want to consider when choosing a turbine:

1. Efficiency: This parameter refers to the ratio of energy output to input power for the turbine. Efficiency varies depending on the size and type of turbine, as well as the fuel used to operate it

$$\cap = \frac{WT_{shaft}}{ghQ} \text{[7]}$$

where $T_{shaft}$is the torque of shaft within Tesla turbine, g is the gravity acceleration and V indicates working fluid velocity.

2. Rated capacity: The rated capacity of the turbine is the maximum power output that the turbine can produce at a given speed and rotation direction.
3. Rated speed: This parameter refers to the speed of the turbine at its most efficient point.
4. Thrust coefficient: This parameter refers to the thrust of the turbine.
5. Angle of attack: This is the angle between the blades and the rotational axis of the turbine and is measured in degrees.
6. Turbine loading: This parameter refers to the amount of torque being produced by the turbine, which is a function of its efficiency and the speed at which the turbine is turning.
7. Generator size: This parameter refers to the size of the generator and its location on the turbine.
8. Rotor diameter: This parameter refers to the diameter of the rotor.
9. Blade pitch: This is the distance between the top and bottom of the blade measured in degrees. The optimum gap size to maintain the boundary layer is:

   b = Ph × (v /w) 1/2 where v indicates the kinematic viscosity of the working fluid, w indicates the rotor rotational speed of the system and the Polhausen parameter, Ph is suggested within the range of 2.5 Ph < 3.5 [8]

10. Number of blades: This parameter refers to the number of blades on the turbine.
11. The number of stages: This parameter refers to the number of stages the turbine has, i.e., how widely spaced the blades are.
12. fluid viscosity: This parameter refers to the viscosity of the fluid that is flowing through the turbine.
13. This parameter refers to the density of a fluid as compared to the density in a vacuum.

3 Experimental Setup

This section presents deeply the materials and procedures for performing the experiments and for measuring the efficiency of the Tesla Turbine

3.1 Test bench

Any experiment requires list of materials to be performed. In our case, here are the list of the required materials:

-Rasbery pi4

-Vibration sensor

-Torque sensor

-Tubes and wires

-Couplings

-Safety box

-Tesla turbine

-Motor

-Chasse

-Air compressor

After that, we checked the available materials at Symme Lab, as well as the mechanical technical one at Polytech. We found there are some missing materials, and ordering them will consume both time and money. For that, some of them were eliminated and changed, others designed and prototyped.

3.2 Safety box

Since we are dealing with a turbine with very high speed of rotation (around 80000 rpm), it is very dangerous to perform the experiment with safety instruments. For that, we designed and prototyped a safety box that covers the turbine and protects us during the experiment. This safety box is made up of plastic material with very high mechanical properties that can handle the deformation caused by the turbine.

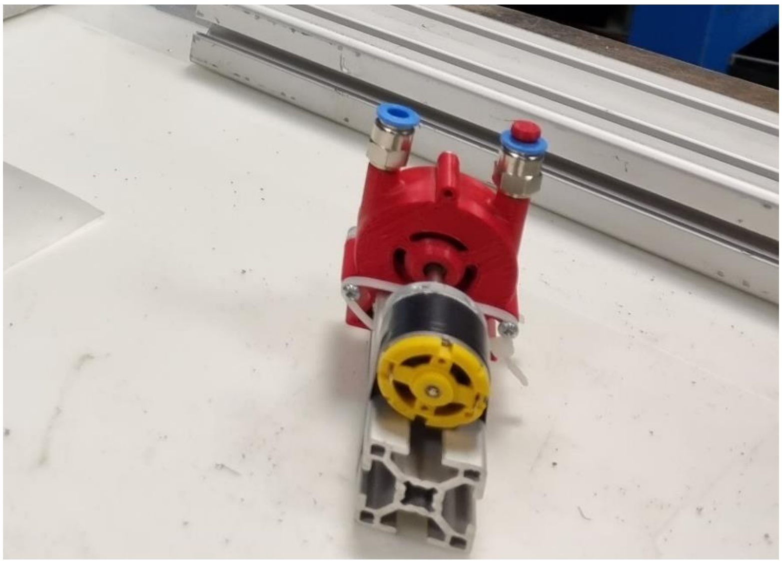


Figure 2 Tesla turbine with a motor without safety box

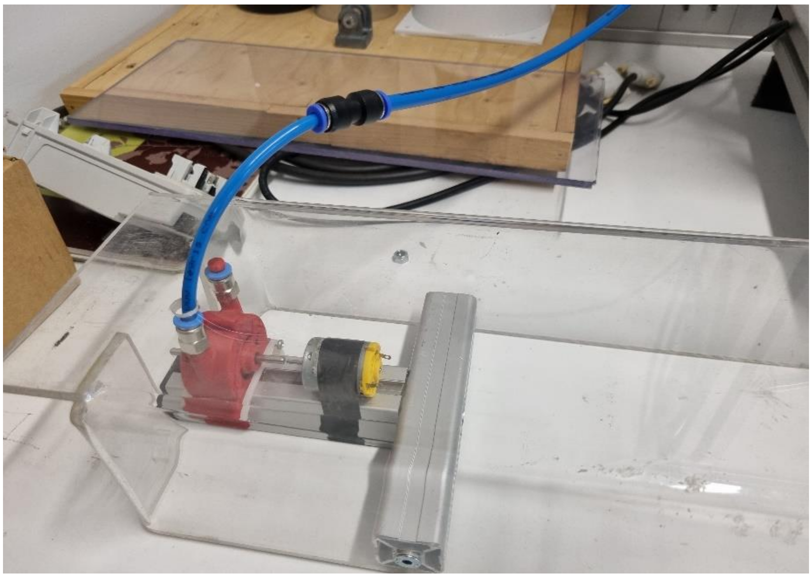


Figure 3 Tesla turbine with the safety box

3.3 Torque measurement

In other to calculate the efficiency of the turbine, as well as investigate the relation between the input pressure and output, torque must be necessary measured.

Lacking torque sensor made us go forward two other methods:

1- Create manual torque test bench using masses

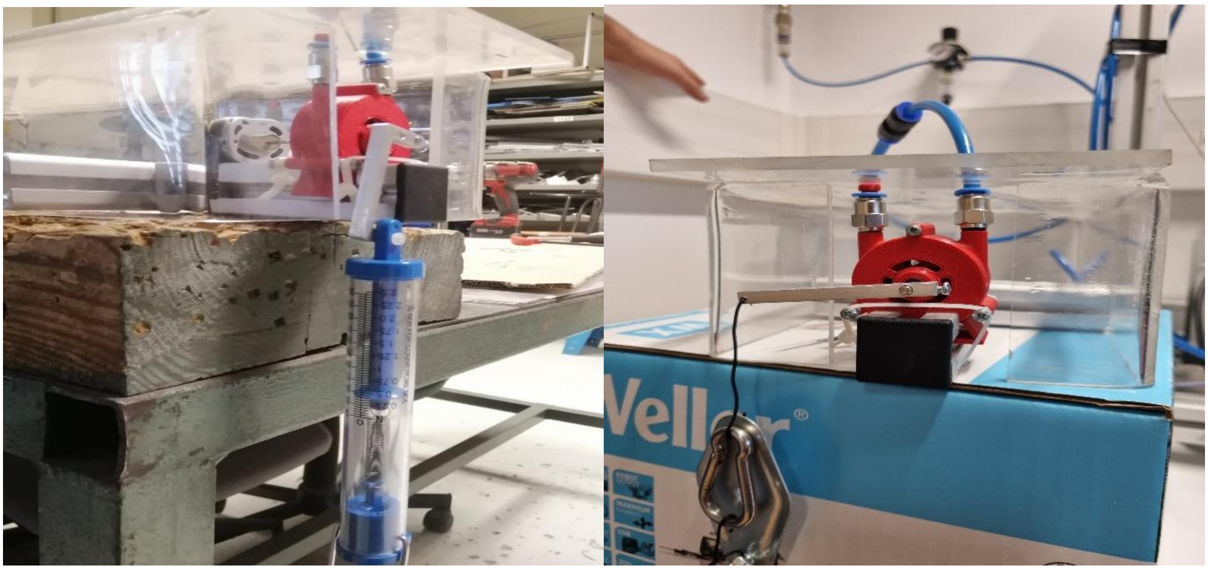


Figure 4&5 the mechanical method used to measure the torque generated by tesla turbine

After that, the torque is calculated by the formula:

T= Force*Radius*sinα

Where α is the angle between Force and the arm and T is expressed by N.m

2- Connect the turbine to a motor for measuring the output power

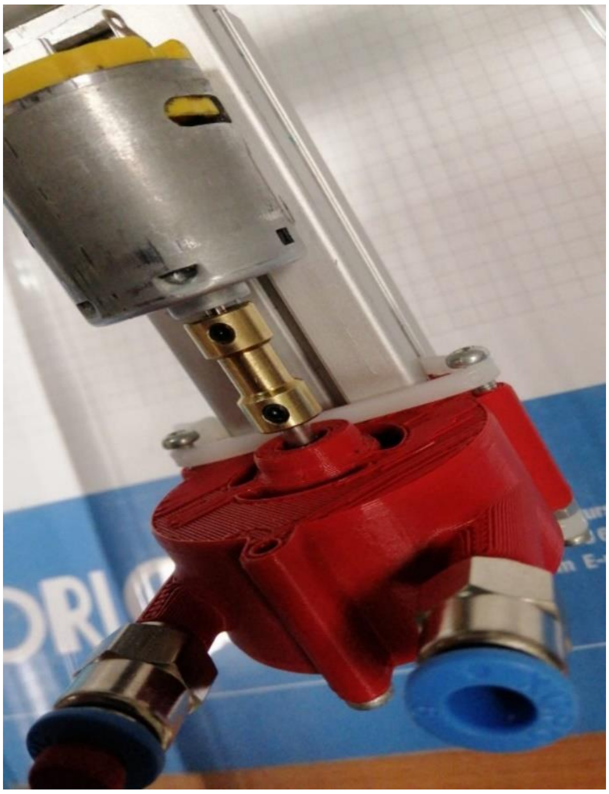


Figure 5 connection between turbine and motor

The output power is calculated by the Voltage * Current which is measured using a volt meter on the terminals of the motor. The efficiency of the motor is estimated around 80%, by this method, the input torque can be calculated using efficiency formula.

3.4 Angular speed

The angular speed is measured by taco meter, where it can be directed to the turbine shaft.

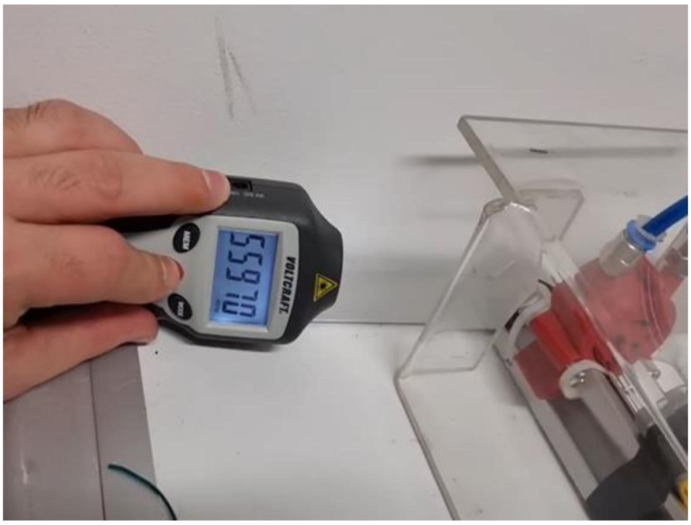


Figure 6 measuring angular speed using taco meter

3.5 Input source

The input source used is air, using air compressor available at Symme lab, it is measured by a flow valve where it give accurately the pressure of air in PA and Bar.

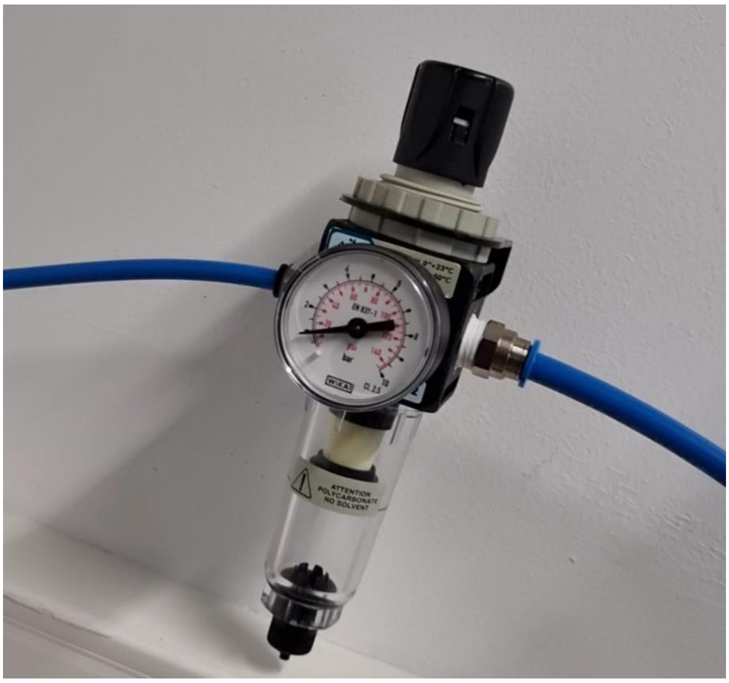


Figure 7 shows the pressure of the input air

4 Experimental results

After performing the experiment, the following results were abtained

4.1 Input Pressure VS Angular speed

Pressure (Bar)	RPM
0.5	25050
0.75	32250
1	35980
1.15	39940

Table 1 Input pressure vs speed of rotation of the shaft

We were not able to proceed with more pressure due to the very high speed of rotation which leaded to turbine failure.

4.2 Input pressure VS added mass

Pressure	original bar mass g	mass added g
1.75	6	10
2.9	6	20
3.65	6	30
6	6	45
6.9	6	50

Table 2 measured values of mass added with various pressure input

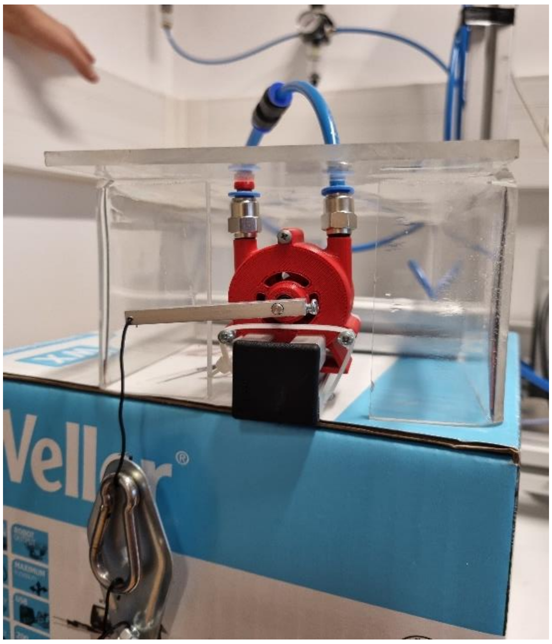


Figure 8 added masses for measuring the torque vs input pressure.

Where the original bar mass is the mass of the bar fixed to the turbines’ shaft, its length is 5.4 cm and its mass is 6g. The added mass is inserted at the edge of the bar, where the distance between the added mass and the shaft is 5.4cm

4.3 Input pressure VS voltage and current

Pressure	Voltage after drop (V)	immediate voltage V	Current A
1.75	0.075	22	0.35
2	0.17	28	0.53
2.5	0.015	32.2	0.7
3	0.01	37	0.9
3.5	0.005	42.3	1

Table 3 output motor current and voltage vs input turbine pressure

The immediate voltage is the voltage measured at the same instant the volt meter connected to the motor, while with m.seconds, the voltage drops to very low value as shown above.

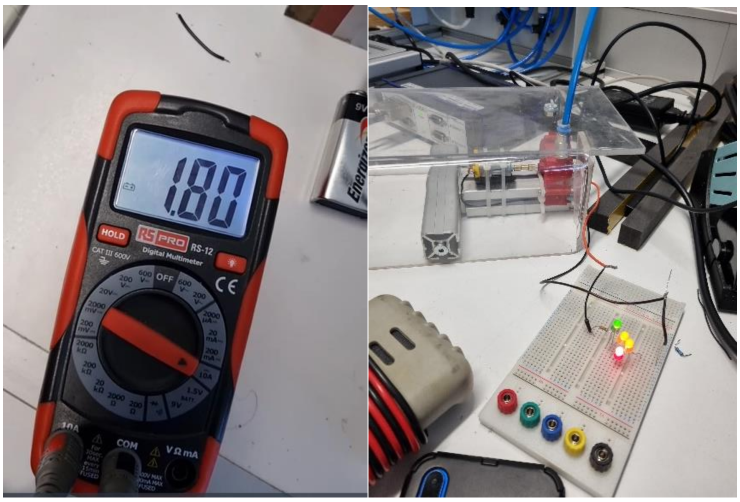
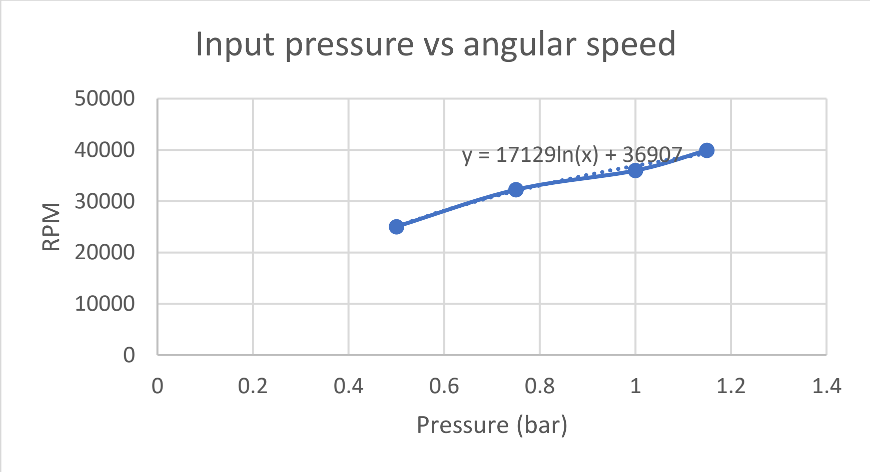


Figure 9 Current and voltage measurements

5 Data analysis and conclusion

Although the Tesla turbine failed before complete collecting the all data required, but we gathered various information that made us capable of achieving our objectives.

5.1 Angular speed



-This graph shows that as the input pressure increases from 0.5 bar to 1.15 bar, the angular velocity of the Turbine increases from 25050 rpm to 39940 rpm. There is a clearly direct proportional relation between the input pressure, and the angular speed.

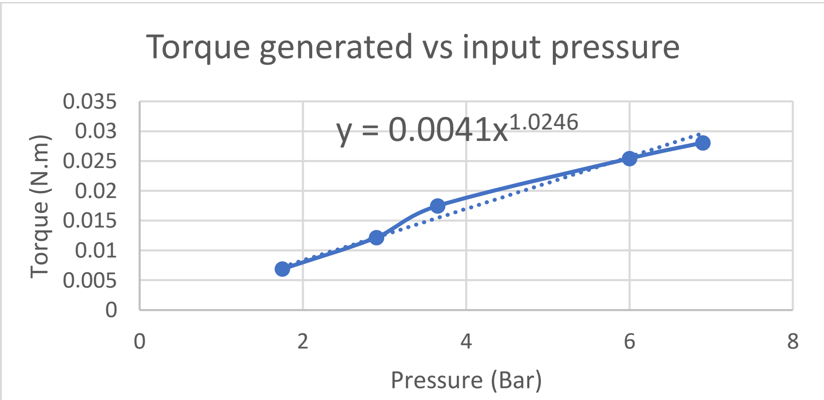
5.2 Torque

The torque is calculated based on the formula T= Force*Radius*sinα

After calculating the torque of the two masses added (the bar which is 6g, and the additional ones on the edge) the following results obtained.

Pressure (bar)	Torque (N.m)
1.75	0.006887
2.9	0.012184
3.65	0.017481
6	0.025428
6.9	0.028073

Table 4 torque according to input pressure

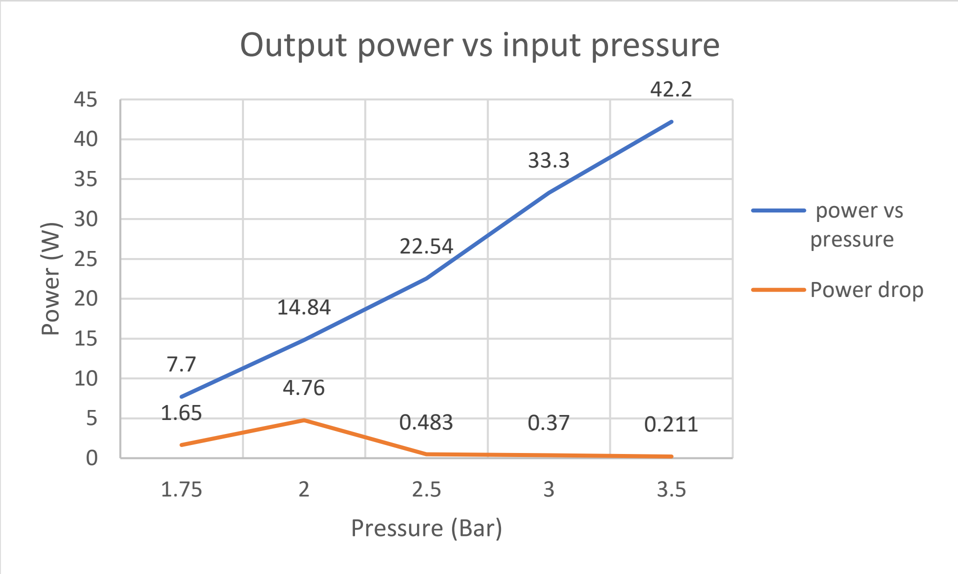


This graph shows a clear directly proportional relation between input pressure, and the torque created. As the input pressure increases from 1.5 bar to around 7 bar, torque increases from 0.015 bar to around 0.028 bar.

This affects the efficiency of the turbine, since $\cap = \frac{WT_{shaft}}{ghQ}$, so increasing the torque leads to an increase in the efficiency.

5.3 Motor power

-Concerning the power generated by the motor, two types of voltages were created, the one which is directly measured, and the second few seconds after as shown in table 3.



This graph shows the relation between output power vs input pressure at the instant moment and after few seconds.

The maximum power generated by the turbine after dropping due to load was 4.76 W at 2 bar, then it continues to decrease.

This verifies that the turbine maximum efficiency can be operated at a specific pressure, and not at very high pressures.

After searching bibliographically for this result obtained, we found a similar CFD study done that verifies the same result.

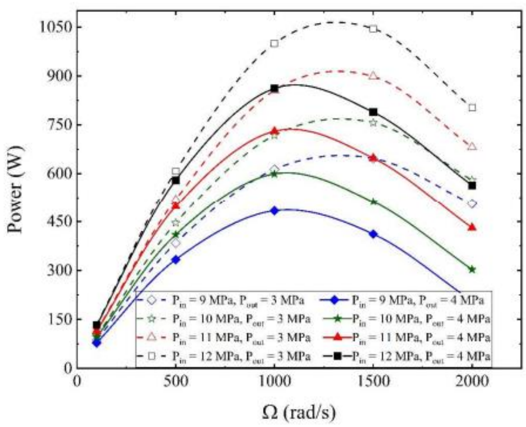


Figure 10 power of Tesla turbine vs Angular speed [9]

5.4 Efficiency

As mentioned above, $\cap = \frac{WT_{shaft}}{ghQ}$

g is the gravity which is 9.81 N/Kg

h is the head pump

Q is the volumetric flow rate

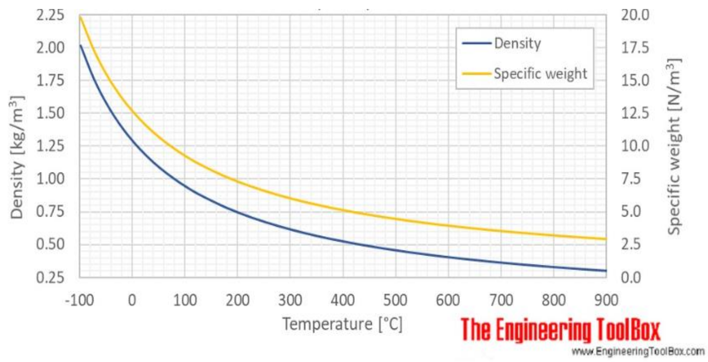
At 2 bar, Torque =0. 0083N.m, it is estimated by the equation of torque which is $y = 0.0041x^{1.0246}$

Angular speed is estimated using two equation types logarithmic and polynomial where:

$$y = -8495.3x^2 + 35960x + 9397.5 \quad \& \quad y = 17129\ln(x) + 36907$$

They both give 47336.3 rpm and 48779.9 rpm respectively, which they are very close.

Head pump* gravity gives specific gravity ¥ which is calculated based on the air density at 2 bar from this graph



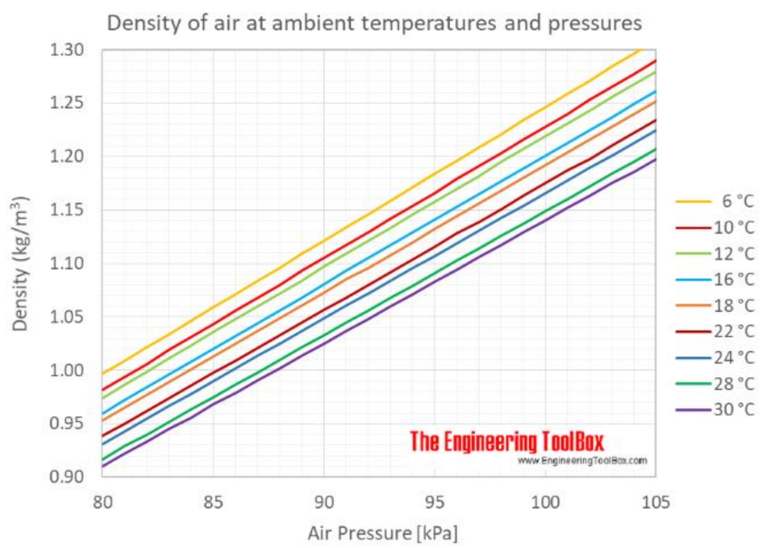


Figure 11 density of air and specific gravity at various pressures[10]

Since the relation is linear, and the required pressure 2bar is not available. We decided to find the equation of density vs pressure, and it was the following: D=1.2P+1 where D in kg/m3 and P in bar

So, at 2 bar, D=2.3 Kg/m3 and ¥= 21N/m3

Power and power drop are 14.84W and 4.76W respectively.

Velocity of air at 2 bar is V=4005√ΔP where V in ft/min and p in W.C [11] this gives V=113542 ft/min=576.79 m/s

Pipe radius is 4 mm, this gives volumetric flow rate of: Q=V*A =576.79*π*0.004^2= 0.02m3/s

Now inserting all these values in the efficiency formula, gives efficiency 14% at 2 bar.

5.5 Conclusion

The efficiency was very low (14%), not only due to some errors, but also due to the deformation occurred at Tesla turbine. Also it was clearly shown the sudden drop of the power upon adding load to the motor, this also verifies that torque what is matter in the efficiency producing power, and not angular speed.

I would like to add that we reached our objective, and the main goal was achieved, efficiency of the turbine is calculated at 2 bar, it is possible to be calculated at higher values but unfortunately the turbine breaks of. Also, the relation of the output power vs input was investigated and shown above in the graphs.

6 Project management, method, and tools

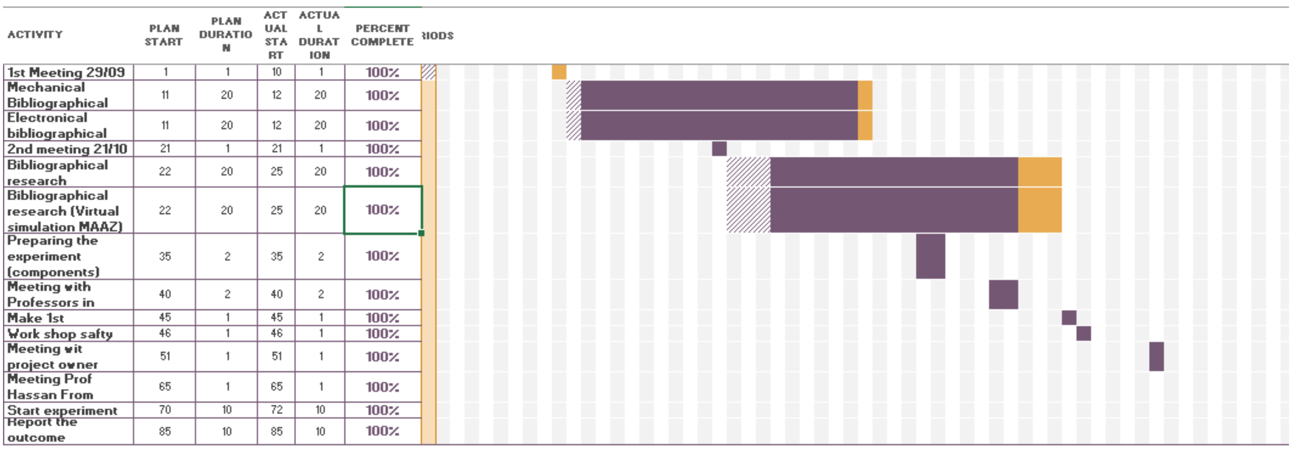
The project information was collected at the start of the project, and the task was reviewed with the project manager. The first step was to learn fundamental knowledge. This foundational knowledge was acquired mainly from the individual projects.

For further information Google Scholar was used to find various scientific resources. Also, we contacted many professors and expertise in Tesla turbine, turbo machinery and thermodynamics. To organize the resources the tool Zotero was used.

To share information and documents we used tools like WhatsApp, mails, and Dropbox. WhatsApp was used for quick sharing of documents because it was fast and could be used on the mobile phone and at the PC. Dropbox was used to have all documents together.

Communication was held at face-to-face meetings at university or during leisure time. But also, via online platforms such as WhatsApp, and Zoom. WhatsApp is also good for retrospectively getting an overview of what was being discussed.

To have the task organized and keep an overview on the assignments the enterprise tool Trello was used. The advantages are that both team member had access to it, and it was given a clear overview. The only disadvantage was that for some features Trello-premium would have been better. To overcome this problem, the goals were also entered in a Gantt-chart on Microsoft-Excel. This Gantt-chart, as illustrated in **Error! Reference source not found.**, visualised the timetable to be more organized and to estimate the time needed for each task.



ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
1st Meeting 29/09	1	1	10	1	100%
Mechanical Bibliographical	11	20	12	20	100%
Electronical bibliographical	11	20	12	20	100%
2nd meeting 21/10	21	1	21	1	100%
Bibliographical research	22	20	25	20	100%
Bibliographical research (Virtual simulation MAAZ)	22	20	25	20	100%
Preparing the experiment (components)	35	2	35	2	100%
Meeting with Professors in	40	2	40	2	100%
Make 1st	45	1	45	1	100%
Work shop safty	46	1	46	1	100%
Meeting wit project owner	51	1	51	1	100%
Meeting Prof Hassan From	65	1	65	1	100%
Start experiment	70	10	72	10	100%
Report the outcome	85	10	85	10	100%

Figure 12 Gantt-chart of the project:

To work together on the same assignments Google-Docs and Microsoft-Word were a good option for us. It was possible to work together in real-time and each of us could see the changes of the other.

For a good distribution of responsibilities and tasks we talked to each other what to do in the next period. If the workload is different, we try to manage the organization.

We had some milestones and we split up the workload in packages which were more suitable of one person.

Figure 13 Milestones for our project

The importance of delegating tasks and scheduling their completion cannot be overstated. Following that, we did:

- Created an organizational plan for the tasks
- Identified the various levels of responsibility
- Organized all the project's papers and procedures in one place
- Created a tracking system.

7 Personal outcome and self-assessment

In this section the personal outcome of each team member is described.

7.1 Maaz Wael

This collective project not only made me share information even traditions with my team member which he is from electronic background ,but also taught me the following:

- Complicated work should be broken down into sections and steps.
- Time management and planning
- Discussion and explanation are helpful to clarify comprehension
- Improve my communication abilities
- Attempt to solve more difficult issues
- Share a variety of viewpoints
- Hold each other responsible
- Encouragement to try new things
- Citing references
- Usage of project and time managing tools
- Be able to work with any student regarding his background

7.2 Ajami Mohammad

This project has allowed me to develop in many areas. Not only the understanding of how to deal with mechanical problems, but also be able to think in a larger scale.

The project also contributed a lot to the development of management skills. Different tools were used that can help both in professional and private life.

Through the project, different scientific approaches that were learnt. Finding solutions to new challenges was promoted.

Because my team member had a different technical background, problems could be analysed from different angles and new solutions could be found.

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