INTERMITTENT STEAM-POWERED ENERGY GENERATION USING DOMESTIC WATER GEYSERS

Author

Kazim Raza
Regn. No. 00000204352

Supervisor

Dr. Najam Ul Qadir

Department of Design & Manufacturing Engineering
School of Mechanical &Manufacturing Engineering
National University of Sciences &Technology
Islamabad, Pakistan

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Author:

Kazim Raza
00000204352

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MS Design and Manufacturing Engineering

Supervisor:
Dr. Najam Ul Qadir

Supervisor's Signature: ___________________

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SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES & TECHNOLOGY, ISLAMABAD

AUGUST, 2021

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Name: Dr. Mushtaq Khan Signature:________________

Name: Dr. Hussain Imran Signature:________________

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I thank Allah Almighty for bestowing me the knowledge, courage and honor for successful completion of this project.

Understanding and implying the emerging concept of energy harvesting would never have been so easy formed without the true support, able guidance and motivation from my respected advisor Dr Najam Ul Qadir. He not only well-informed me from his knowledge but also motivated me in working hard to find the solution of the problems that I faced during the process. I am highly indebted to his efforts and precious time that he gave me after working hours for the successful completion of my project. I also extend my sincere thanks to my supervisor, as he not only pursued my project with his personal interest but also provided me the guidance to learning the new software's and applying them, which in-turn resulted in the completion of my project besides exploring my own capabilities. I am also thankful to Dr. Mushtaq and CAD / CAM Lab Staff who were always ready to help and guide whenever the project demanded.

I am also extremely thankful to my parents, family members and my kids for their benevolent prayers, petitions, backing, love and unlimited persistence towards my drawn out working hours. Without their prayers, petitions and backing, the task couldn't be a triumph.

DEDICATION

I dedicate my effort on this project to my parents, family and kids who have relinquished their precious time for my success.

ABSTRACT

This project is aimed at proposing an idea of producing electricity on intermittent basis through trickle charging the current produced by a tesla turbine. The turbine runs on the steam produced by a domestic water geyser. The current so produced, can be stored in a UPS battery or can be used directly in case of power failure. With this proposed idea, a cheaper solution to power shutdowns is expected. This will allow the UPS battery to fulfill domestic needs of electricity for longer time period. In case, when commercial electrical power is available, the assembly will charge a shunt power capacitor whenever steam pressure turns the turbine. When the charging of capacitor is completed, the stored charge can be converted into 220 V with the help of a step-up voltage transformer. In this way the electricity produced will augment the main commercial power supply thereby reducing consumption of electricity from commercial source and reduce the monthly electricity bill to a certain extent. It is worth highlighting here that steam pressure plays the key role in amount of electricity that can be produced through tesla turbine and hence, it is the most important parameter in whole design. Higher the steam pressure, greater will be the turbine RPM and more will be the current produced which will determine the speed of charging the UPS battery or the capacitor. Finally, it will decide the extent to which this current can be used to fulfill domestic electrical needs. The thesis presents prototype design and 3D model of the power generation system through integration of domestic water geyser with the turbine, generator and the AC DC inverter. The simulation of turbine is also done based on the input of steam pressure and then turbine RPM is used to run the generator to produce electricity. The optimization of proposed power generation system through involvement of industry is expected to devise a cheap and economic solution to the current energy crises being faced by Pakistan.

Keywords: Steam Turbine, UPS, Domestic Geyser, 3D Modeling, Simulation, Integration, Optimization.

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Chapter No 1

Introduction

1.1 Pakistan is facing a consistent shortfall of electricity across all regions which is adversely affecting almost every aspect of daily work and living of the community. This energy crises is badly interrupting living and means of earning of general public as the poor population of Pakistan cannot afford high cost energy produced from generators. Moreover, it also adversely affects the environment by adding noise and smoke. In this backdrop, the thesis presents a quite simple solution of producing hybrid electricity through steam power on a small scale. The domestic water geysers which are heating water through natural gas and producing steam as a byproduct. This low pressure steam is utilized and directed to a small tesla turbine. The turbine operates on the steam pressure at certain RPM and in turn produces certain amount of current. This output current is stored in a UPS battery for future use on as required basis. The proposed idea will help in promoting the sale of domestic water geysers in local market and upon success; it may also prompt the government to assist local industry in manufacturing of small-scale low-pressure steam turbines on commercial scale at lesser cost.

Objective and Scope

1.2 The main objective of the thesis and innovation is to present an economic solution to one of the largest problems of energy scarcity in Pakistan both at industrial and domestic level. The objective is to meet domestic electrical power requirement of society through already available resources like natural gas and domestic water geysers. The product is supposed to be more useful in summers when there is lot of load shedding and electricity requirement is more due to usage of fans, water coolers and other cooling appliances at domestic and commercial levels.

Anticipated Customer

1.3 It is expected that the materialization of the idea will resolve the domestic power requirements of Pakistani society at large especially in urban areas where natural gas and water geysers are available in every home. Especially, those citizens who are living in areas where power shut downs are very frequent, the slight more consumption of natural gas can produce a considerably cheaper electricity that will be able to fulfill the domestic energy requirements. The industrial sector is also expected to benefit out of it once it turns out to be a cheaper solution to energy crises. Moreover, it is expected to increase the sale of water geyser and associated accessories.

Problem Statement

1.4 According to our best knowledge, the proposed idea is a patent design as no previous literature could be found presenting it. Although a number of hybrid energy producing models have been proposed; there could not be found any established setup in the commercial sector or at domestic level that has applied the methodology explained in this proposal which generates electric power from steam and supplements commercial electric power to meet domestic power shortfalls. Through this method, commercial sector can also utilize the low-grade waste heat a by-product which is released from the local industries during different combustion processes. This heat can be used to generate steam in commercial boilers. This steam will in turn run the small / large scale steam turbine and produce electrical power. The industrial machinery can use this electrical power when there is shortfall of electricity or lesser voltages. Hence, the electricity produced through this method can be used directly to supplement the commercial electricity supply for cost effectiveness.

1.5 The materialization of the proposed idea and its economic output depends upon whether the accessories used in the method are available in the local market and that too on cheaper rates. Especially, the availability and cost effectiveness of the low pressure steam turbine in local market will matter the most. Pakistani industry does not manufacture steam turbines, importing them from international market will involve additional costs which will increase the overall cost of the proposed design and therefore, result may not be that cost effective. However, if the prototype manufacturing succeeds to gain interest and attention of the public / government, the government may take steps to reduce its import costs or persuade local industry to manufacture the same at cheaper rates. Therefore, the manufacturing and availability of low pressure turbine by local industry in Pakistan will ensure success of the idea in true spirit as the project presents an excellent alternative to meet the energy demands of the society and power starved local industry during prolonged commercial power shutdowns.

Chapter No 2

Thesis Scope

2.1 The scope of the thesis is divided into following phases:-

(a) Making a prototype design of the proposed assembly.

(b) Perform 3D modeling of the proposed assembly.

(c) Theoretical prediction of the output power that can be produced from this design by using simulation software.

Methodology

2.2 In this project, steam produced by domestic water geysers is used to run a low pressure steam turbine known as tesla turbine. The RPM of the steam turbine will determine how much electrical power can be produced by this method. The output electrical current will be either stored in the UPS battery or can be used directly to augment the commercial power. Following parameters will play prime role in the proposed design:-

(a) The pressure of the steam generated which will decide how fast the UPS can be charged and thus for how long it can be used to fulfill domestic electrical needs in times of power shut downs.

(b) The design of the steam accumulator which will decide how much maximum steam pressure can be delivered to the steam turbine.

(c) The insulation used on the outer surface of the steam accumulator which will decide how much maximum drop in temperature can occur in the temperature of the steam entering from the source.

Literature Review

2.3 A lot of research is being performed across the globe for sustainable and green energy harvesting. Researchers have tried to convert one form of the energy into to the other forms alongwith an effort to make minimum energy wastages. There have been researches on optimization of energy produced by the turbine in the past, however using a steam produced by domestic geyser to run a turbine and produce electrical current on small scale could not be traced in the available literature.

2.4 In the research paper on study of steam turbine, Amanraj explained the basic concept of steam turbine, the operating principle and the steam cycle[1]. Surafel Shimeles tried to design and simulate the fluid flow in a multiple disk tesla turbine using Gambit software

[1] Research paper on study of steam turbine by Amanraj (2015)

for modeling and then ANSYS software for simulation[2]. He presented the steady state incompressible CFD models for multiple-disk Tesla turbine for two-dimensional fluid space with disk gap estimation based upon turbulent flow conditions. Through his research on modeling and simulation of tesla turbine, he established that total power yield, total turbine efficiency, individual disk efficiency and inter-disk space loading coefficients vary in different models.

2.5 Hanjun Ryu and Hong-Joo Yoon in their research on hybrid energy harvesters tried to sum up recent significant progress in the development of hybrid nano-generators for a sustainable energy harvesting system that use natural and artificial energies such as solar, wind, wave, heat, machine vibration, and automobile noise[3]. They discussed different hybrid energy harvesting systems: integration of mechanical and photovoltaic energy harvesters, integration of mechanical and thermal energy harvesters, integration of thermal and photovoltaic energy harvesters, and others. They also briefly covered the structure, working mechanism and output performance of hybrid nano-generators.

[2]Design, simulation of fluid flow and optimization of operational parameters in tesla multiple-disk turbine by Surafel Shimeles and Dr.-Ing.Abebayehu Assefa (2014)

[3]Hybrid Energy Harvesters: Toward Sustainable Energy Harvesting by Hanjun Ryu and Hong-Joo Yoon (2019)

Chapter No 3

Project Description

3.1 In the proposed design, domestic water geyser has been used as a source of producing steam. A space is created between the hot water compartment and the burner to accommodate a circumferential pipe. The hot water of the geyser is passed through respective valves and accumulated in the circumferential pipe where it is converted into dry steam. This dry steam is then accumulated in the accumulator after passing through another valve. The steam accumulator is thermally insulated to preserve heat. Furthermore, it maintains vapor pressure of steam to inside the accumulator to a sufficiently high value. Once sufficient high vapor pressure is achieved, the steam is routed to the tesla turbine to rotate the turbine shaft to attain certain RPM by utilizing its kinetic energy. Since the shaft is directly connected to 150 WAC alternator, which rotates and produces electric current. This current can be used in following ways: -

(a) In case of commercial power shutdown, the electric power produced by the turbine is converted to DC current using a AC-to-DC inverter and then it is utilized to trickle charge the UPS battery via a control switch S1. Hence, the proposed assembly can serve as an attractive alternative at times when commercial supply stops and the UPS is turned on. The proposed assembly will keep on trickle charging the UPS battery and keep the UPS running for a much longer time period than a normal UPS without this assembly.

(b) In case when there is no commercial power shutdown, it is utilized to trickle charge a shunt power capacitor via a control switch S2. When the capacitor is fully charged, the stored charge is converted to 220 V via a step-up voltage transformer and finally merges with the main commercial power supply thus saving the monthly electricity bill to a certain extent.

Anticipated Benefits

3.2 Since the steam operated tesla turbine will be charging the UPS battery alongside the commercial electrical power, hence it is expected that UPS battery will charge at faster rate and can be utilized for longer time periods when compared with normal UPS. In the context of Pakistani local industry, the proposed design is also aimed to also prompt commercial sector and the government of Pakistan to invest in manufacturing of small scale turbines and increase the production of domestic water geysers. It will also promote the use of the low-grade waste heat for usable energy production. The industries and commercial boilers that produce low-grade waste heat as a byproduct can instead utilize it to run the steam turbines and produce significant amount of electricity to meet their energy requirements during shortage / load shedding of commercial electrical supply thereby also contributing towards green energy.

Project Prototype Design

3.3 The prototype design of the proposed assembly is shown in Figure 3.1 below: -

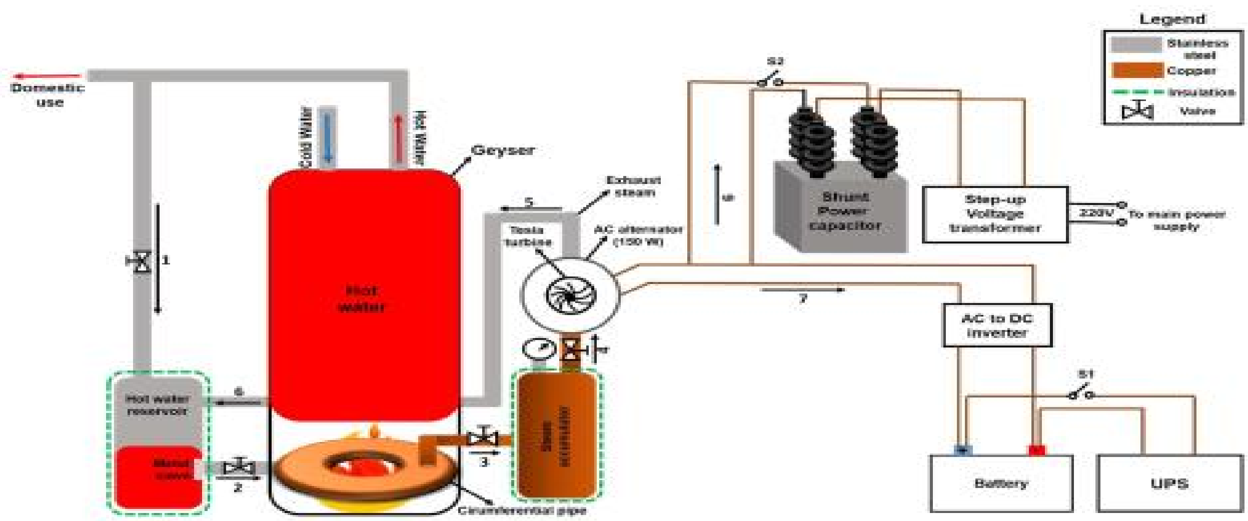


Fig 3.1: Project Prototype Design

Schematic Design of the Proposed Assembly

3.4 Hot water enters from the geyser to a thermally insulated hot water reservoir. Hot water from the reservoir enters through a metallic sieve to a copper circumferential pipe held over the burner. Dry steam enters from the circumferential pipe into a copper steam accumulator. Pressurized steam enters through a valve from the steam accumulator to a low- pressure Tesla turbine. Exhaust steam is re-circulated back to the hot water reservoir. Whenever the commercial electrical power will be available, electricity generated through this method will charge the UPS battery or a shunt power capacitor. This can later merge into the commercial power supply through a step-up voltage transformer. The electrical power generated in this way will charge the UPS battery through AC-to-DC inverter and thus prolong the working time of the UPS.

Physical Resources and Facilities

3.5 Following accessories and items are considered essential part of the assembly:-

(a) **Domestic Geyser.** This is easily available in the local market. However, small modification in terms of separation of hot water compartment and addition of circumferential pipe between the burner and hot water compartment will be required.

(b) **Circumferential Copper Pipe.** This can be easily bought or manufactured from local market.

(c) **Connecting Copper Piping / Plumbing.** Different types of plumbing will be required to integrate the parts of the proposed assembly.

(d) **Steam Accumulator.** Steam accumulator will be required to store the steam produced from domestic geyser. It consists of copper compressed gas cylinder with insulation on outer side. These type of accumulators are commercially available or they can also be easily manufactured through local market.

(e) **Tesla Steam Turbine and Generator.** The Tesla turbine is a bladeless centripetal flow turbine which was patented by Nikola Tesla in 1913. It is also called bladeless turbine because it uses the boundary layer effect, not fluid impinging upon its blades, as in conventional turbines. Therefore, it is also called "boundary layer" turbine. This can be manufactured through any design laboratory or industry. A 150 W AC alternator is joined with the turbine shaft to take input from the turbine to produce certain amount of electric power depending upon turbine RPM.

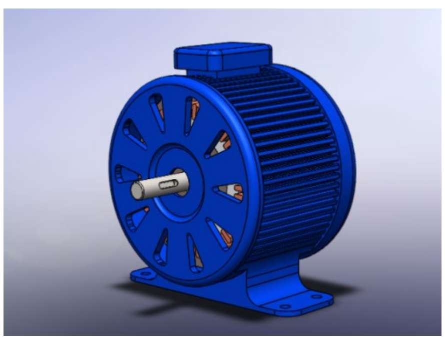
(f) **Pressure Regulator Valves with Sensors.** The valves and sensors used in the proposed design are also readily available in the local market.

Chapter No 4

3D Modeling of Prototype Design

4.1 3D modeling of the proposed prototype design is required for theoretical assessment of the proposed assembly. For this purpose, 3D modeling software "SolidWorks" has been used. Being the extremely powerful Computer-Aided Design (CAD) software, it uses parametric variables / mathematical equations to build modular designs and then assemble / integrate them. Due to its capability of mating modules, it is largely being used in designing industrial products. It allows analyze the mass properties of individual parts, allows to make changes before manufacturing at any point of time and can also share data with other engineering software's as an input source. In other words, it is a kind of one-stop design software that allows engineers to turn their ideas into reality.

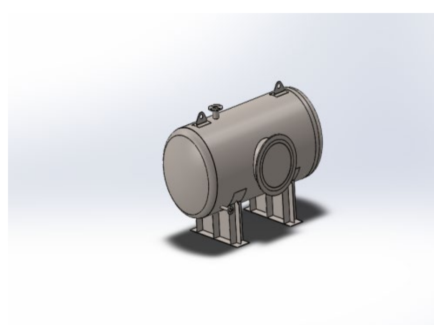
4.2 In order to make the complete prototype assembly, first 3D modeling of the individual modules has been done. The modules have been reduced to the scale of 1:10 except for the Tesla Turbine which is made to the scale of 1:1. The 3D models of various modules of prototype design are placed at Figure 4.1 and Figure 4.2 below: -



Induction Motor 150 W

Induction Motor 150 W

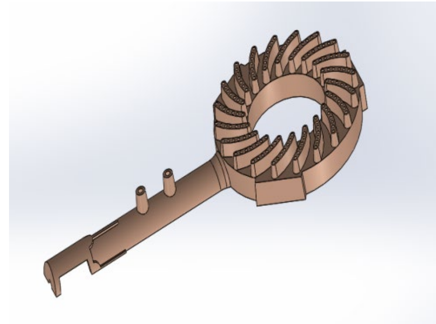
Transformer



Vessel

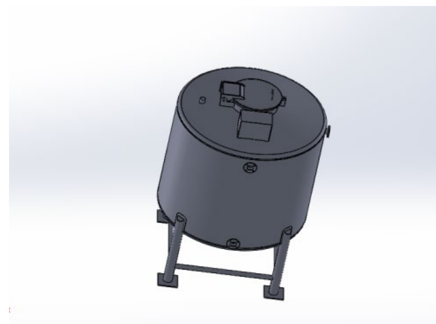
Fig 4.1: Components of Prototype Design

Battery



Burner

Geyser



Reservoir

Fig 4.2: Components of Prototype Design (Cont'd)

3D Modeling of Tesla Turbine and Generator

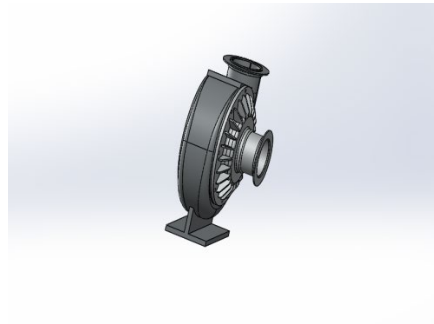
4.3 The bladeless centripetal flow **Tesla turbine** was patented by Nikola Tesla in 1913. It uses the boundary-layer effect and not a fluid impinging upon the blades as in a conventional turbine. It consists of a set of smooth disks, with nozzles applying a moving fluid to the edge of the disk. The fluid drags on the disk by means of viscosity and adhesion of surface layer of the fluid. As the fluid slows and adds energy to the disks, it spirals into the center exhaust.

4.4 Tesla wrote: "This turbine is an efficient self-starting prime mover which may be operated as a steam or mixed fluid turbine at will, without changes in construction and is on this account very convenient. Minor departures from the turbine, as may be dictated by the circumstances in each case, will obviously suggest themselves but if it is carried out on these general lines it will be found highly profitable to the owners of the steam plant while permitting the use of their old installation. However, the best economic results in the development of power from steam by the Tesla turbine will be obtained in plants especially adapted for the purpose."[4]

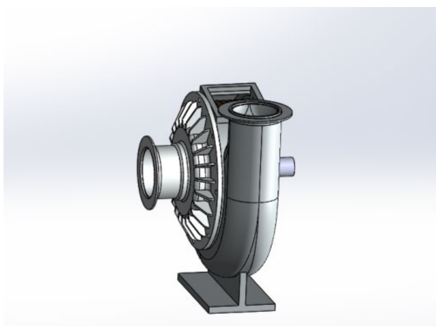
[4]Nicola Tesla in British Patent 179,043 on RexResearch.

4.5 The 3D models of tesla turbine components are placed below: -

Tesla Turbine Part 1

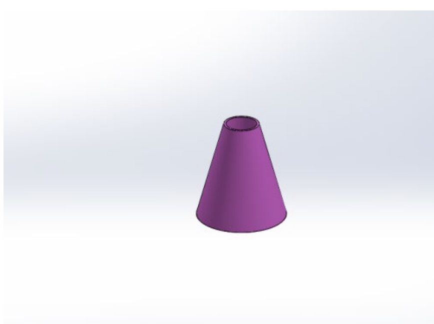


Tesla Turbine Part 2

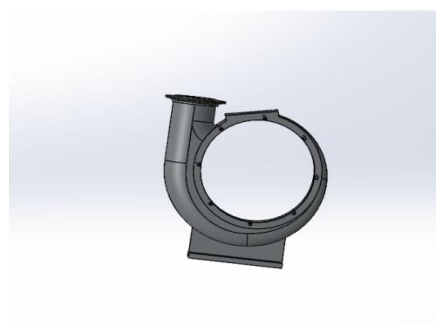


Tesla Turbine Part 3

Tesla Turbine Part 4

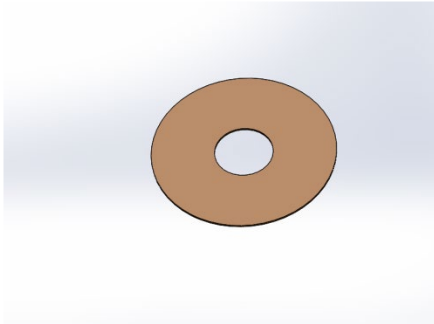


Diffuser Part 5

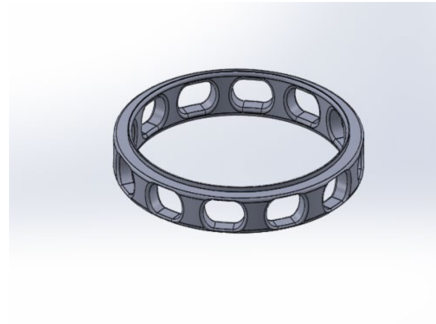


Tesla Turbine Part 6

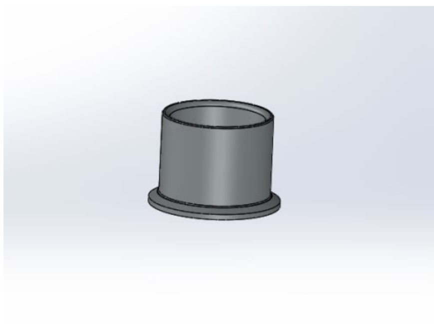
Fig 4.3: Components of Tesla Turbine



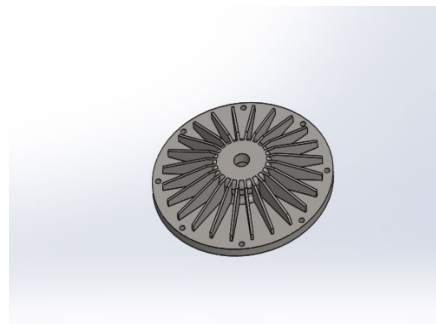
Tesla Turbine Part 7



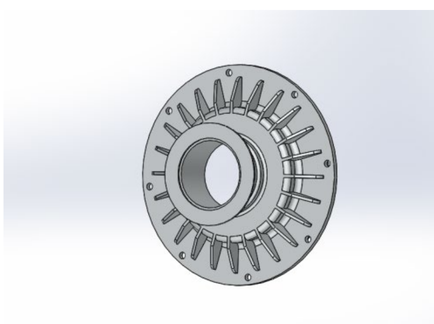
Tesla Turbine Part 8



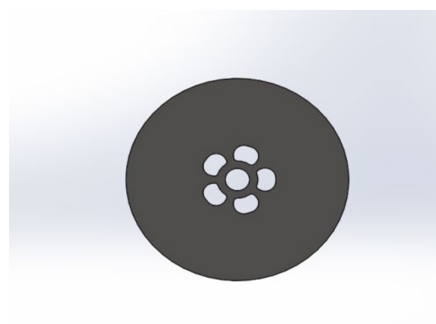
Tesla Turbine Part 9



Tesla Turbine Part 10

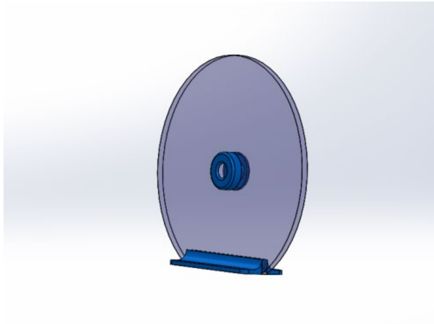


Tesla Turbine Part 11

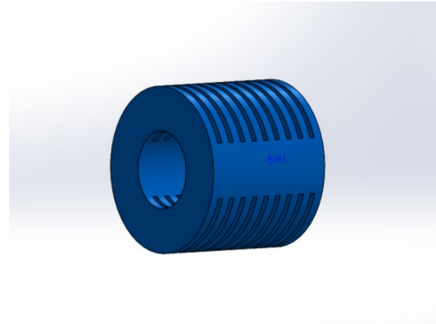


Tesla Turbine Part 12

Fig 4.4: Components of Tesla Turbine (Cont'd)

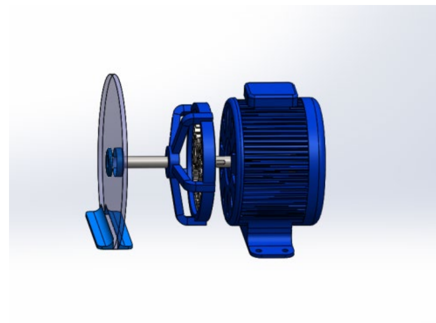


Tesla Turbine Part 13



Tesla Turbine Coupler Part 14

Tesla Turbine Base Part 15



Generator 150 W AC

Fig 4.5: Components of Tesla Turbine (Cont'd)

4.6 The 3D model of Tesla Turbine coupled with Generator is placed at Figure 4.6 below: -

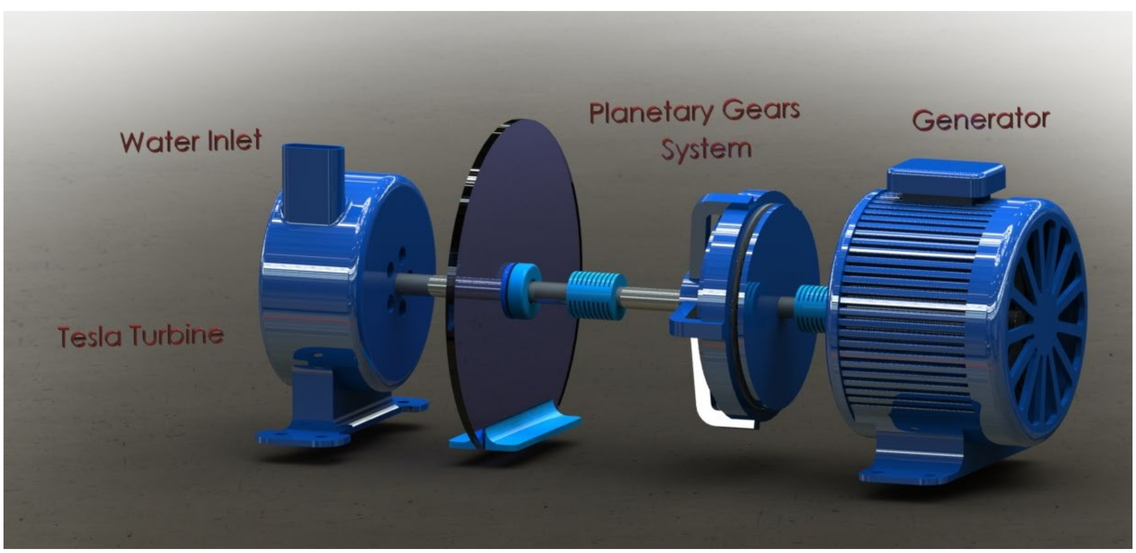
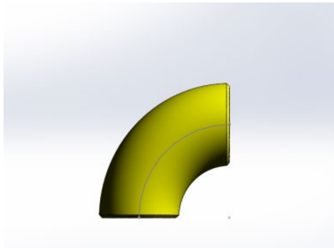
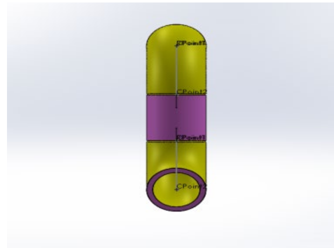


Fig 4.6: Tesla Turbine Coupled with Generator

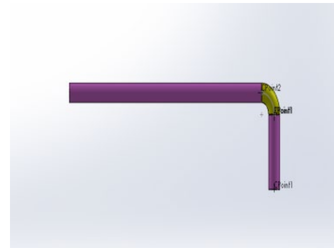
4.7 The 3D models of the plumbing are placed at Figure 4.7 below: -



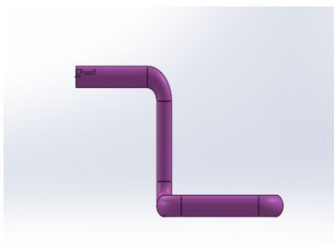
90º Elbow Pipe 1



Pipe 2



Pipe 3



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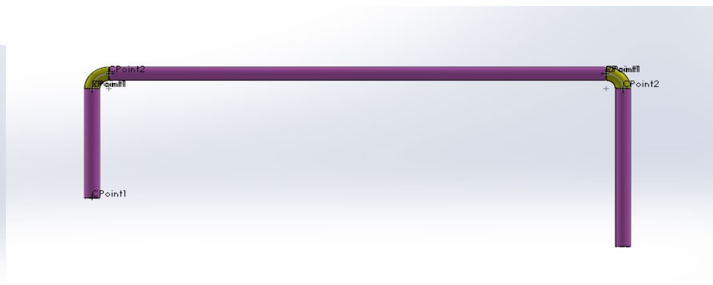

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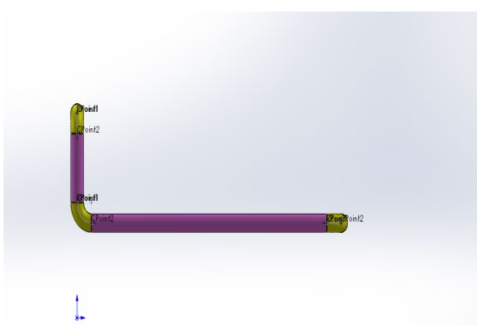

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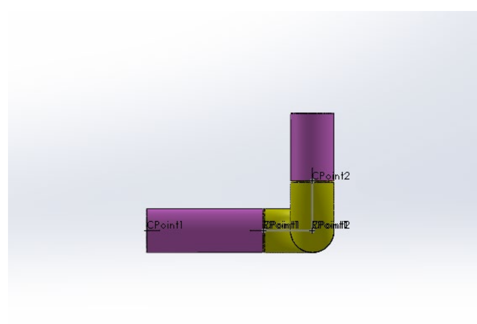

Pipe 7

Fig 4.7: Plumbing of Prototype Design

4.8 3D Model of the complete prototype design in assembled form is placed at Figure 4.8 below: -

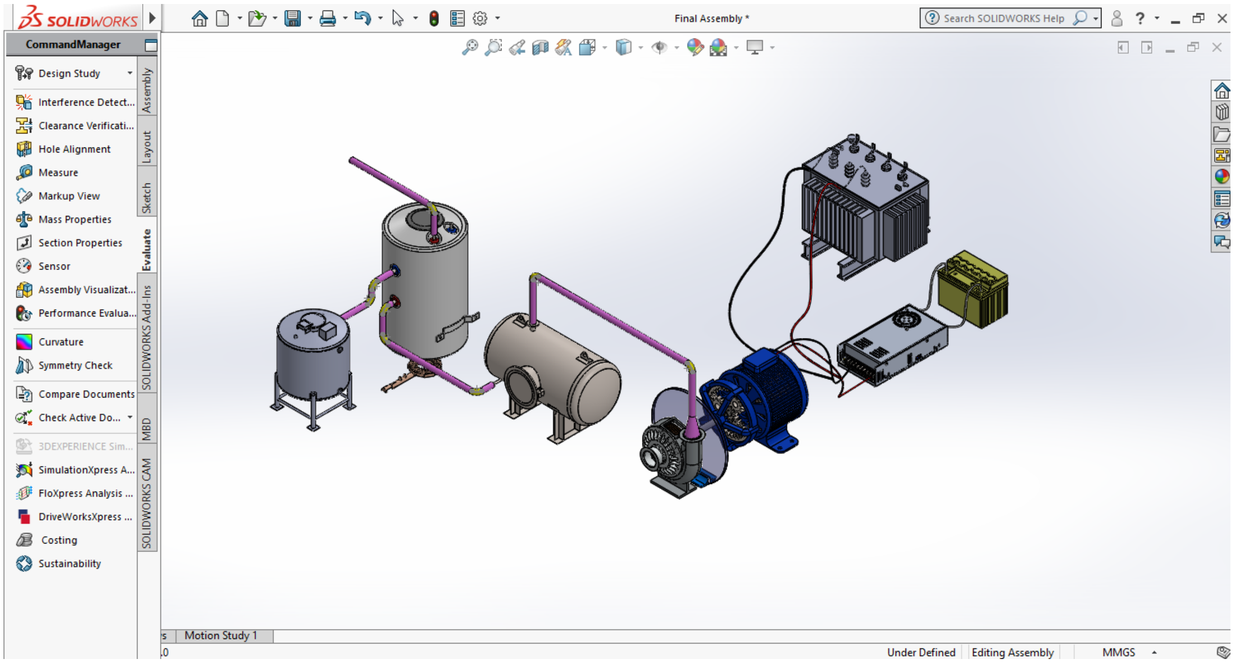

Fig 4.8: 3D Model of the Complete Prototype Design in Assembled Form

Design Optimization

4.9 In order to achieve best results, proposed design geometry has been created in 3-D modeling software. The operation of the proposed design is simulated to check its productivity and efficiency through simulation software by applying real-time service conditions. The proposed design has been tested at various input conditions to determine the primary contributor towards system efficiency and the maximum output that can be produced within available circumstances. The optimization of the design operational variables is necessary to get optimal theoretical output. This is done through trial of different conditions in the simulation software. As a result, theoretically maximum achievable system efficiency has been estimated as compared to the extra natural gas consumed.

Chapter No 5

Operation of Proposed Design Assembly

5.1 The operation of proposed design assembly consists of three stages mentioned below:-

(a) Generation of pressurized steam through geyser burner.

(b) Operation of turbine through pressurized steam to run the generator.

(c) Generation of electric power through generator for subsequent use through transformer / storage in a battery for usage in case of electrical load shedding / power breakdown

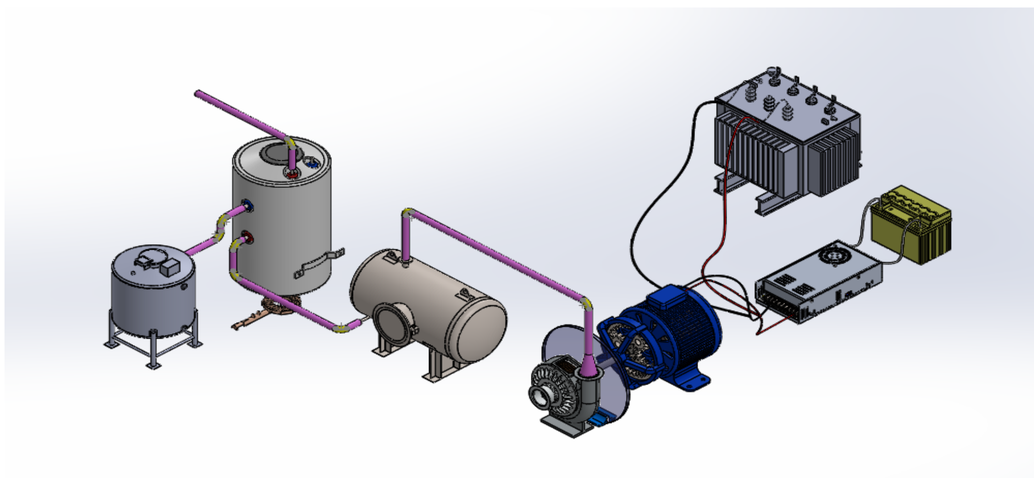

Fig: 5.1: Final Prototype Design

Generation of Pressurized Steam

5.2 The water from reservoir enters the geyser where it is heated through burner to the temperature of 100 ^{o} C to generate steam. This pressurized steam is accumulated in the accumulator. The pressurized steam enters the turbine with an inlet velocity ranging between 25 to 40 m/s. For saturated steam, 25-40 m/s velocity provides adequate dynamic pressure to rotate the turbine, while the best value is practically achieved with the velocity of 40 m/s. Beyond this velocity, negative effects of erosion and noise over shadow the positive output, especially if water particles are present in it. However, the velocity up to 76 m/s has also been quoted for dry steam in some papers.

Simulation of Turbine Operation

5.3 For simulation of the proposed design, simulation software "ANSYS" has been used which has both FEA and CFD software of the top notch. It has the capability to simulate 3D and

2D CAD geometries after importing them from different CAD software's. Equipped with the variety of inbuilt algorithms, non-linear material models, time dependent simulations and the capability to optimize various features like the geometrical design, boundary conditions ANSYS has been selected as the software of choice.

Operation of turbine and Flow Analysis

5.3.1 For simulation of turbine operation, the 3D model of the turbine has been imported from SolidWorks to ANSYS software. The inlet, outlet and frame of turbine (Stationary Domain) are shown green, whereas the inner cylindrical body is the turbine (Moving Domain) in Figure 5.2 below. The turbine dimensions are as follows: -

(a) Inlet = 40mm

(b) Outlet = 40 mm

(c) Rotating domain = 100 mm Diameter

(d) Stationary domain = 150 mm Diameter

(e) Shaft space plus bearing block = 50 mm

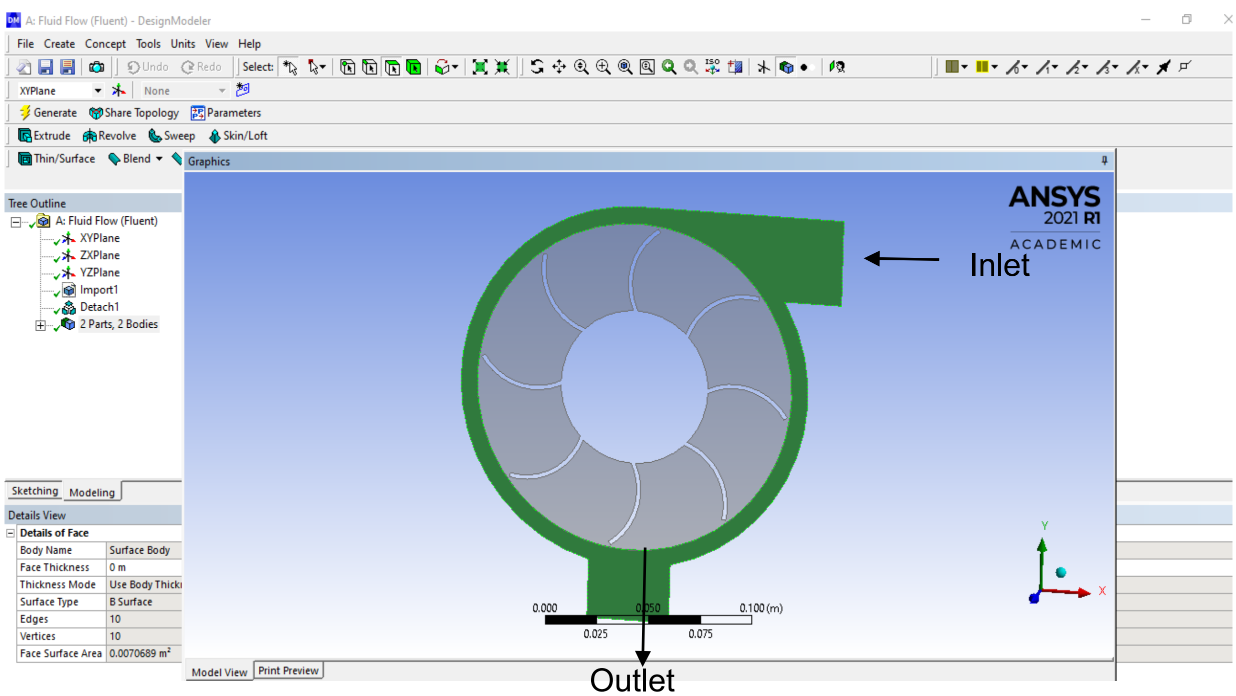

Fig: 5.2 Tesla Turbine Stationary and Rotating Domains

Meshing of Turbine

5.3.2 In order to carry out simulation of turbine operation, meshing of the turbine surface area is required. Meshing involves breaking of turbine surface area into smaller surfaces (mesh) so that precise fluid flow analysis can be performed to achieve accurate results.

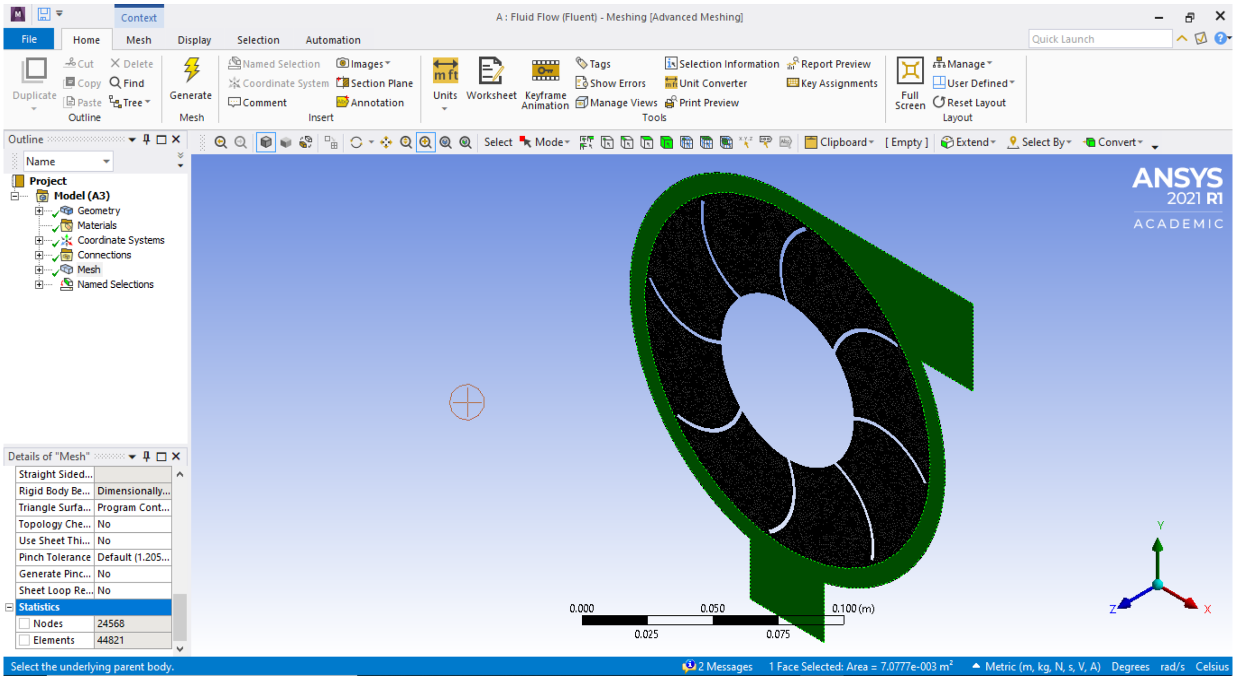

Fig: 5.3 Meshing of Turbine in Fluent

5.3.3 For meshing of the turbine surface area,"All Triangle"method has been used along with inflation on the turbine walls. With the selected mesh size of 1 mm, a total of 24,568 nodes (44,821 elements) are created of the turbine surface area as shown in Fig 5.4.

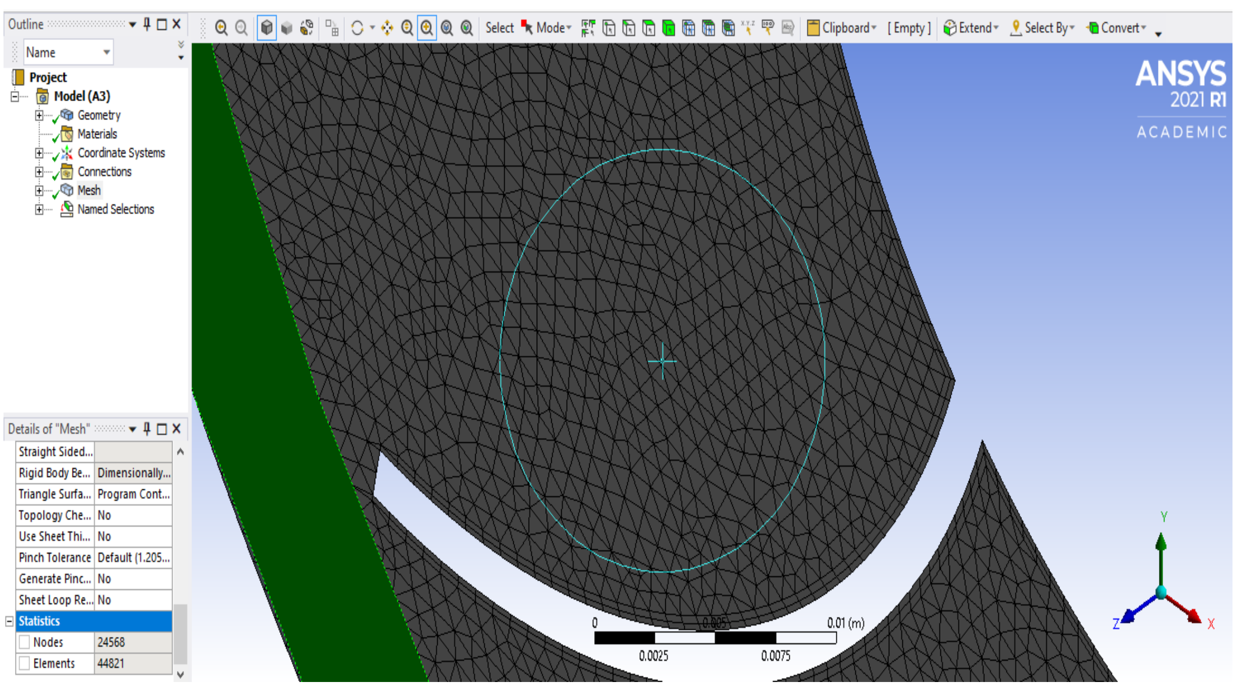

Fig: 5.4: Meshing of Turbine "All Triangle" Method

Simulation of Turbine Operation

5.4 The simulation of turbine operation has been performed in Fluent using K-Epsilon modelwhich is used for fluids motion in moving domains.

Calculations and Iterations

5.5 For turbine simulation run following inputs conditions are applied:-

(a) The steam inlet velocity: 25 m/s

(b) Inlet temperature: 100 °C

(c) Inlet pressure: 1678 Pa

(d) Turbulence intensity of 5%.

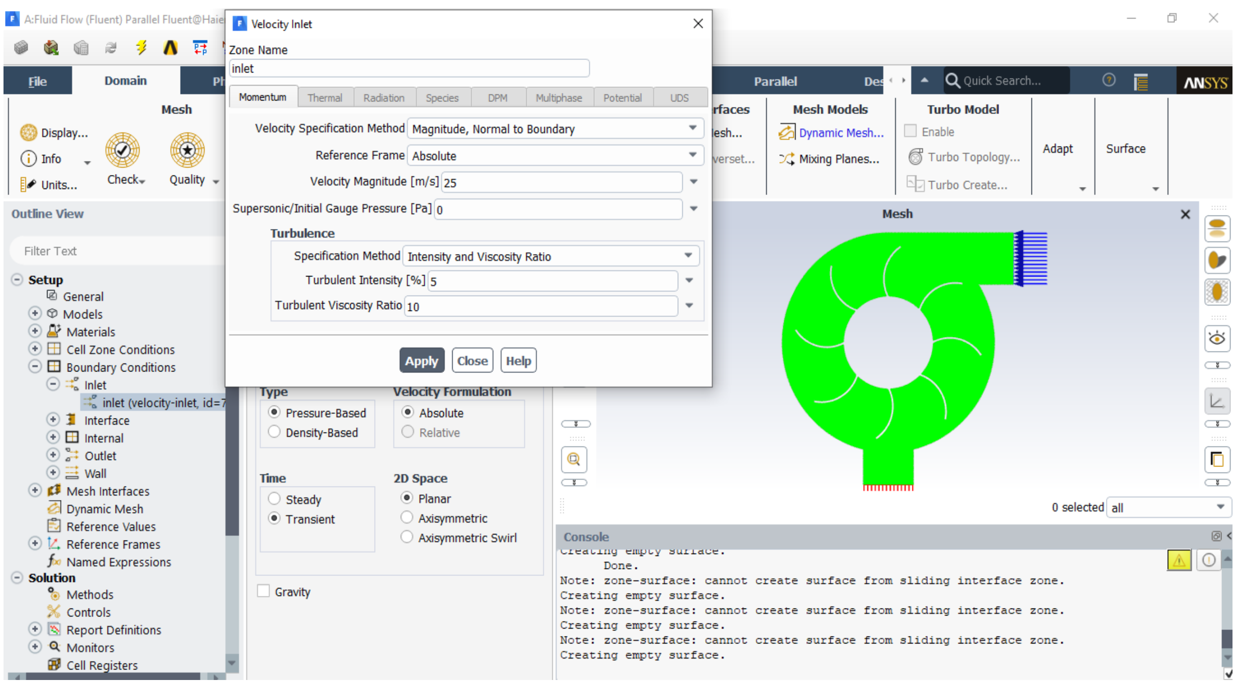

Fig: 5.5: Input Conditions of Steam at Turbine Inlet

5.6 For calculation run, time step of 0.0001 second been selected with total of 1000 time steps and 30 iterations per time step. The solution got converged at 270th time step; however the iterations were performed till 300th time step for convergence verification.

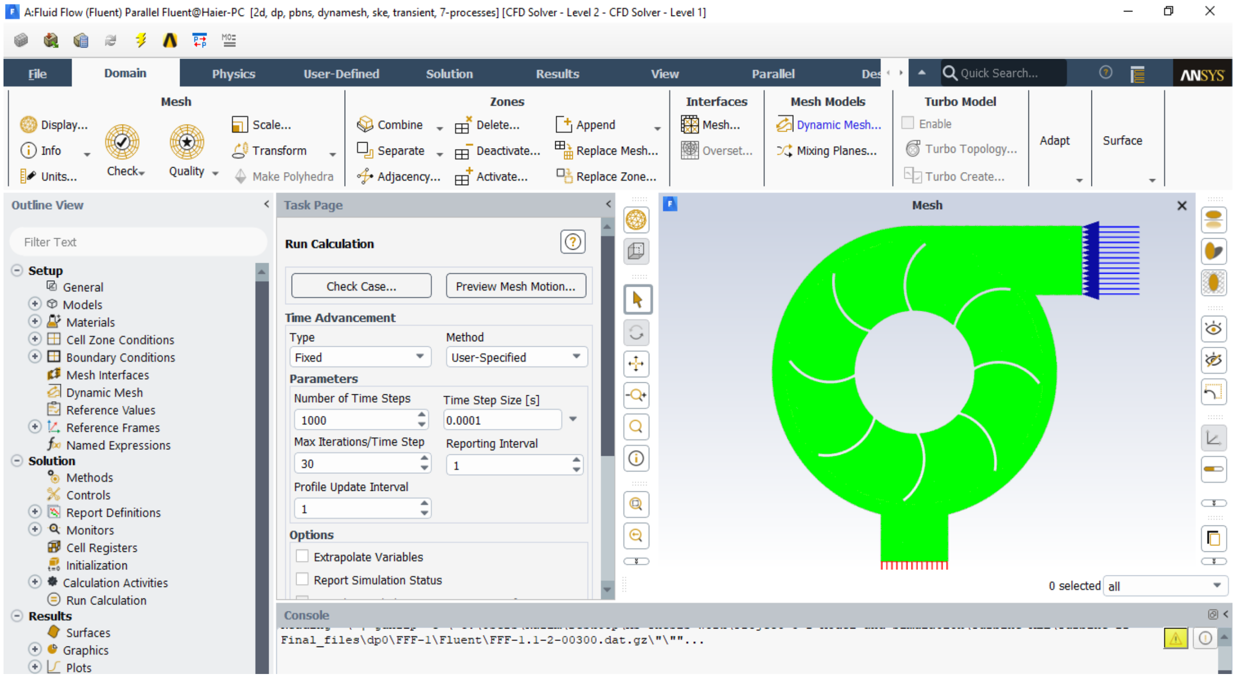

Fig: 5.6: Run Calculation

Simulation Resultsand Analysis

5.7 The post CFD analysis revealed 11 velocity contours ranging from 7.881e^{+1} to 0.0e^{0} m/s as shown in Fig 6.1:-

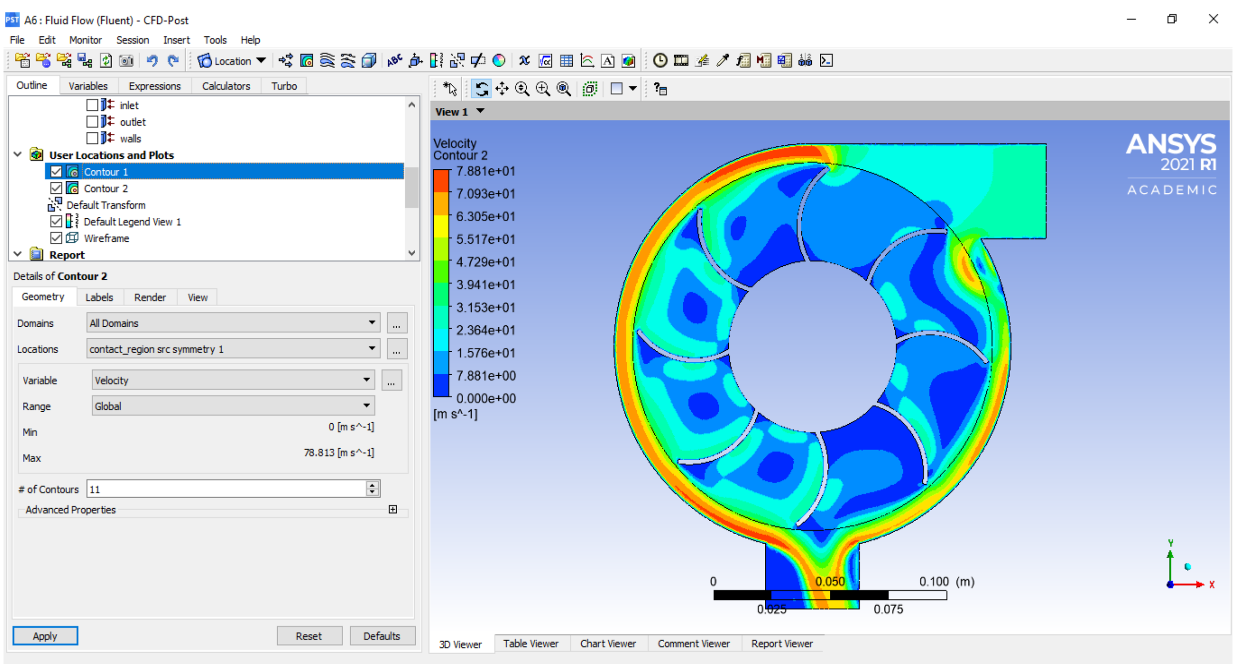

Fig: 5.7: Velocity Contours Formed During Simulation

5.8 The maximum observed velocity at the inlet is 78.813 m/s and minimum observed velocity at the out is 0 m/s. Similarly, 11 pressure contours formed during simulation run ranging from $4.159e^{6}$ Pa to $-9.193e^{5}$ Pa as shown in Fig: 5.8 below: -

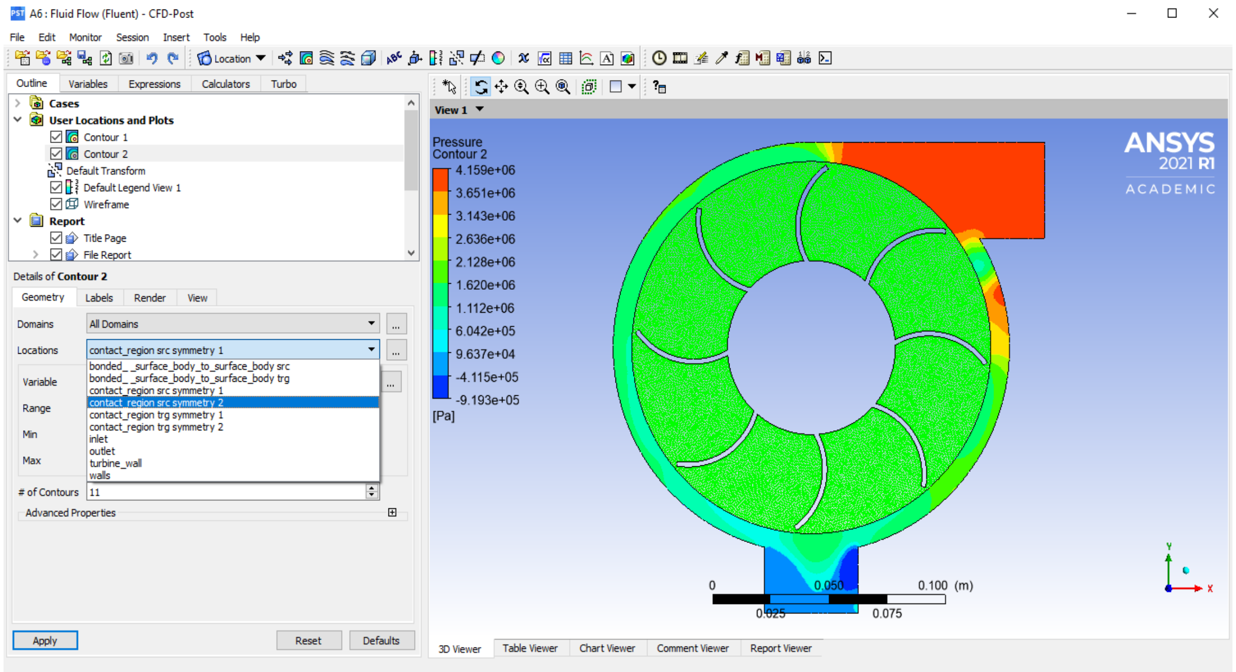

Fig: 5.8: Pressure Contours Formed During Simulation

5.9 The density contour remained constant at $9.982e^{2}$ kg/m^3 as shown in Fig 5.9 below: -

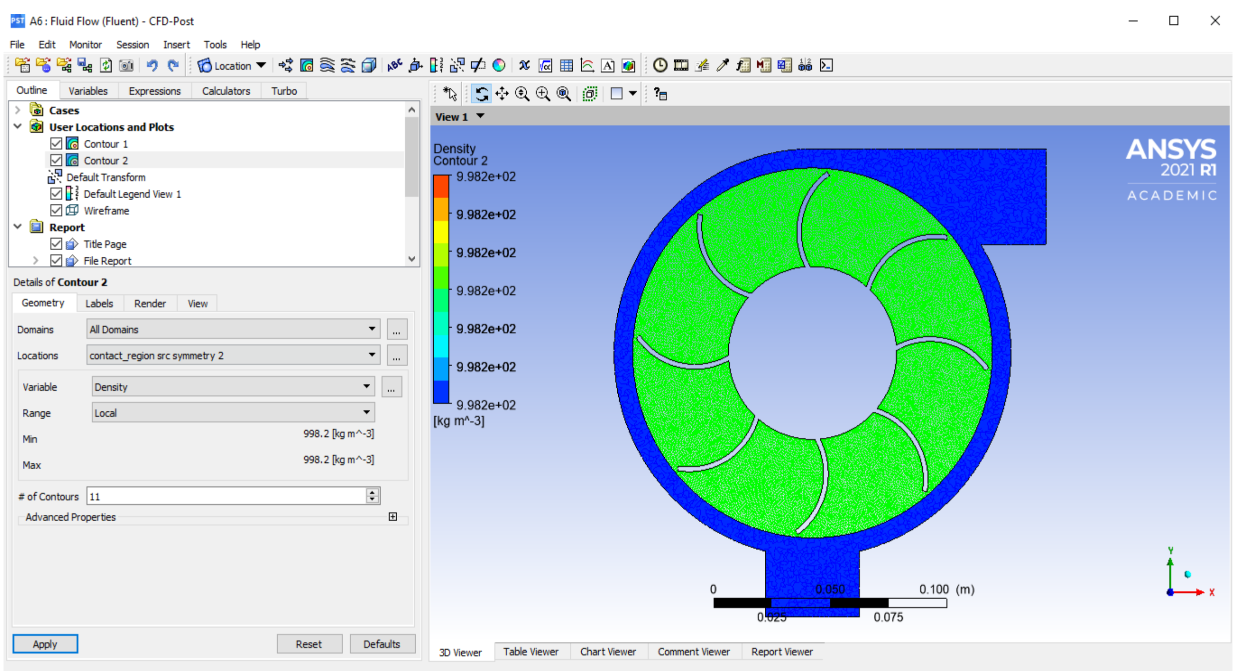

Fig: 5.9: Density Contours Formed During Simulation

5.10 The outlet pressure of the steam is found 0 Pascal as shown in Fig 5.10 below: -

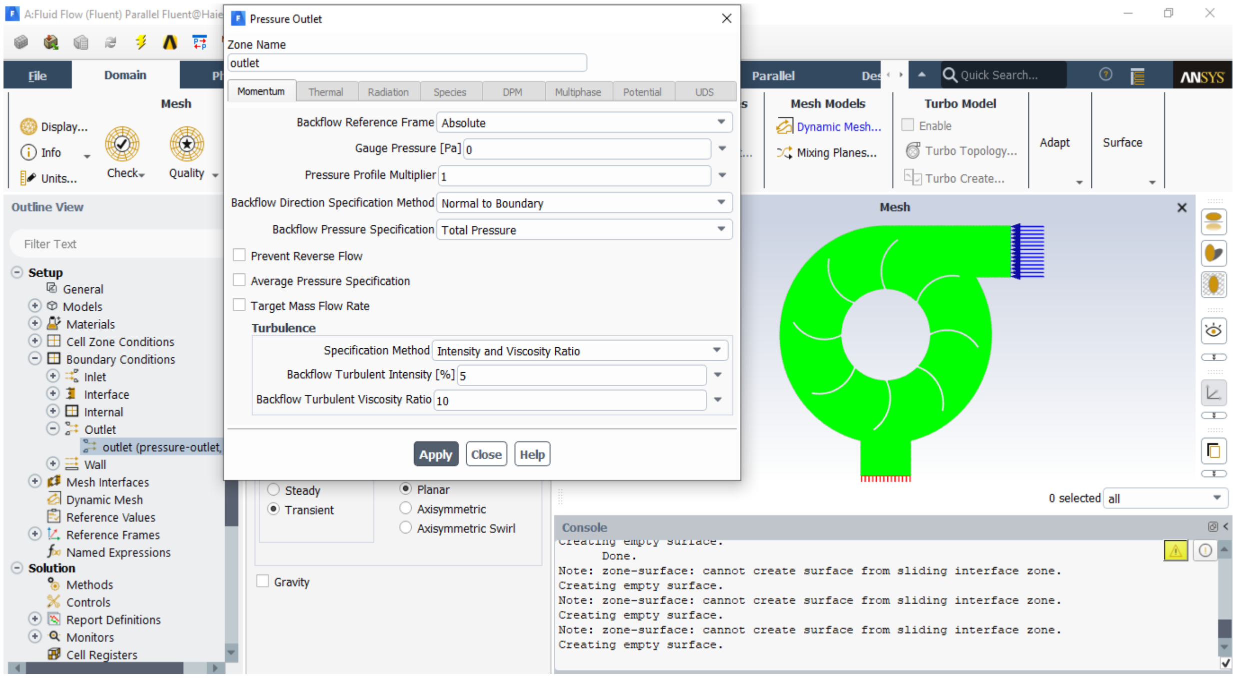

Fig: 5.10: Pressure at the Outlet of Steam Turbine

5.11 The results revealed that turbine RPM of 800-900 was achieved. The output obtained from tesla turbine with given input (steam velocity of 25-40 m/s and pressure 1678 Pa) is as follows:-

Inlet Pressure (Pa)	Inlet Velocity (m/s)	Turbine RPM	Output Voltage (V)	Output Current (Amp)	Output Power (Watts)	Efficiency
1678	25 - 40	800-900	11 - 12	1.5 - 2	16.5 - 24	58%

Table 5.1: Output of Tesla Turbine

Chapter No 6

Conclusion

6.1 The 3D modeling and simulation of the prototype design has been done with an aim to provide alternate solution to acute shortfall of electrical power being faced by domestic and commercial users of Pakistani population. The effort forms basis for further study and practical implementation of the conceived idea. The experimental prototype design of energy generation from domestic water geyser has theoretically produced positive outcome in terms of power generation; however, the design needs further optimization through involvement of the industrial experts before it can be produced on commercial scale for generation of low-cost energy. The efficiency of this model will depend upon the amount of output generated in terms of electrical power as compared to the amount of natural gas consumed for generating the steam and running the steam turbine. If the practical outcome of the proposed design is cost effective, it can be promoted on large scale to produce cheaper electricity for domestic and commercial needs.

Recommendations for Future Work

6.2 Following are the recommendations that can be worked upon to achieve more fruitful results in this domain: -

(a) The theoretical optimization of the prototype assembly may be carried out to achieve maximum output.

(b) The 3D modeling and simulation of the prototype assembly may be practically experimented through involvement of the industrial partner.

(c) After achieving desired output during optimization process, the product can be commercialized to attain cheaper power production domestically and on industrial scale.

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