PERFORMANCE ANALYSIS OF SAVONIUS HYDROKINETIC TURBINE

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IN

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Submitted by:

PAWAN KUMAR PULIJALA

2K18/CDN/05

Under the Supervision of

Dr. RAJ KUMAR SINGH

MECHANICAL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi - 110042

MECHANICAL ENGINEERING DEPARTMENT
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi - 110042

CANDIDATE'S DECLARATION

I, PULIJALA PAWAN KUMAR, Roll No(s). 2K18/CDN/05 student of M.Tech (Computational Design), hereby declare that the project report titled "**Performance Analysis of Savonius Hydrokinetic Turbine**" submitted to the department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award, of the degree of Master of Technology, is original and not copied from any source without proper citation.

Place: Delhi PAWAN KUMAR PULIJALA

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MECHANICAL ENGINEERING DEPARTMENT

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi - 110042

CERTIFICATE

I hereby certify that the Project Dissertation titled "**Performance Analysis of Savonius Hydrokinetic Turbine**" which is submitted by Pulijala Pawan Kumar, Roll No. 2K18/CDN/05 Mechanical Engineering Department, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Date: 29/08/2020

Dr. RAJ KUMAR SINGH

(PROFESSOR)

Mechanical Engineering Department

DTU, DELHI

ABSTRACT

Small Hydro power can be seen as a trend in the recent times. The difficulties associated with the setup of conventional hydro power systems can be significantly compensated by the utilization of the hydrokinetic technology. Hydrokinetic turbines transform the kinetic energy of flowing water into electric power. This project deals with the study of one such class of hydrokinetic turbines namely the Savonius Hydrokinetic rotors. The SHKT is a drag based double S-shape bladed turbine although not ideal for power generation can produce electricity in the strongest flows without incurring damage and operating quietly. Besides they are low cost turbines which utilize the natural flow of water and do not cause harm to the environment. The aim of this project is to analyze the performance of a Savonius rotor in free and restricted flows and to study the effect of deflector plates on the upstream side level of the turbine and also to optimize the position and inclination of deflector plate shielding the returning blade of the turbine. The CFD simulations were carried out through the ANSYS-CFX module wherein the 3D geometry of rotor's blades have been developed through the Ansys Design Modeller. A transient blade row model using the k-ε turbulence model with medium turbulent intensity was chosen for the pre-processing and the necessary boundary conditions such as inlet velocity, exit static pressure and no slip wall were given to the meshed domains of rotor and the water channel and were subsequently initialized. Important flow parameters such as velocity, pressure, turbulence kinetic energy and streamlines have been captured by the various contour plots which helped to calculate performance parameters such as torque, coefficient of torque and coefficient of power. In order to gauge the performance and validate the results, simulations were carried out considering the same speed of the rotor and were compared with the experimental results of Kailash Golecha et. al. The effect of deflector plates shows an increase in its coefficient of power (Cp) from 0.23 to 0.27 which thus confirms to a significant improvement in the rotor's performance. Also the simulation validates the performance of the rotor at various angles of the deflector plates and confirms to account for a maximum coefficient of performance of 0.21 at an angle of 101° as obtained by Kailash Golecha et.al, thus indicating an improved performance in the working of the Savonius rotor.

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I would like to express my deepest gratitude to my supervisor, Dr. RAJ KUMAR SINGH for his excellent guidance, caring, patience, and providing me with an excellent atmosphere for doing research. Your advice on both research as well as on my career have been priceless. The opportunity, support, exposure and atmosphere provided by the Delhi Technological University, to carry out my studies are highly appreciated.

A special debt of gratitude is owed to the authors whose works I have consulted and quoted in this work.

Last but not least, I am forever grateful to my parents, family and friends for their unconditional support and best wishes.

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NOMENCLATURE

ρ	Density of water	($1000 kg/m^3$)
μ	Dynamic Viscosity	(Pa.s)
Ψ	Blade Arc Angle	(Degrees)
A	Swept area of rotor	(mm^2)
D	Diameter of rotor	(mm)
d_s	Diameter of Shaft	(mm)
d	Diameter of blade	(mm)
r	Radius of blade	(mm)
R	Radius of the rotor	(mm)
H	Height of Blade	(mm)
H'	Height of enclosure	(mm)
D'	Diameter of enclosure	(mm)
T	Torque	(N-m)
T_{act}	Torque Obtained	(N-m)
v	Velocity of fluid	(m/s)
U	Free stream velocity	(m/s)
V_1, V_2	Upstream and Downstream Velocities	(m/s)
$P_{shaft} = P_{act}$	Power Produced	(Watt)
P_{input}	Hydrokinetic Energy	(Watt)
P_{th}	Theoretical power	(Watt)

ω	Angular velocity	(rad/s)
H_w	Height of water Channel	(mm)
W	Width of water Channel	(mm)
N	Angular Velocity	(RPM)
t	Blade thickness	(mm)
e	Length of overlap	(mm)
η	Efficiency of Turbine	
ε	Epsilon	
C_T	Coefficient of Torque	
C_p	Coefficient of Power	
C	Celsius	
α	Aspect Ratio	
β	Overlap Ratio	
B	Blockage Ratio	
λ	Tip Speed ratio	
Re	Reynold's Number	

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CHAPTER 1: INTRODUCTION

1.1 NEED FOR RENEWABLE HYDRO POWER

In the recent times it can be observed that the growing population, the advancing demands, the springing developments and the intense competition arising between individuals and countries are leading to factitious sophistication at the cost of nature. The reckless utilization and over exploitation of natural resources, seriously lacking the concern for the forthcoming generations and the health of our planet explains the graveness of the present situation. The existing demand for fossil fuels and their utilization is fast depleting the reserves that once took millions of years to aggregate. Also, the emissions involved in the the combustion of these fuels have impacted and abundantly contributed to the global climate change. Therefore, a need arises to utilize alternate, eco-friendly, renewable and clean energy resources which can solve the existing energy crisis to some extent.

Among the various renewable energy sources such as solar, wind, tidal, geothermal, ocean-thermal, bio and hydro forms, Hydroelectricity is often considered the best sustainable alternative. But the construction of massive mega powered hydro projects has some intrinsic problems such as displacement of local communities, submergence of land and loss of biodiversity etc,. thus necessitating the need for small-scale hydropower generation. Nearly 33 percent of the world's population is living without electricity in rural and remote areas although these places have the access to flowing water with little or zero head. Thus utilization of these minimalistic, inexhaustible yet untapped resources can reduce the burden on the consumption of the conventional fuels in power generation in addition to ensuring these locations to be connected to the power grid.

In accordance to the above facts, an invention in the early 1920s by Sigurd Johannes Savonius of Finland comes into the lime-light: Savonius Turbine. The savonius turbine is a drag-based turbine whose operation is similar to a cup anemometer assembly. It is an S-Shaped turbine comprising of an assembly of two cut halves of a hollow cylindrical section which make its blades which can be straight or skewed and rotate when the incident fluid strikes them. Earlier this turbine was only for wind-power generation, but research proves that these turbines generate more power in their hydro-use because of the high power density of water. Hence these 'Hydroelectric turbines' although not ideal for power generation can produce electricity in the strongest flows without incurring damage and operating quietly.

HKTs is a class of power generating technologies which uses kinetic energy of the flowing water with minimal velocity and low head, thus having the definition of Zero Head or Instream Turbines.

Some of the greatest advantages of HKTs include simple design, easy manufacturing, safe mounting and the costs incurred are very less. But the key barrier in their use is the lack of adequate research and unawareness of its technical, economical and environmental benefits. They have a low coefficient of power when compared to Darrieus turbines which is mainly due to low RPM in spite of having a high torque value. Their efficiency is mere 27% i.e,. only 27 percent of the total Hydro-Kinetic energy of the water hitting the rotor is converted into rotational mechanical energy.

The working principle of Savonius HKTs is based on the difference of drag force between concave and convex parts of the rotor blades when they rotate around a vertical shaft as the back of the blades experience much less drag in comparison to the front,facing the fluid. Thus the force exerted on the concave side is more than that of the convex side of the blades.

HKTs are prominently of two types - axial flow and cross flow turbines. Axial flow turbines are those turbines whose rotational axis of the rotor is parallel to the incoming water stream, whereas cross flow turbines have their rotational axis of their rotor parallel to the water surface but orthogonal to the incoming water stream. The advantage of cross flow turbine is that they can rotate unidirectionally even when the flow is bidirectional. They are further classified into two types namely vertical axis and inplane axis turbines

Vertical axis means axis is vertical to the water plane. H-Darrieus, Squirrel Cage Darrieus, Gorlov, savonius are some of the examples of vertical axis turbines.

The main drawbacks associated with these turbines are: low starting torque, torque ripple and lower efficiency. They turbines may not be self starting and therefor some kind of external starting mechanisms need to be adopted.

In- plane axis means axis on the horizontal plane of the water surface. They are also called as floating water wheels. They are drag-based turbines and less efficient than their lift based counterparts. They are self starting and no issue of start up. But their main disadvantage is they are not economical.

Some of the areas of applications of these hydrokinetic devices include some household uses such as operating water pumps, charging batteries, lighting homes; agricultural uses such as irrigation, and they can also be used to power telecommunications and other low power utilities which can utilize this form of electricity.

In this project we have considered a Vertical Axis Savonius Hydrokinetic turbine whose three dimensional computational model has been developed for simulating its performance. The numerical simulation has been done using the realizable k-ε turbulence model an the solution of transport equations were done using the commercially available ANSYS CFX (vR19.0) which uses finite volume method (FVM) to describe the flow field.

The flow field is studied with the help of velocity contours and pressure contours. The pattern of velocity is observed and upon investigation it is found to be in accordance to the boundary conditions. The tip of the blade depicts a high-speed zone and when the turbine rotates a wake zone or a low speed zone was found prevailing behind the rotor blades whose flow velocity is decreasing sharply. Turbulence is caused because of high randomness which can be observed in the flow field on the rear side of the rotor.

The investigation proceeds to identify the upstream and downstream flow conditions and aims to find out about the magnitude of velocity variation upon the installment of the static deflector plates across the flow channel. Based on the above observations suitable calculations such as torque, coefficient of torque and coefficient of power are calculated. The project also compares the percentage improvement on the performance of the turbine with deflector plates to that of a turbine without these plates.

Finally, the optimization of deflector plate angle and its position were performed by placing the plates at various positions corresponding to 90º, 101º, 137º, 44º and 159º and individual CFD simulations were performed whose results such as torque, velocity contours were obtained from the post processor which were utilized to compute the Coefficient of torque and Coefficient of power. The results were subsequently compared and validated with the experimental results obtained by Kailash Golecha et.al,.[24][27]

1.2 AREAS OF APPLICATION OF SAVONIUS ROTOR

Small scale savonius rotors are used in advertising signs whose rotation aids in customer attraction towards the product being advertised.

Due to its low cost and reliability factors the use of this rotor is found even in anemometers where efficiency of the turbine does not play any role when measuring the wind speed.

Generally vertical axis turbines are effective in pumping water along with other low speed and high torque applications.

They are most widely used in Flettner rotors which aid as cooling systems in vehicles such as buses, trucks and vans which indeed is a good source of ventillation.

But prominently they are used to generate electricity from tides or ocean currents and streams which can either be natural-river streams or diverted channels such as river canals. Although ocean currents are unidirectional in nature, its versatile feature of accommodating even bidirectional flows helps to facilitate power generation through tides.

Power production through these hydrokinetic turbines is extremely helpful in achieving grid connectivity because they can be deployed at a large scale to drive power from tides or river streams and this electricity can be utilized to power up small villages and remote centres of the world which usually are considered to be stand-alone loads.

The hydrokinetic turbines can even be used alongside the existing hydroelectric plants. The used tail race of the river stream from these massive power plants can be utilized for capacity augmentation thereby utilizing the resource at the maximum possible level for accretion in the overall power generated.

Also, other potential areas of end use are sea water desalination systems and space heating.

1.3 <u>BENEFITS OF USING PMMS</u>

Hydropower is generally classified into small and large categories. India up to 25MW station capacity is sanctioned for PMMS. PMMS hydropower stands for Pico Micro Medium and Small hydropower.The electricity demand in the country is expected to grow at 10 percent per annum. With the Electricity Act (2003), Electricity Policy (2005) and Tariff Policy 2006/2016) in possession, the country has created a conducive atmosphere for investments in the power sector. It has been realized that there is a need to tap all possible sources of energy to meet this challenge and PMMS is considered as a reliable option for grid interactive as well as decentralized power generation.

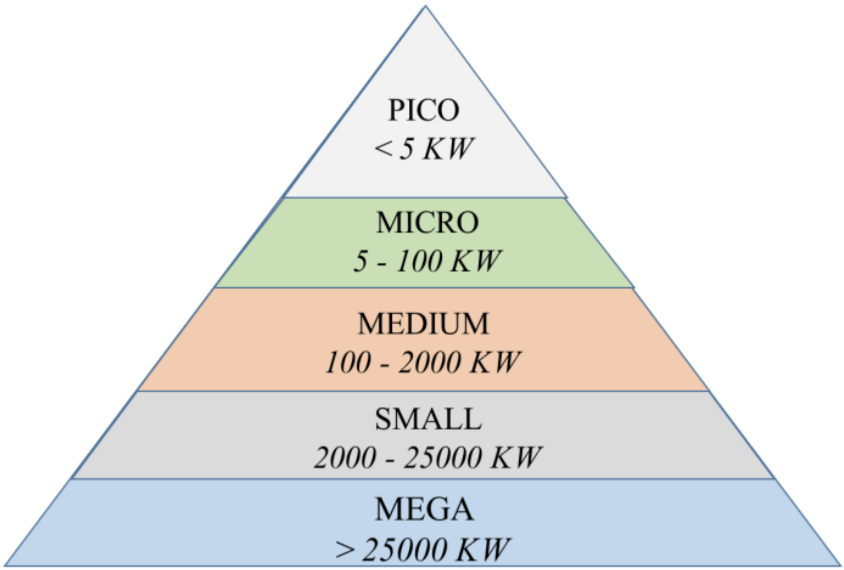


Fig 1.1. Structure of power generation

There are a number of socioeconomic and environmental aspects concerned with PMMS hydropower as it is regarded as a key element of sustainable development because of the following factors:

1. Effective utilization of water resources

Without much of a harm to local population as there is no need for storage of water resources this technology aids in utilizing water flowing in creeks, streams, canals, rivers etc,.

2. Renewable

The water which is being used to generate power is a renewable source and is never exhausted.

3. Cost effective and sustainable

Since the construction associated with PMMS hydropower is simple with minimal number of operating parts makes it quite economical and the cost associated with power production is much lesser than the routine thus even making it sustainable.

4. Reliable power source

This technology ensures continuous supply of electricity in comparison to other small renewable technologies.

5. Efficient energy source

Only a small flow approximately up to 2 feet high may be required but on the other hand the power produced can be transported even to a mile away.

6.Conservation of fossil fuels

Some of the scare fossil fuel consumption can be minimized and the objective of "Go renewable Go electric" can be achieved.

7. Low / NIL Polluting

There is no green house gas emissions here unlike fossil fuels thus contributing to clean energy and sustainabililty.

8. Development of rural and remote areas

A wholesome economic and social development can be ensured by deploying this renewable technology to rural areas as well as remote areas situated in difficult terrains thus makes it a power for developing countries.

9. No reservoir requirement

PMMS functions like a ‘run-of-river’ system, meaning that the water passing through the generator is directed back into the stream with relatively little impact on the surrounding ecology.

10. Other uses

Other benefits are found in regions where small plants are installed, such as irrigation, water supply, tourism, fisheries, and flood prevention.

CHAPTER 2: LITERATURE REVIEW

The savonius hydrokinetic turbine is a drag based turbine whose operation is similar to that of a cup anemometer. It is regarded as one of the most promising hydrokinetic technologies often untapped and a clean energy source of power production from the low-head flowing water whose kinetic energy is transformed into electricity.

The present literature survey shows some research papers which had the objective to measure the performance of SHKT using various inclinations of the setup in an open channel having constant velocity of water.

The Cp was measured for different load conditions and the flow characteristics were determined. Torque and power were being estimated for increasing load conditions starting from zero and calculated with the help of a spring balance arrangement and time was calculated using a stop watch.

The important conclusions which can be drawn are that torque and power both increase with the increase in coefficient of power; also a relation between load vs. power where in if load increases power decreases and at a particular angle the power remains unchanged irrespective of the load.[1]

Now the next question is what happens when the inlet velocity of water to the turbine is changed? Thus a research work where the performance was analyzed by application of varying speeds of water flow thus creating multiple conditons.

The key findings were that if velocity increases RPM increases of the rotor thus causing an increased hydraulic efficiency and higher mechanical power output. Therefore an increase in velocity of flow causes a substantial increase in the power produced by a rotor. [2]

So, does it mean if we increase the number of turbines we can harness more power? To answer this question a work of scientific research points out that an SHKT keeping velocity as a constant and varying the speed in rad/sec. It was observed that the power generated by the turbine is maximum when four of them were used and Cp is maximum when one was used and turbulent intensity remaining constant. Therefore, no decisive conclusion was made. [3]

However if a turbine was made in certain number of stages, does it add to any benefit? There were two models developed : Model A and B where in Model A, here SHKT was applied with two stages for low speed operations and whereas in model B it was mere a single stage turbine under similar operating conditions. The wind tunnel was driven by an inverter speed AC motor. Model B’s performance was better than that of A with reference to power, efficiency and lower discharge flow rate, increased power, high self starting capacity at low speed fluid. [4]

In an extension to the earlier research, a novel Savonius turbine with multiple stages and varying diameter of rotor at each stage was made with the prime objective of enhancing the performance of the rotor.

A three stage SHKT with a variable diameter in each stage was meticulously designed and its 3D computational model was constructed. Simulation was carried out in ANSYS under open channel flow.

According to the results obtained in their research, it was to be noted that performance of the rotor increases with an increase in TSR up to and certain limit (here it was found to be 0.8) and beyond this limit it declines gradually. However this research lacked experimental validation of this novel concept which is bound for future scope. [5]

Studies also showed when a nano-hydrokinetic turbine was to study the effects of phase difference between the blades affects the rotor’s performance and also presented an improvement mechanism with double step rotor from the visualization of the flow patterns and the rotor.

Three types of Savonius rotors were constructed and tested in a water tunnel to improve and measure power.

Rotor A was a standard savonius blade; Rotor B has 4mm thick partition plate in the central section; Rotor C is same as rotor B along with a 90º phase difference.

Results showed an improved performance with phase. The double step rotor had a phase difference in blades created the meandering flow in central cross section in both upstream and downstream tip of the rotor. [6]

Experiments tried to increase the torque along the angular position when torque is low by introducing secondary blades in front of the concave side of main rotor blades.

They interact with the fluid when the primary ones are not in action. Comparison with the conventional type was carried out and it is concluded that with overlap there is reduction in negative torque and maximum pressure difference between the blades. [7]

Gradually it lead to a doubt about the blade profile. Research work with reference to modifying the turbine blades to improve the power generation and performance on the whole have been performed. One such paper highlighted a modified turbine blades with cut slot of compartment, although it can be used by wind energy.

This test aims to reduce the power loss by rotor vibrations. Therefore, a higher performance is achieved with reduced power loss and enhanced efficiency with the modified savonius rotor.[8]

Then comes the study of SHKT using a tandem blade model. Comparison between three types of Tandem Blade savonius which were overlap, symmetrical and convergence types upon being tested was carried out. The idea was to broaden swept area that can increase drag force production on the blade.

2 D model was constructed and simulation was performed on Ansys. Pressure distributions for various angles at 0º, 30º, 60º and 120º (rotor angle) were computed. Also, their streamlines being plotted.

The major conclusions which could be drawn were that the peak performance was achieved when rotor angle reaches 150º, and also due to maximum difference in pressure upstream and downstream, when noted, gave the maximum performance for convergence TBS. [9]

Now in an attempt to improve the performance further, the savonius tandem blade setup is adjoined with a moving plate deflector (MPD). The objective behind this setup is to counter and reduce the negative torque generated by the flow itself and thereby improving its efficiency. This model was designed and analyzed using CFD. The CFD simulation testified positive torque when the STB is accompanied with a radial moving deflector plate. Comparison was done between STB coupled with MPD for both MPDs i.e, radial and tangential and results prove that efficiency of tangential MPDs performing better than those of radial. Finally experimentation was also done to validate the computational results and conclusions. [10] [25]

Savonius turbines are the ones which have the potential of renewable energy produced without the expense or exploitation of nature unlike other conventional hydel power sources. One such SHKT was designed and fabricated for its use in natural circumstances of river flow. Therefore it was designed for a momentum of water current at low velocity from 0.3m/s to 0.9m/s for an open channel flow. There was an experimental analysis being done over its working and performance was gauged. Torque and power have been computed and the key findings of this research were that both torque and power increase with increase in free stream water velocity. But the prolonged impact of this high free stream velocity reduces the blade's durability over time.

Another crucial finding from this research was the power extracted is varying with respect to different water layers. The top most layer has the highest velocity gradient, thus leading to highest power being extracted in comparison to other layers. But ironically, the power obtained from the bottommost layer is higher than that of mid layer due to the shear layer that separates from the channel's bed.

Therefore its effect on power is not to be considered in extracting design information about performance of the turbine. So its effects on power is not considered for knowing the design information. The performance shown is best when at 90º angle of rotation.

All the above results have been compared with a wind turbine with the same initial criteria, input power, reveal that the hydro-turbines performance is lower because of the occurrence of circulation and flow separation at the top of the blades, also due to separations from the concave face of returning blade and thrusts that act in opposite direction of rotation of the turbine. [11]

Research was also carried out to study what would be the impact on the performance of the savonius rotor by varying its height? A hydrodynamic test bench comprising intake, a control gate, pen stock and canalization, a turbine, a test section an outflow and a pump was used to carry out the experimentation. Parameters like power, dynamic torque, coefficient of torque, coefficient of power increases with decrease of height of the rotor. Thus this idea helped in optimum selection of height of the rotor in this project. [12]

Further a similar study of the performance criteria under similar flow conditions was once again being done on a hydraulic test bench to analyze the effect on the performance when the blades of the rotor are being overlapped. [13]

Basically to improve the driving force, the idea of reducing the reverse force on the returning blade or by increasing the positive force on the advancing blade. Thus thus concept led to the induction of obstacles in the flow path to the returning blade and concentrating the flow towards the advancing blade. Optimal position of plates were to be found out such that output power is increased multifold. [14] [20]

Also, study of a review article suggests the importance of upstream flow pattern in the functioning of the savonius rotor. Upstream flow patterns for the Savonius rotor are divided into four types, namely uniform flow, guided flow, rotor wake flow and oscillating flow to supplement upstream patterns, numerical simulation and experiments were performed in the present study. A numerical scheme was adopted for numerical computation which is RANS-Reynolds averaged Navier Stokes equations, including continuity and momentum equations which were used as governing equations. [15]

Presents effects of design factors on mechanical performance of Vertical Axis Wind Turbines (VAWTs), and an experimental investigation of optimal VAWT performance under low wind speed conditions in Thailand.Design factors include types of wind turbines, number of blades, types of materials, height-to-radius ratios, and design modifications. Potential VAWT models with different design factors are numerically analyzed within a virtual wind tunnel at various wind speeds by utilizing XflowTM Computational Fluid Dynamics (CFD) software. [16]

A research was carried on to utilize waste water running through the pipes which have the potential to produce electricity. The study establishes the effects of overlapping the blades mounted on a circular pipe at maximum head of 2m at Savonius Horizontal Axis Wind Turbine (SHAWT) to the Cp and TSR. The optimum results were obtained at blade overlap ratio of 0.3 on every discharge [17]

2.1 <u>RESEARCH GAP</u>

1. Profiles and geometry of deflector blades have yet not been thoroughly analyzed and standardized in detail and suggestions on the optimum design haven't been provided.
2. Optimization of the number of deflector plates in a channel for a turbine.
3. Researchers have also not analyzed parameters such as slip, discharge, no. of stages, no. of blades and secondary blades, RPM of rotor, considering the deflector plates. Only certain parameters such as torque, and minimizing the negative toque were focused and that too with moving plate deflectors and not stationary plate deflectors.
4. Analysis of the above parameters as to how they would change *w.r.t* a turbine which does not have deflector blades has not been performed and thus a comparative study has not been established.
5. Provision of nozzle inside the rotor enhances the performance of the turbine resulting in greater torque and high power. However, sufficient research has not been performed in this arena as well.

CHAPTER 3: AN OVERVIEW ON HYDROKINETIC TURBINES

3.1 INTRODUCTION TO HKTs

A hydrokinetic turbine is a turbine which transforms the kinetic energy of flowing water in rivers, streams, canals etc., into electrical energy or electricity. This renewable source of electricity production can be harnessed from a low head of moving water. A similar design can be opted for wind turbines as well but water being 832 times denser than air and the abundance of water resources such as tides, waves, ocean currents and freely flowing rivers presents us with more options to tap the highly concentrated and clean energy source on this planet.

Before getting into the classification of various hydrokinetic turbines it is important to assess the various advantages and disadvantages of hydrokinetic turbines.

ADVANTAGES

- These turbines do not need a reservoir.
- Hydrokinetic turbines utilize natural flow of water.
- They do not cause any harm to the surroundings.
- Not much of any costly equipment is required.
- They are an economic energy source.

DISADVANTAGES

- They require suitable site charateristics.
- The power generated is low and even lower during the summer months.
- The efficiency overall is low.

3.2 CLASSIFICATION OF HYDROKINETIC TURBINES

There are different classifications of hydrokinetic turbines and the major classification is based on the axis of rotation and the direction of water flow which is:

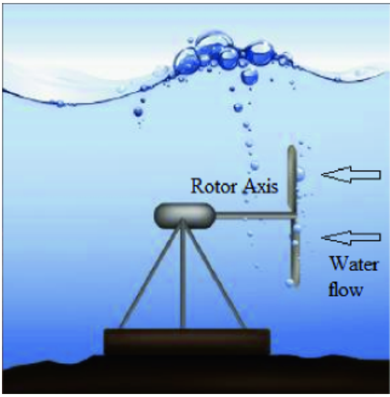
1. Horizontal axis hydrokinetic turbine

In this turbine, in order to generate electricity, it is mandatory for the rotational axis be oriented to the direction of flow of the water current.

2. Vertical axis hydrokinetic turbine

In this class of turbines, the rotational axis is oriented perpendicular to the direction of the flow of the water current.

The below figure illustrates the horizontal and vertical hydrokinetic turbines.



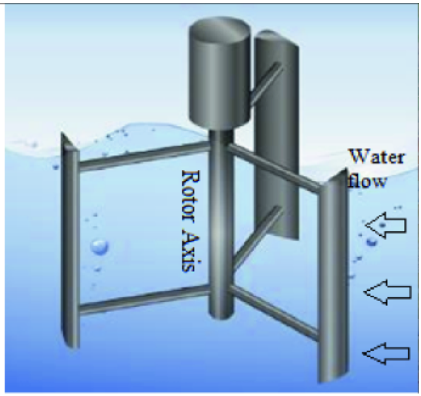


Fig 3.1 Horizontal Axis Hydrokinetic turbine   Fig 3.2 Vertical Axis Hydrokinetic turbine

It is to be recognized that the efficiency of vertical axis hydrokinetic turbines is much lower than the horizontal axis hydrokinetic turbines. However, the main advantage of vertical axis hydrokinetic turbines is that every section of the blade is subjected to the same water speed and therefore does not demand for a twisted blade profile likewise in horizontal axis turbines. This advantage aids in easier design and replication and fabrication of the blades thus impacting in reducing the costs and making it more economical. The low efficiency of the vertical axis hydrokinetic turbines can be attributed to low starting torques and dynamic stability problems.

There is another classification of hydrokinetic tuirbines which is axial flow and cross flow turbines.

1. Axial Flow hydrokinetic turbine

In the concept of axial flow turbine it can seen that the rotational axis of water is parallel to the incoming water stream.

2. Cross flow hydrokinetic turbine

In these turbines, the rotational axis of the rotor is parallel to the water surface but is orthogonal to the incoming water current.

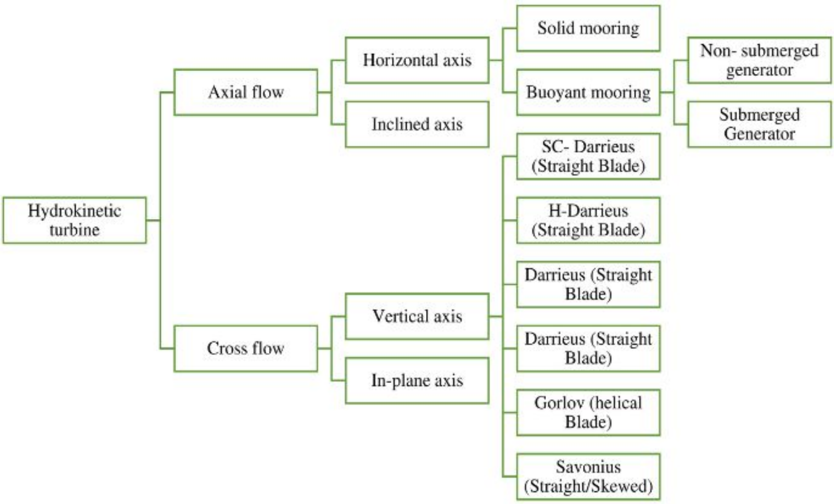


Fig: 3.3 Classification of Hydrokinetic turbines

Darrieus Turbine

It is type of vertical axis turbine which can generate electrical energy from flower water or wind possessing kinetic energy. This type of turbine comprises of curved profile aero foil blades around the rotating shaft as shown below. It is a lift based turbine

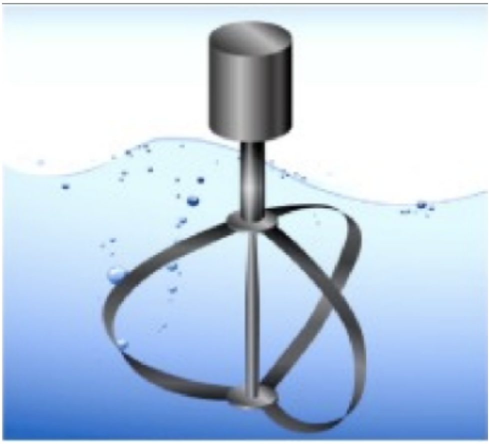


Figure 3.4 Darrius turbine

Although the tip speed ratio (TSR) of Darrieus turbine is high which makes its rotation much faster but the turbine requires expensive material in blades thus making it non-economical. The various types of Darrieus turbines are illustrated below.

Fig 3.5 Squirrel cage Turbine

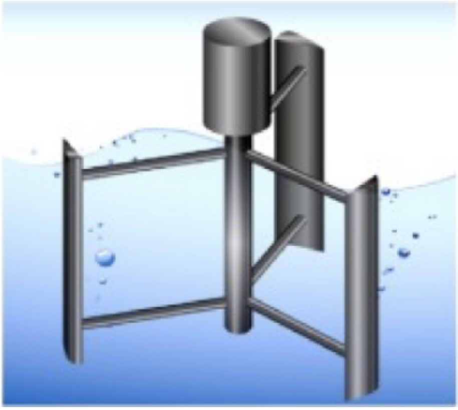


Fig 3.6 H-darrieus Turbine

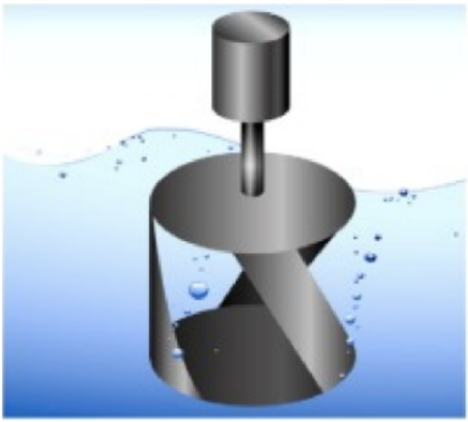


Fig 3.7 Gorlov Turbine

SAVONIUS TURBINES

These are drag based turbines with either straight or skewed blade profiles. Their efficiency is low in comparison to darrieus turbines.

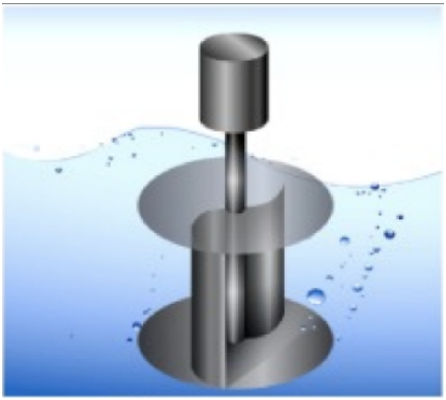


Fig 3.8 Savonius Turbine

Another classification of hydrokinetic turbines includes in-plane axis and inclined axis turbines.

In-plane axis turbines - These turbines have axis on the horizontal plane of the water surface. They are also called as floating water wheels. They are also drag based in nature similar to savonius turbines. The main disadvantage is the use of large amount of material which increases the cost of manufacturing of these turbines. The below figures illustrates in-plane axis and inclined axis turbines.

Fig 3.9 In-plane axis rotor

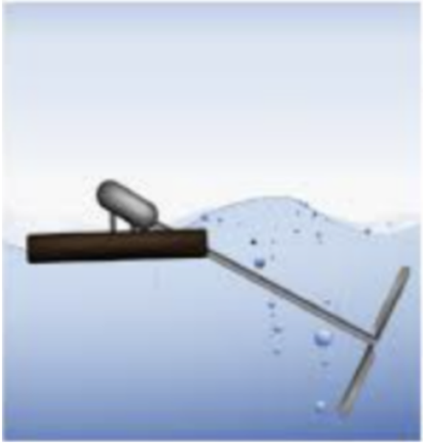


Fig 3.10 Inclined axis rotor

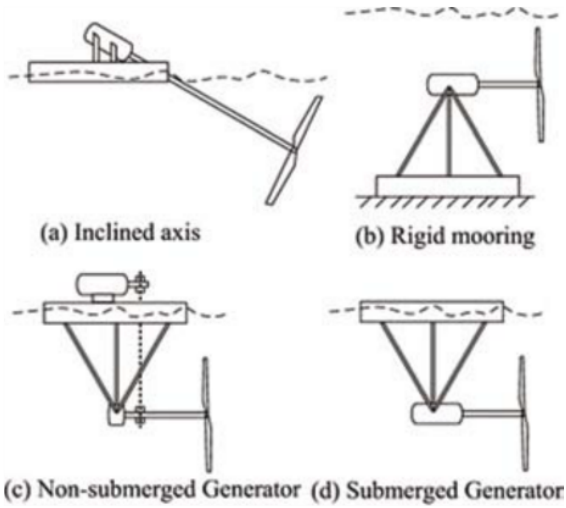


Fig 3.11 Hydrokinetic Technology

3.3ADVANTAGES & DISADVANTAGES OF AXIAL AND CROSS FLOW TURBINES

ADVANTAGES OF AXIAL FLOW TURBINES

- Higher efficiency than cross flow turbines
- No torque ripple.
- Ability to self start.

DISADVANTAGES OF AXIAL FLOW TURBINES

- Higher manufacturing and transportation costs.
- Difficult for the turbines to be stacked together in small and narrow flow streams.

ADVANTAGES OF CROSS FLOW TURBINES

- They are having a cylindrical shaped rotor thereby utilizing the space more effeciently.
- In case of duct augmentation the costs associated is low.
- Manufacturing and transportation is low because of smaller ans simplicity in the parts.
- Maintenance is low since generator can be placed above the water level.

DISADVANTAGES OF CROSS FLOW TURBINES

- Torque ripple is present.
- Inability to self start.
- Low efficiency.

CHAPTER 4: PROJECT OBJECTIVES AND WORK PLAN

4.1 PROBLEM DEFINITION

- To find the effect of deflector plates on the upstream side level.
- To find the effect on discharge on the upstream side level using turbine.
- To find the performance of hydrokinetic turbine. (Torque, coefficient of power, etc,.) and optimize the deflector plate angle.

4.2 METHODOLOGY

1. Identification of parameters for numerical simulation of turbine.
   i) Fixed Parameters
   ii) Working Parameters
2. Creating 3-D model of Savonius Hydrokinetic turbine and open channel and creating mesh.
   i) Using ANSYS Design Modeler and ANSYS Mesh.
   ii) Variable Parameters.
3. Import Mesh to ANSYS FLUENT.
   i) Define Initial conditions for unsteady analysis.
   ii) Define boundary conditions.
   iii) Define Turbulence Model.
   iv) Set number of time step and time step size.
4. Run simulation for n revolutions of turbine.
5. Analyze results and validate results with experimental results.
6. Based on the above results optimize the results.

CHAPTER 5: DESIGN OF SAVONIUS HYDROKINETIC TURBINE

5.1 SAVONIUS ROTOR

The word Savonius derives its origin from the Finnish engineer Siggard Johannes Savonius who invented the savonius vertical axis wind turbine in 1922. It is one of the simplest turbines. It is basically a drag based rotor. The rotor comprises of curved blades positioned in manner such that it is S-shaped. Due to this type of curvature it experiences less drag when moving against the flow than when moving with the water flow. The differential drag is responsible for the rotation of the turbine.

Savonius rotor is simple in construction with low cost and produces less noise. It has the ability in accepting fluid from any direction with good characteristics. It has low aerodynamic efficiency in comparison with darrieus turbine.

The working principle behind savonius rotor is based on the difference in drag force between the concave and convex surfaces of the blades. The drag coefficient for concave surface is more than that of convex surface. So advancing blade with concave side facing the water flow would experience more drag force than returning blade.

A typical two bladed Savonius rotor is shown in Figure

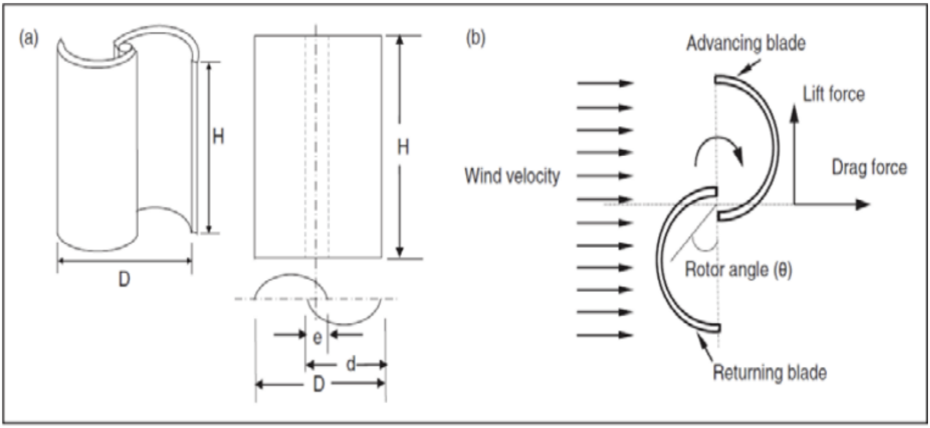


Fig 5.1 Illustration of 2-bladed savonius rotor.

The conventional single stage Savonius rotor has a large static torque variation with the rotor angle. At certain angular positions it can be seen that the rotor also produces a negative torque which may have an adverse impact on the rotor applications. Research points out that this type of rotor can be utilized for low speed applications because it has low starting torque because of being simple in its making and the economical factors suggests its use in electricity generation coupled with a generator involving minimal and easier maintenanace.

5.2 DESIGN PARAMETERS

1. Aspect ratio

The ratio of height (H) to the diameter (D) of the rotor is called as aspect ratio (α). An aspect ratio of 0.7 is best suited for a hydrokinetic turbine to produce maximum efficiency.

$$\alpha = H/D$$

2. Overlap ratio

When one vane is twirled against another vane about the rotating axis then its called an overlap or bucket overlap (e). It is an important criterion in altering the effectiveness of the turbine.

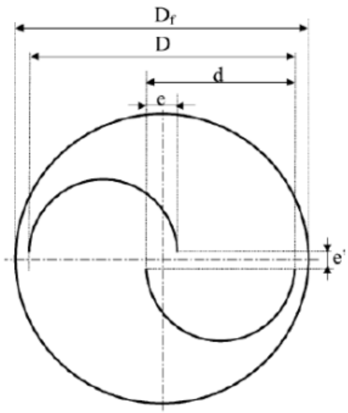


Fig 5.2 Overlapping in savonius rotor

The overlap ratio (β) is the ratio between the overlap and the diameter of the blades.

$$\beta = e/d$$

Research points out that with an increase in overlap ratio there is decrease in the amount of power produced. In one of the studies there is a maximum power coefficient of 51% obtained under a no overlap condition.

3. Blockage ratio

Blockage ratio (B) is defined as the ratio of the frontal swept area of the turbine to the frontal swept area of the channel. It can be written as:

$$B = HD/H_W W$$

Where, H is Height of the turbine, D is Diameter of turbine rotor, H_W is Height of the water in channel, W is Width of the channel. In accordance of research work of Alexander and Holownia, if the blockage ratio exceeds 0.3 then there needs to be a modification in the rotor's design.

4. Blade Arc Angle

Angle between the two blade profiles is called as blade arc angle.

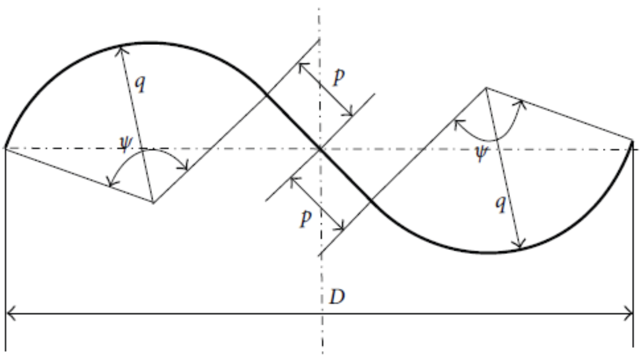


Fig 5.3 Blade Arc Angle of savonius rotor

It is found that in a modified savonius rotor with an aspect ratio of 0.7 having no blade overlap if the blade arc angle is kept at 124º then the turbine functions with maximum efficiency. The power coefficient was found to be 0.21 at a Reynolds number of 1,50,000. The blade arc angle is shown in the figure given below.

5. Tip speed ratio

The ratio of the speed of blade at its tip to the speed of flowing water is defined as tip speed ratio (λ).

It can be expressed as:

$$\lambda = \omega R/2V$$

Where,

ω = Angular velocity of Turbine blade

R = Radius of the blade

V = Water flowing speed

6. Number of Stages

In accordance to academic findings the coefficients of power and torque and no load tip speed ratio increase with increase in the Reynolds number (water velocities) for one, two and three stage hydro kinetic turbines. The number of stages is illustrated in the figure.

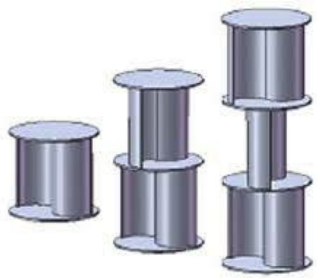


Fig 5.4 Single, Two and Three Stage Savonius rotor

7. Number of Blades

A Savonius rotor can be accommodated with odd or even number of blades in order to variate its performance.

The various configurations based on previous research is shown below.

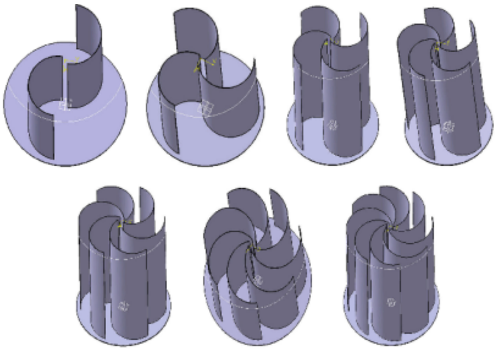


Fig 5.5 Number of Blades in a savonius rotor

8. Augmentation

Augmentation refers to the encapsulation of the entire rotor in a duct in order to enhance the hydrokinetic turbine's performance. Ducts or diffusers are engineered structures that elevate the energy density of a water stream as observed by a hydrokinetic converter. By introducing an augmented channel surrounding the rotor not only increases the power produced but also regulates the speed of the rotor and reduce problems caused by low-speed drive train design.

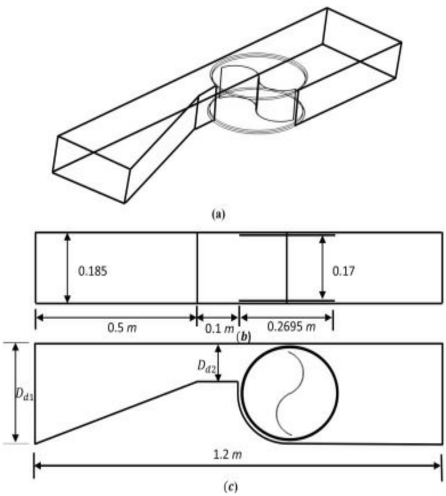


Fig 5.6 Illustration of Augmentation in water channel

5.3 CAD MODELLING OF SAVONIUS HYDROKINETIC TURBINE

Depending upon the various design parameters discussed in the earlier section we have designed the savonius rotor. A brief description of the components of a savonius rotor is shown below.

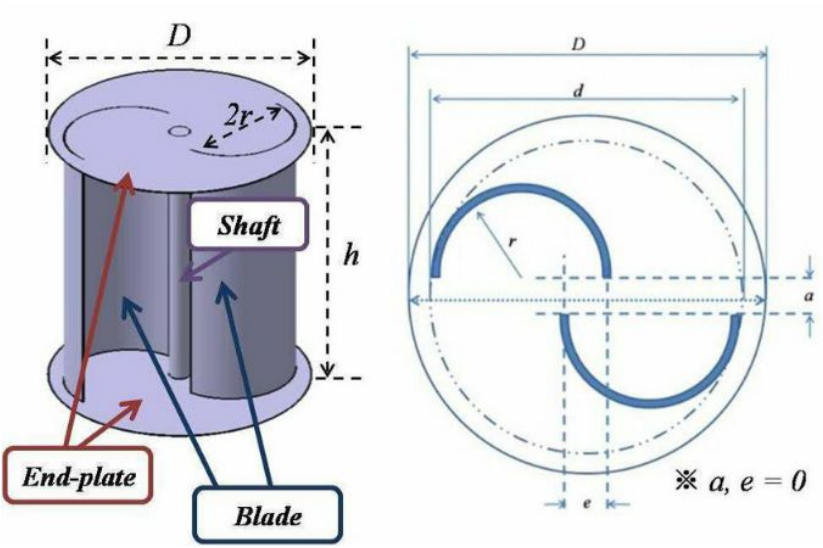
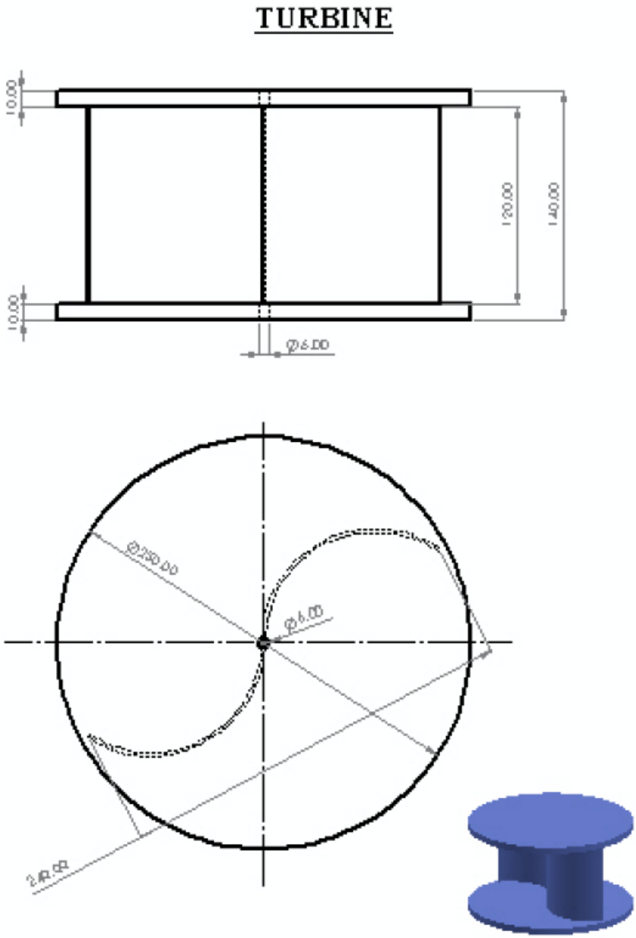


Fig 5.7 Nomenclature of Savonius rotor

Table 5.1: Design Parameters (CAD model in Solidworks)

PARAMETER	VALUE
Height of the Rotor (H)	140 mm
Blade arc angle (Ψ)	124º
Diameter of Shaft (d_s)	6 mm
Length of Shaft (L)	140 mm
Diameter of Blades (d)	135.9 mm
Thickness of Blades (t)	2 mm
Diameter of the Rotor (D)	240 mm
Overlap (e)	0 mm
Diameter of End Plates (D´)	250 mm

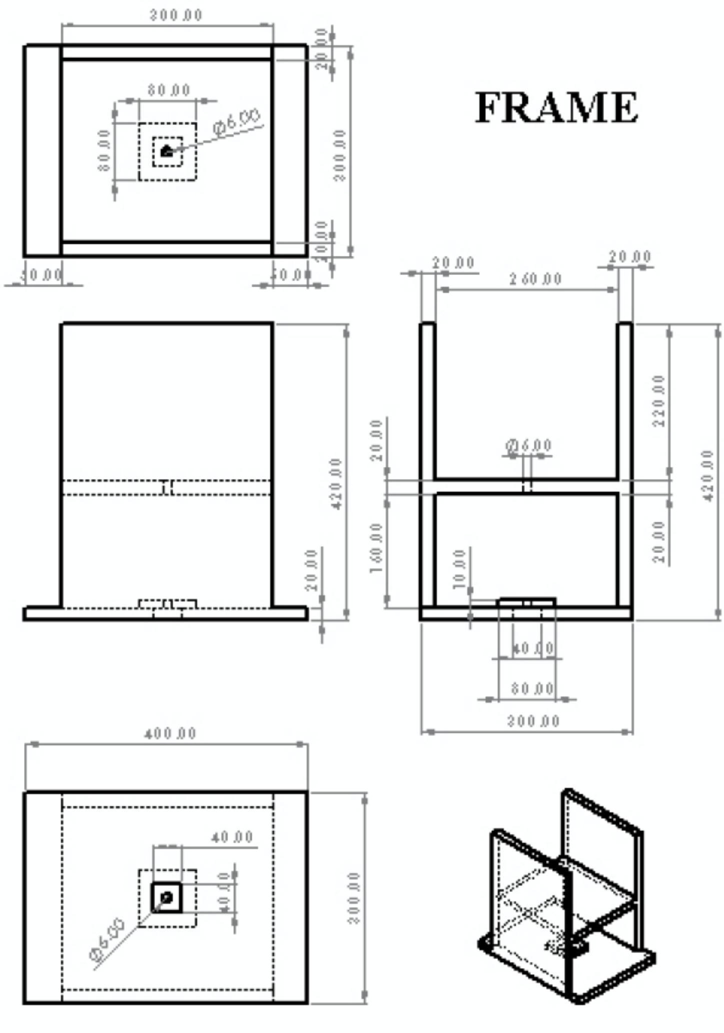
The design of the savonius rotor was done in SOLIDWORKS 2019. The geometry of the rotor was constructed using various options such as sketch, extrude, cut etc,. The geometry constructed is illustrated below.



(All dimenions in mm)

Fig 5.8 CAD model of Turbine

The rotor however has to be affixed within a frame to support its working. The frame is also constructed using the same design software. The part drawing of the frame is show below.



(All dimensions in mm)

Fig 5.9 CAD model of Frame

The assembly of both the constructions are shown in the figure below.

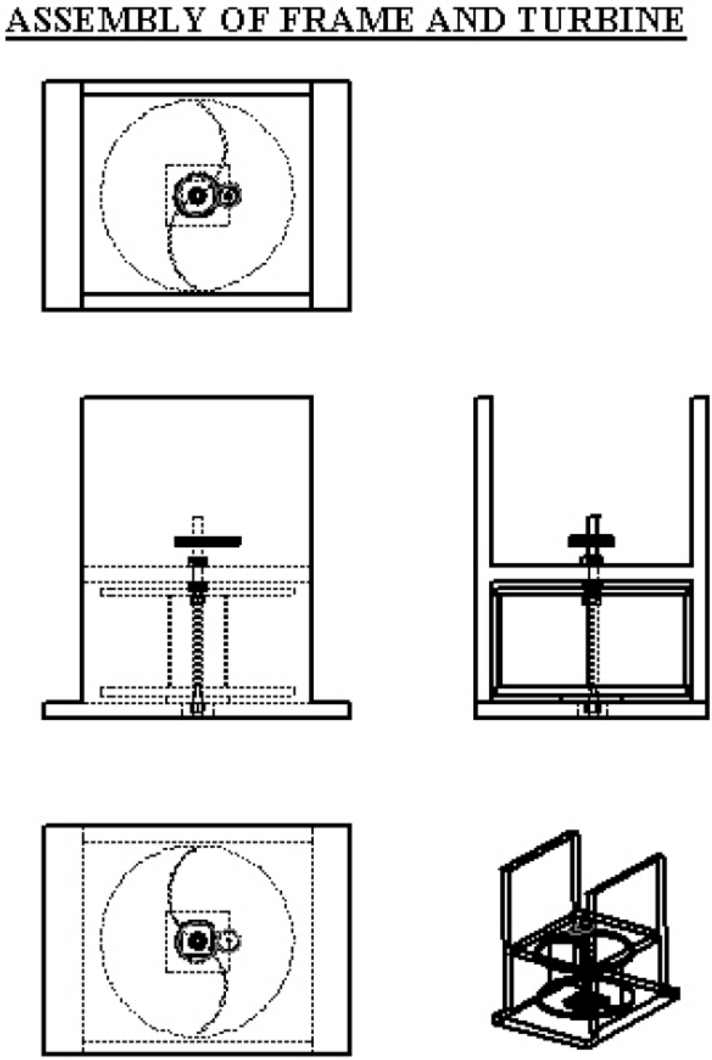


Fig 5.10 CAD Assembly model of turbine and its frame

The three dimensional images of the turbine, frame and its assembly are shown in the following figures.

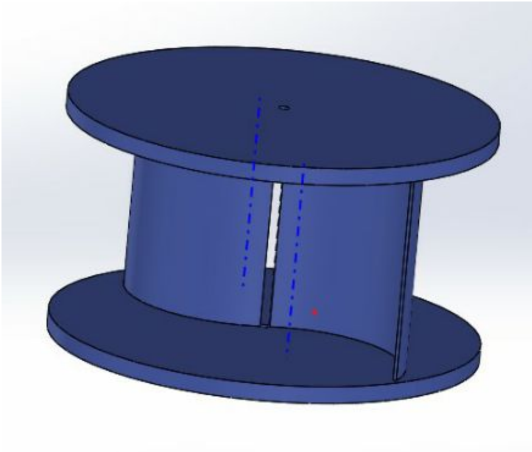


Fig 5.11 3D model of Turbine

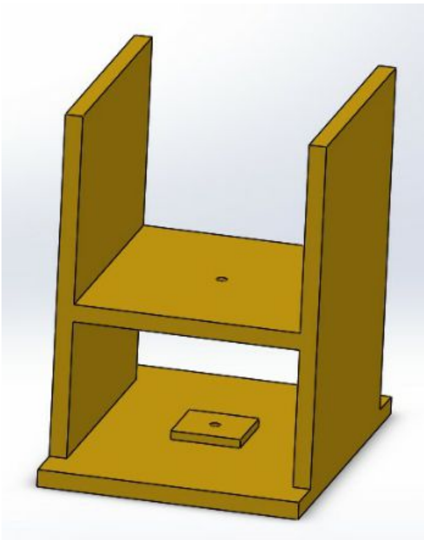


Fig 5.12 3D model of Frame

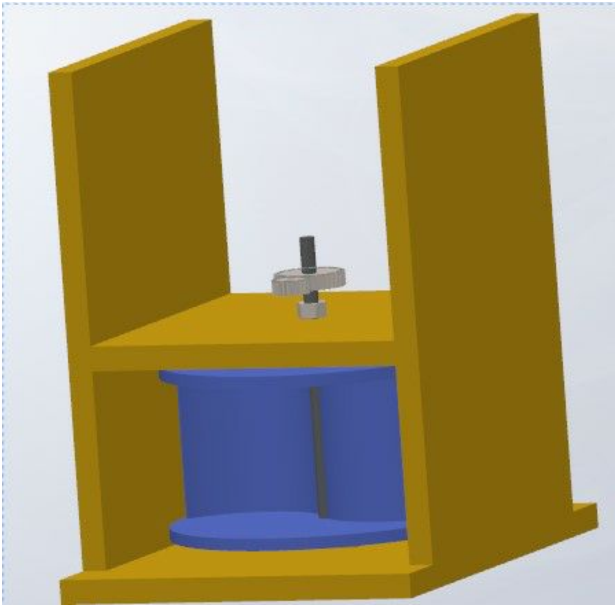


Fig 5.13 3D model of Turbine Assembly

CHAPTER 6: CFD ANALYSIS OF SAVONIUS ROTOR

6.1 CFD ANALYSIS OF ROTOR AND STATOR

6.1.1 CREATION OF GEOMETRY

The geometry is modeled in ANSYS Design Modeler considering the various design parameters for both stator and rotor as mentioned below.

[1] Rotor Geometry

Initially the sketch is constructed in a 2D plane (here XY plane), which is later converted into a 3D model upon extrusion up to a finite length. The Direction of extrusion is considered to be 'symmetrical' and the material is considered to be 'Frozen'. The blades have inner and outer thickness specified because they have been subjected to a 'thin surface extrusion'. The shaft underwent a solid extrusion, following which the entire rotor is enclosed by a cylindrical enclosure (defines the fluid domain). The blades and shaft geometries are removed from the cylindrical enclosure through the Boolean-Subtract and named sections have been given for the faces which need to be interfaced.

Table 6.1: Design Parameters (Ansys Design Modeller)

PARAMETER	VALUE
Height of the Rotor (H)	140 mm
Blade arc angle (Ψ)	124º
Diameter of Blades (d)	135.9 mm
Thickness of Blades (t)	2 mm
Diameter of the Rotor (D)	240 mm
Height of Cylindrical Enclosure (H´)	150mm
Diameter of Cylindrical Enclosure (D´)	250 mm

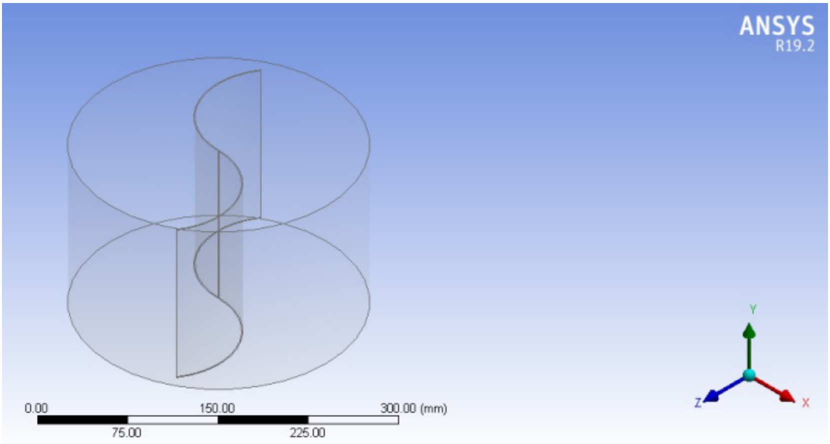


Fig 6.1 Creation of rotor geometry and its enclosure

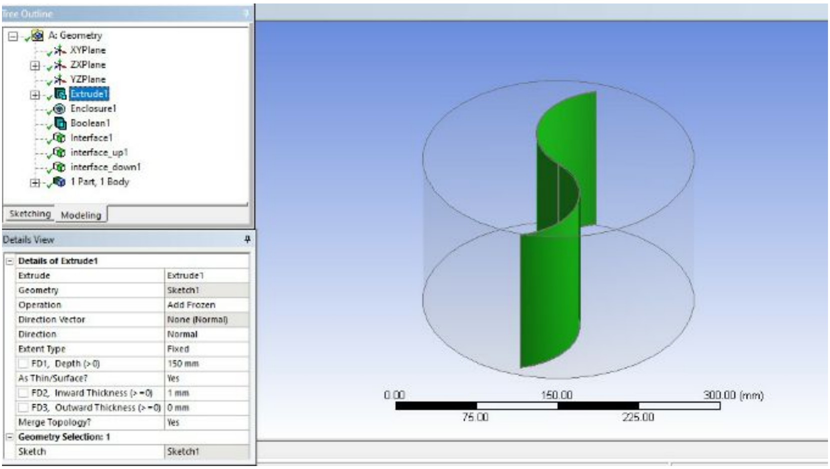


Fig 6.2 Extrusion in the blade geometry

[2] Stator Geometry

A similar procedure is adopted in the design for stator. The stator here is a rectangular channel of water flowing along the z direction. The sketch is constructed in XZ plane and is extruded along the y axis as shown in the figure. Later named sections have been assigned for the purpose of interfacing and applying boundary condfitions.

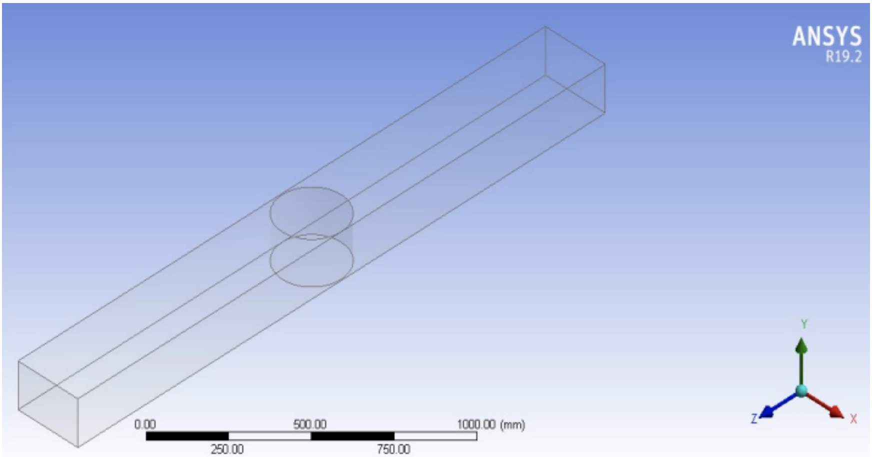


Fig 6.3 Creation of Stator geometry

Table 6.2: Other Parameters

PARAMETER	**VALUE**
Tip Speed Ratio	0.409
Blockage Ratio	0.108
Overlap Ratio	0.000
Aspect Ratio	0.7
Number of Stages	SINGLE STAGE
Number of Blades	2

6.1.2 MESH GENERATION

The stator and rotor geometries are meshed with a resolution of 7.0 using the ANSYS R19.2 Meshing Module with the physics preference kept at CFD and CFX as the solver preference.

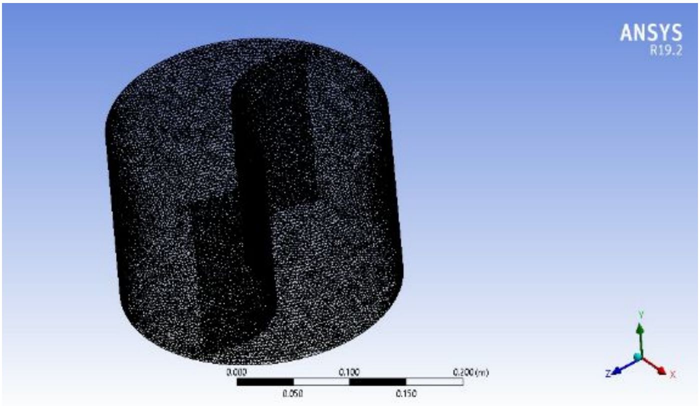


Fig 6.4 Mesh profile of rotor

Sizing	
Use Adaptive Sizi...	Yes
Resolution	7
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Slow
Span Angle Center	Fine
Initial Size Seed	Assembly
Bounding Box Di...	0.3893 m
Average Surface ...	2.8493e-002 m^2
Minimum Edge L...	1.e-003 m

Table 6.3 Sizing involved in mesh generation

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Element Order	Linear
Element Size	Default

Table 6.4 Mesh Creation

Statistics	
Nodes	106950
Elements	571401

Table 6.5 Mesh Statistics

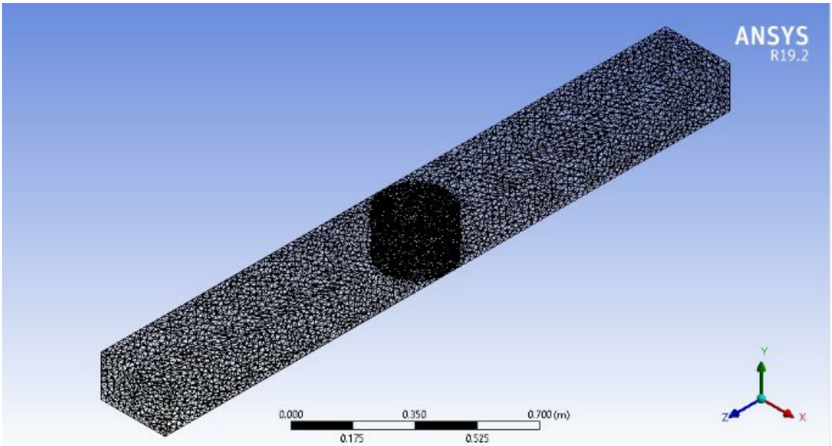


Fig 6.5 Mesh profile of Stator with rotor’s cavity

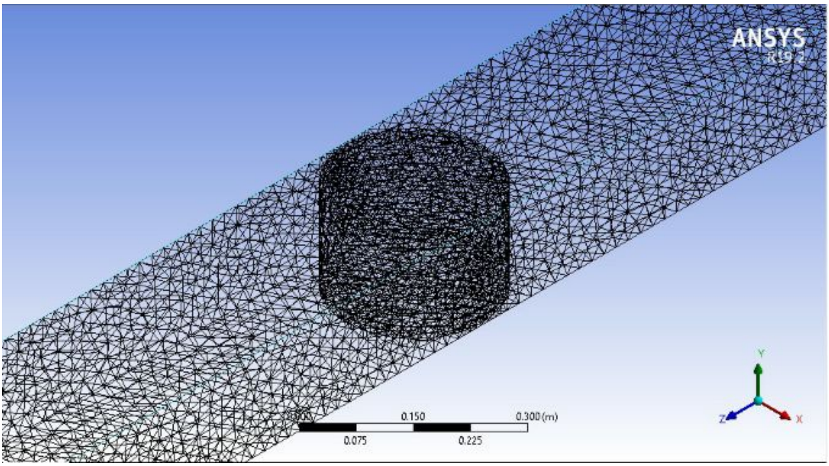


Fig 6.6 Meshing in stator geometry

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Element Order	Linear
Element Size	Default
Sizing	
Quality	
Inflation	
Advanced	
Statistics	
Nodes	11479
Elements	52640

Table 6.6 Mesh generation

Sizing	
Use Adaptive Sizi...	Yes
Resolution	7
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Slow
Span Angle Center	Fine
Initial Size Seed	Assembly
Bounding Box Di...	2.2713 m
Average Surface ...	0.24379 m²
Minimum Edge L...	0.164 m

Table 6.7 Sizing involved in mesh generation

6.1.3 PRE-PROCESSING

The fluid problem is preprocessed with the aid of ANSYS CFX-PRE Setup module wherein all the necessary criteria and constraints have been provided and initialized.

[1] Rotor

At first a Rotor Domain is created and the corresponding rotor geometry is selected and assigned to this domain following which a water is designated as the working fluid with a reference pressure 0 atm and a buoyancy model is entitled to the current problem by giving an acceleration of 9.81m/s^2 in the negative Y - direction. The rotation axis is set along the Y - axis with an angular velocity of 0.001 RPM. There is no mesh deformation in this problem.

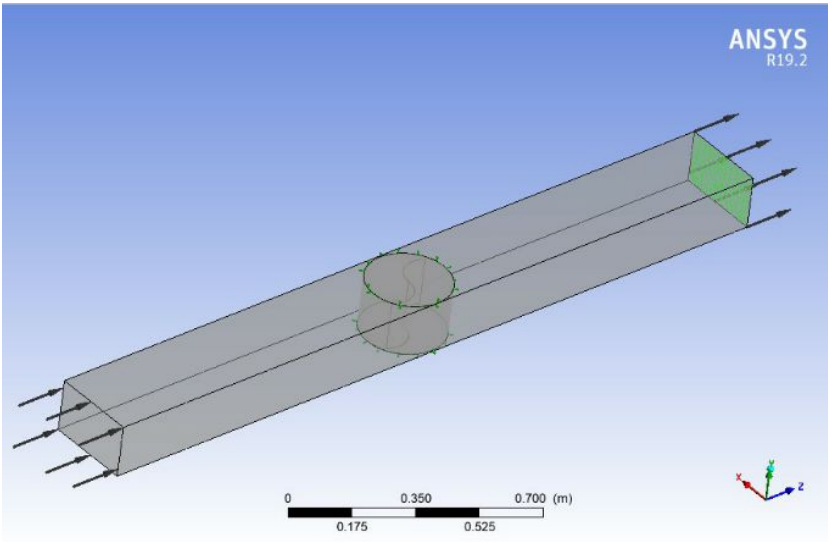


Fig 6.7 Creation of Rotor domain

[2] Stator

In a similar manner a domain is created and is being assigned for the stator as well with the working fluid as water at 25º C with the consideration of Buoyancy by giving an acceleration of 9.81 m/s^2 in the negative Y direction. The domain motion is set to stationary and the reference pressure is set to 0 atm. There is no mesh deformation in this problem.

[3] Analysis Type

The analysis type is set to 'transient blade flow' with time integration as the Transient method. The transient Blade Row model is conducted with 100 time steps and each time step is 62.8319s. The number of periods per run is set to 1.

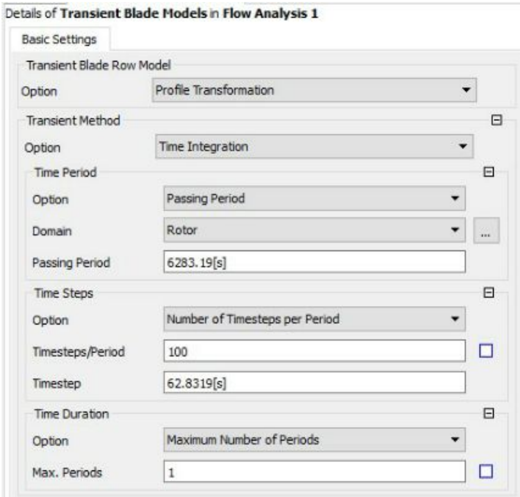


Fig 6.8 Transient Blade Flow analysis

The surfaces interacting between the rotor and stator are interfaced by the creation of domain interfaces and thereby matching the rotor's and stator's interacting surfaces in accordance to their respective geometries. This can be illustrated in the figure given below.

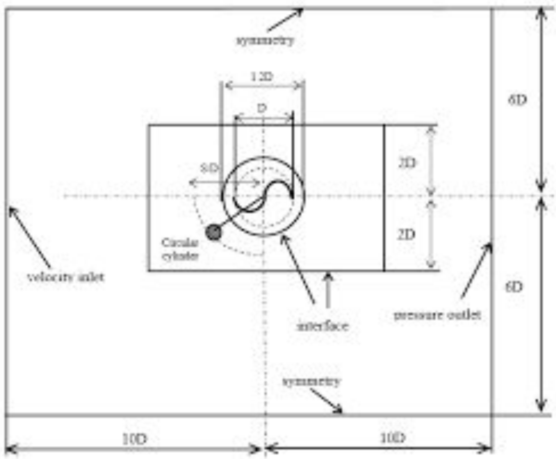


Fig 6.9 Interfacing of rotor and stator domains

[4] Boundary Conditions

The inlet face of the stator is given a velocity inlet of 2m/s and the outlet is given a relative pressure of 1 atm or a mass flow rate after the creation of boundaries in the stator. The boundaries in the stator once created have to assigned to the named sections of the stator. The other side of the stator are given 'wall' as their boundary conditions without any slip.

[5] Solver Control

The solver is set to K-ε Turbulence model with a medium intensity of turbulence. The transient scheme is a Second Order backward Euler scheme.

[6] Initialization

The stator and rotor domains are initialized by specifying the initial velocity of flow i.e., 2m/s in the w (Z direction) and zero m/s in u and v. Also a relative static pressure of 1atm is kept without which the program cannot be compiled. The frame type in both stator and rotor is kept stationary.

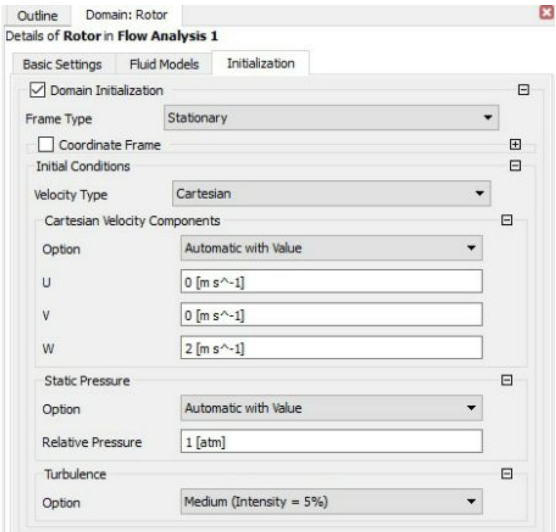


Fig 6.10 Initialization of Rotor

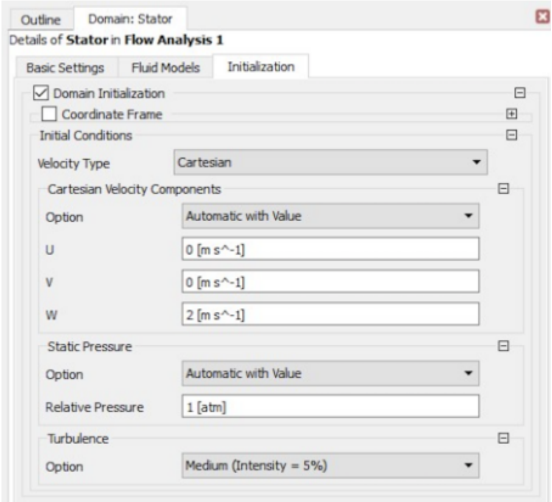


Fig 6.11 Initialization of Stator

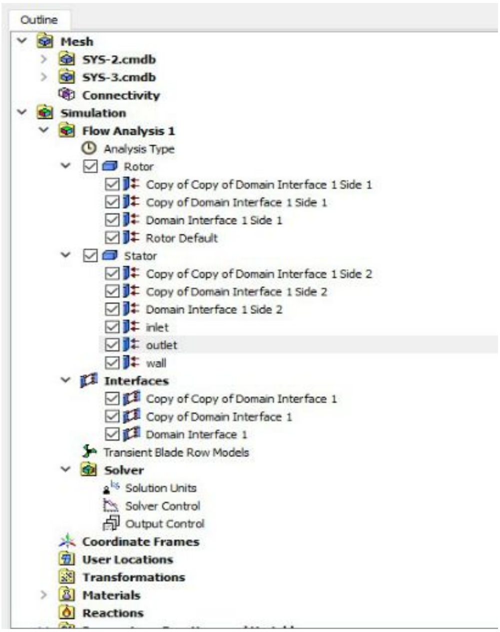


Fig 6.12 Outline of CFX-PRE

6.1.4 SOLUTION AND POST PROCESSING

The pressure and velocity contours are plotted and are represented below.

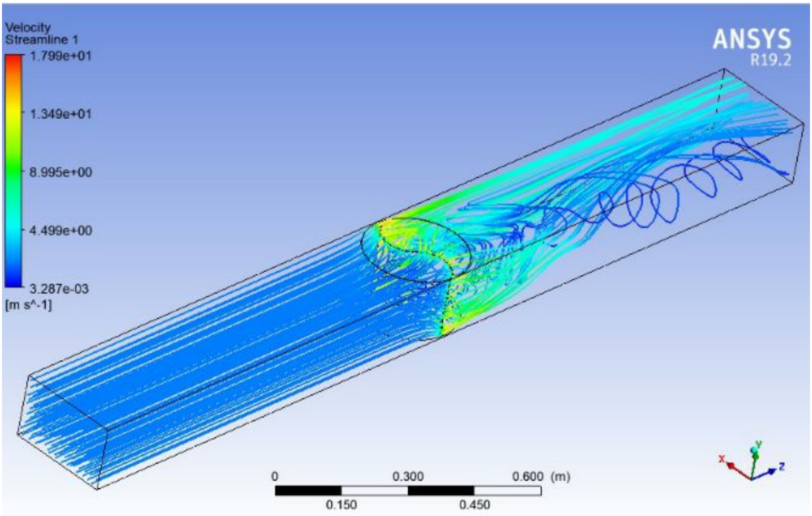


Fig 6.13 Velocity Streamline

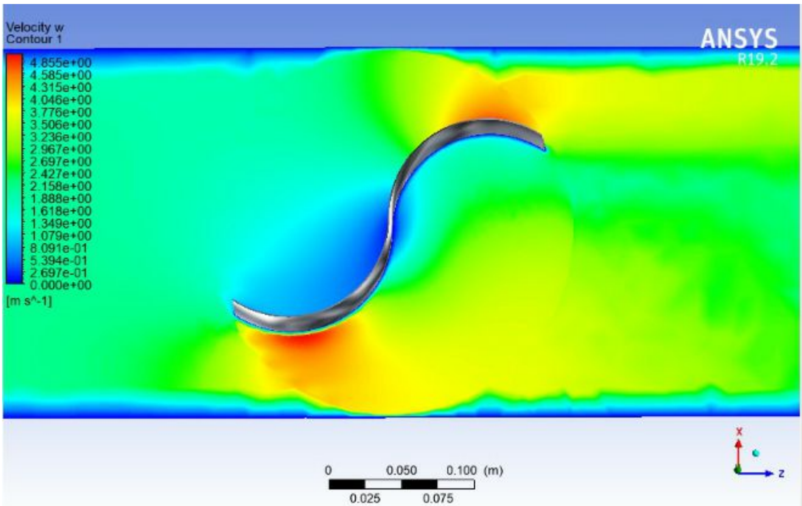


Fig 6.14 Velocity Contour in the Z-direction

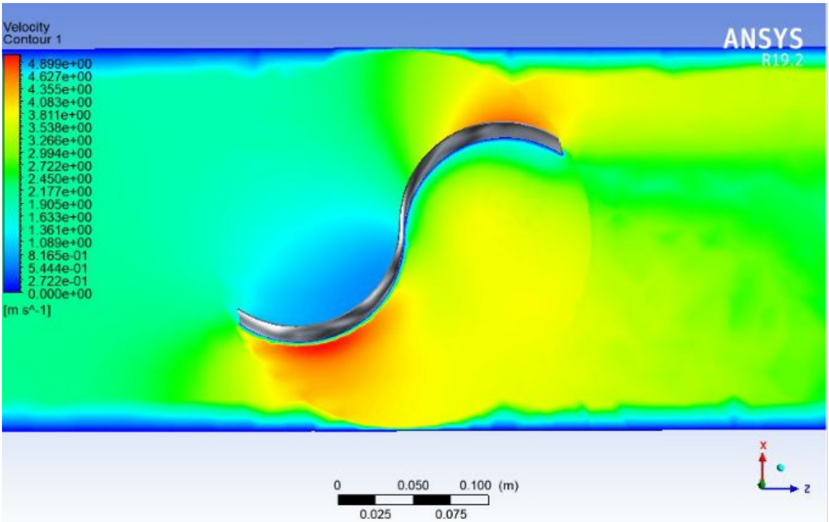


Fig 6.15 Total Velocity Distribution

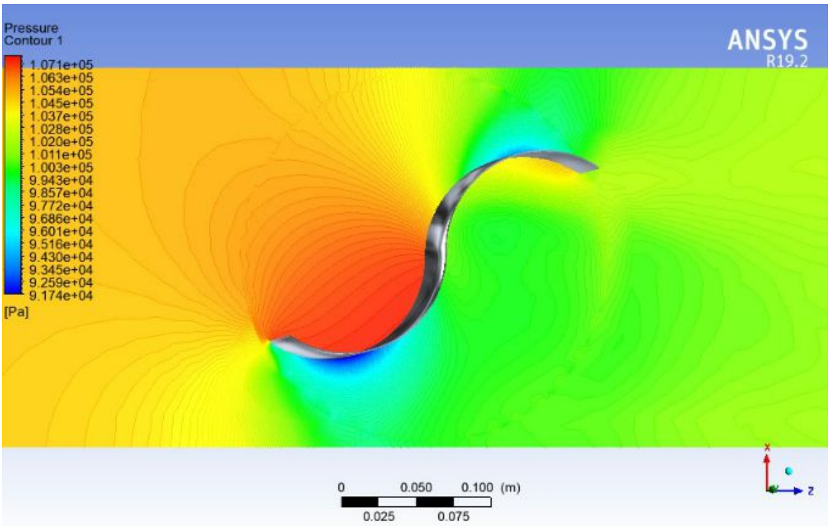


Fig 6.16 Pressure Distribution

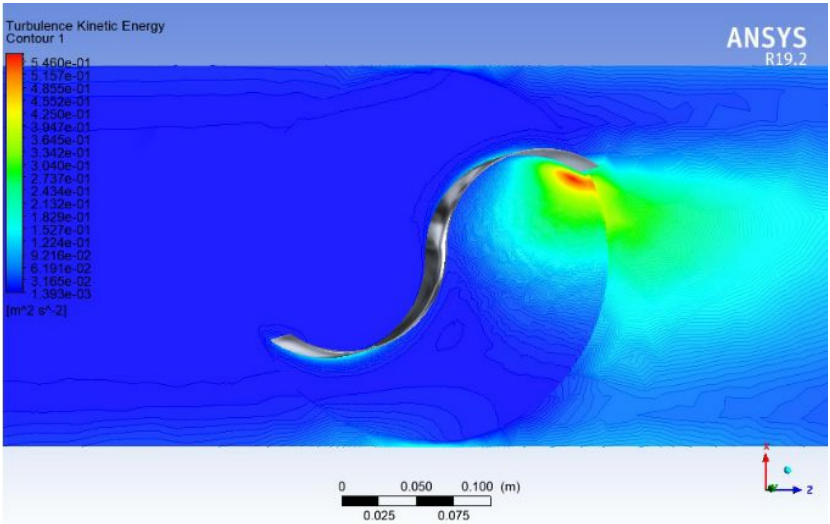


Fig 6.17 Turbulence Kinetic Energy.

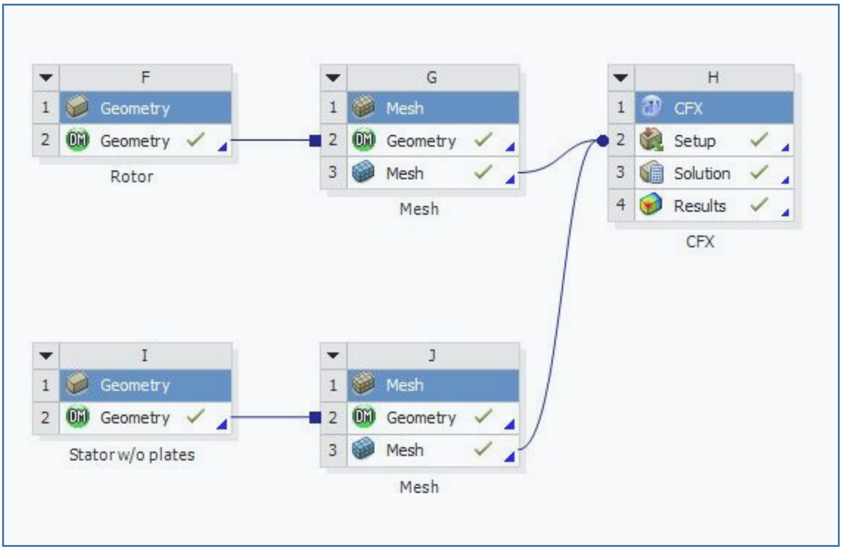


Fig 6.18 Summary of CFD 6.1 Analysis

6.2 CFD ANALYSIS OF STATOR WITH DEFLECTOR PLATES IN ITS CHANNEL

In this segment we have tried to analyze the behaviour of the water flow in the channel by fixing stationary deflector plates one of its kind on opposite walls of the channel. The dimensions of the long plate are 180mm X 150mm X 2 mm and that of the shorter plate is 120mm X 150mm X 2mm. The purpose behind this simulation is to verify whether there is an increment in the upstream velocity, the velocity with which the turbine begins to rotate. Also we are obtaining the measure of this increment in order to estimate the amount of power increased manifold.

6.2.1 CREATION OF GEOMETRY

At first we design the stator with the required dimensions up to the water level in the channel. The stator is designed with the help of ANSYS DESIGN MODELLER which comes along in ANSYS WORKBENCH. Then the plates which were supposed to be designed prior to the stator are to be imported into the current geometry and are to be given a suitable enclosure. Then a boolean operation is carried out by subtracting the plates geometrical profile from the stator's geometry. The figure below illustrates the stator comprising of the cavity concerned with the deflector plates.

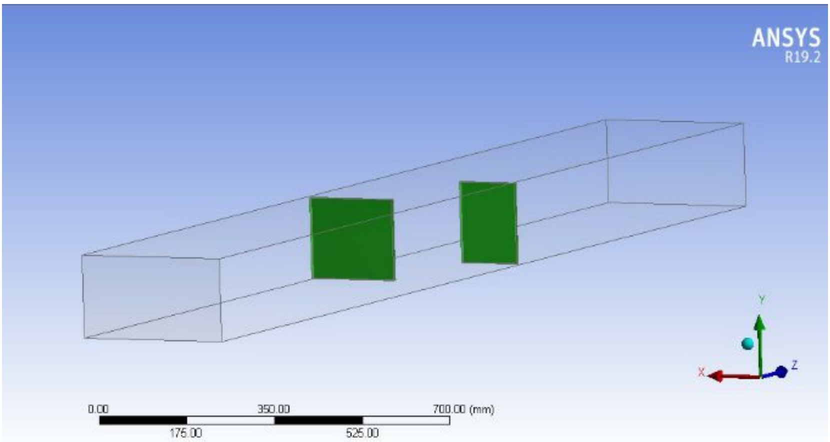


Fig 6.19 Creation of deflector plates in the flow path of stator

Enclosure	Enclosure2
Shape	Box
Number of Planes	0
Cushion	Non-Uniform
FD1, Cushion +X value (>0)	2 mm
FD2, Cushion +Y value (>0)	2 mm
FD3, Cushion +Z value (>0)	1000 mm
FD4, Cushion -X value (>0)	2 mm
FD5, Cushion -Y value (>0)	2 mm
FD6, Cushion -Z value (>0)	1000 mm
Target Bodies	All Bodies
Export Enclosure	Yes

Table 6.8 Details of Enclosure

6.2.2 MESH GENERATION

The mesh for the above geometry is done similar to the earlier procedure using the ANSYS R19.2 Meshing Module with the physics preference kept at CFD and CFX as the solver preference. Once again a resolution of 7.0 was allocated to the mesh.

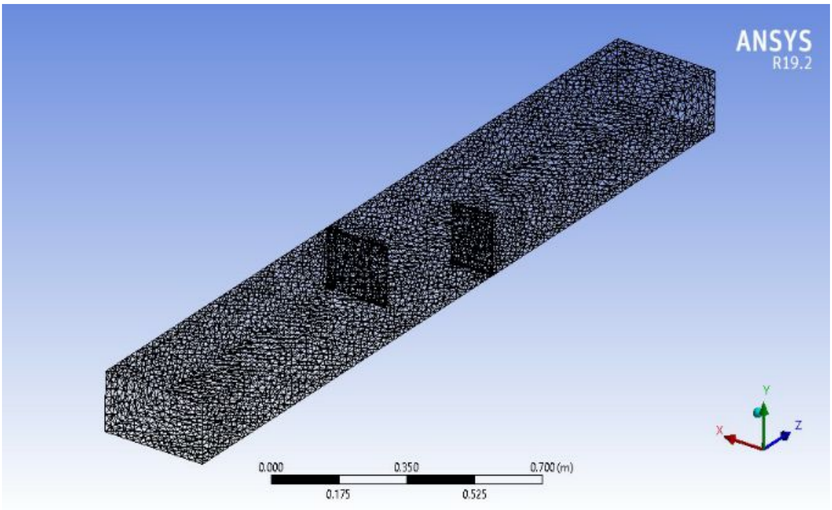


Fig 6.20 Grid generation of stator with deflector plates

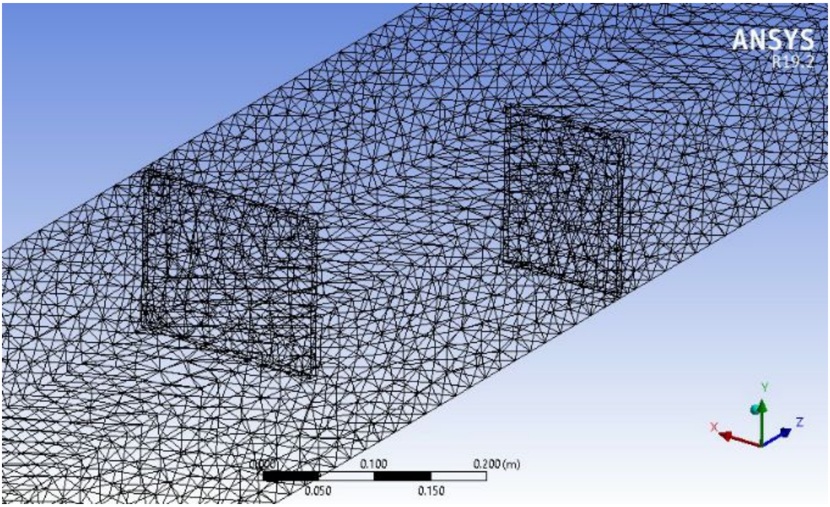


Fig 6.21 Resolution of Grid

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	CFX
Element Order	Linear
Element Size	Default
Sizing	
Use Adaptive Sizi...	Yes
Resolution	7
Mesh Defeaturing	Yes
Defeature Size	Default
Transition	Slow
Span Angle Center	Fine
Initial Size Seed	Assembly
Bounding Box Di...	2.3386 m
Average Surface ...	0.13035 m^2
Minimum Edge L...	8.e-003 m

Table 6.9 Mesh Sizing options

Statistics	
Nodes	11301
Elements	55152

Table 6.10 Mesh Statistics

6.2.3 PRE-PROCESSING

The Preprocessing of this channel is done through ANSYS CFX PRE setup module.

[1] Definition of Domains

Here the default domain is the stator's domain and there is no separate domain creation, assignment and definition involved. A buoyant flow model was chosen and assigned in the negative Y direction.

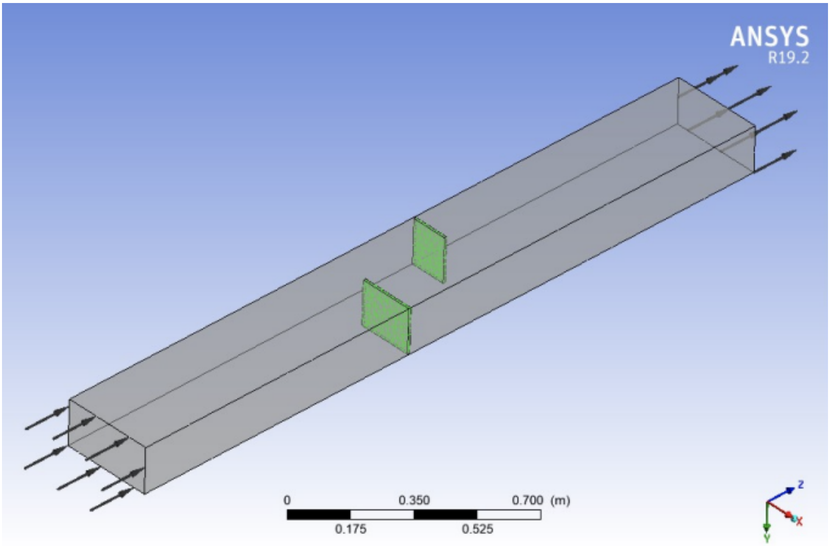


Fig 6.22 Creation of domain

[2] Boundary conditions

In order to apply boundary criteria to the geometry, first boundaries such as inlet, outlet and wall faces are created and names assigned respectively.

The inlet boundary is assigned an inlet velocity of 2m/s and the outlet boundary is kept at normal static pressure of 1 atm. The wall faces including the plate surfaces are assigned to be in no slip conditions.

[3] Solver Control

The solver is set to K-ε Turbulence model with a medium intensity of turbulence. The transient scheme is a Second Order backward Euler scheme.

[4] Initialization

The stator domain is initialized by specifying the initial velocity of flow i.e., 2m/s in the w (Z direction) and zero m/s in u and v. Also a relative static pressure of 1atm is kept without which the program cannot be compiled. The frame type in stator is kept stationary.

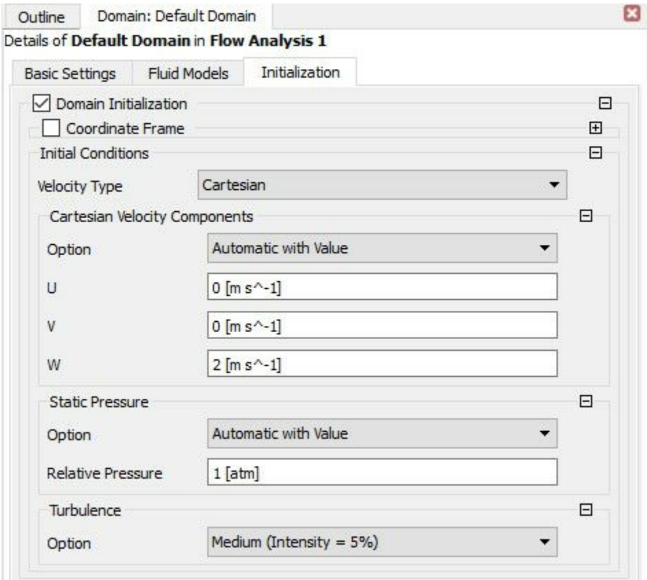


Fig 6.23 Initialization of domain

6.2.4 <u>SOLUTION AND POST PROCESSING</u>

The pressure and velocity contours were plotted on an iso surface created midway along the height of the stator.

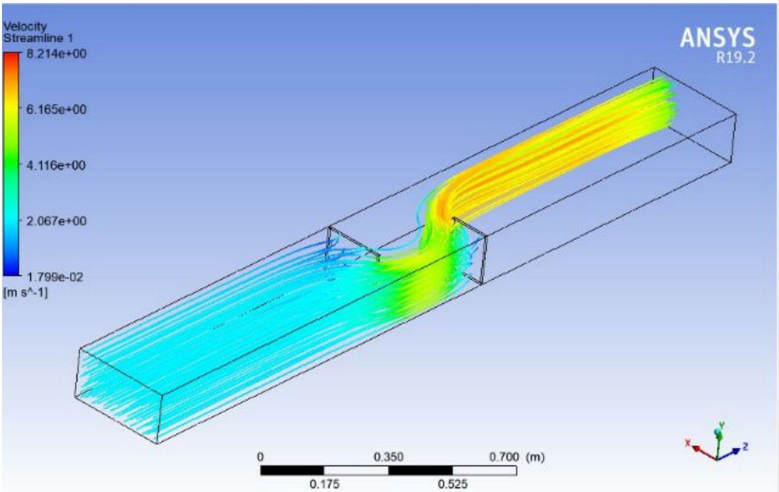


Fig 6.24 Velocity Streamline

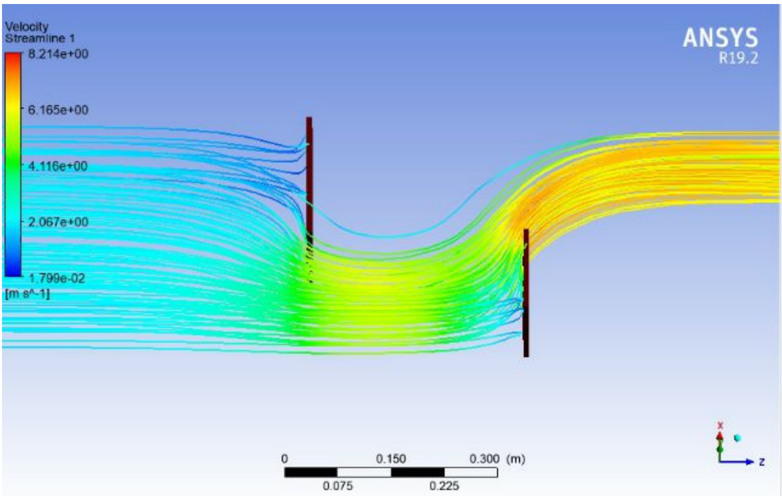


Fig 6.25 Side View of Streamline

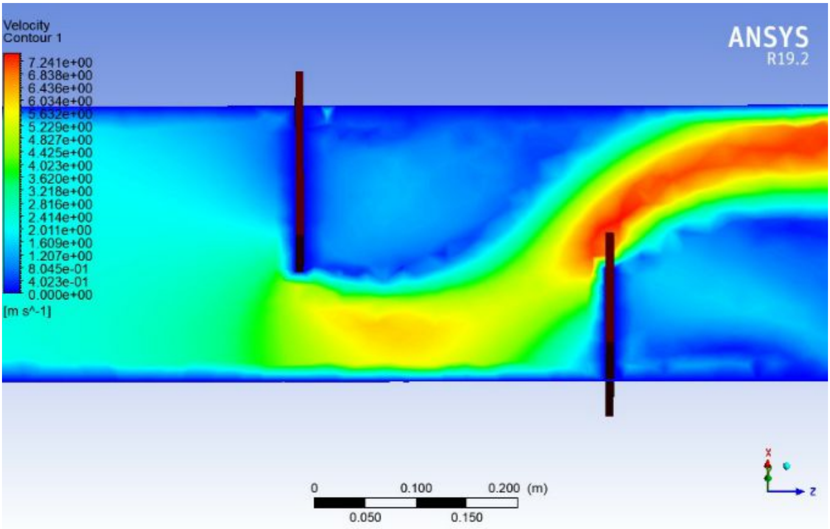


Fig 6.26 Total Velocity Distribution

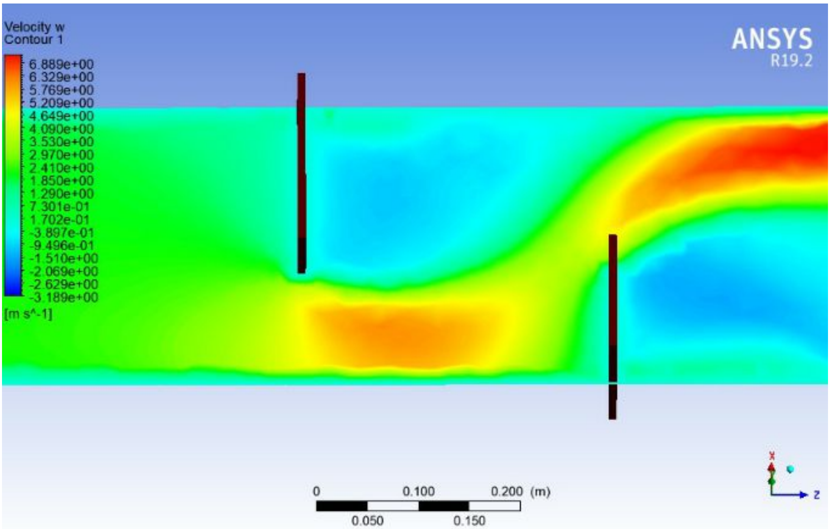


Fig 6.27 Velocity Distribution in Z-direction

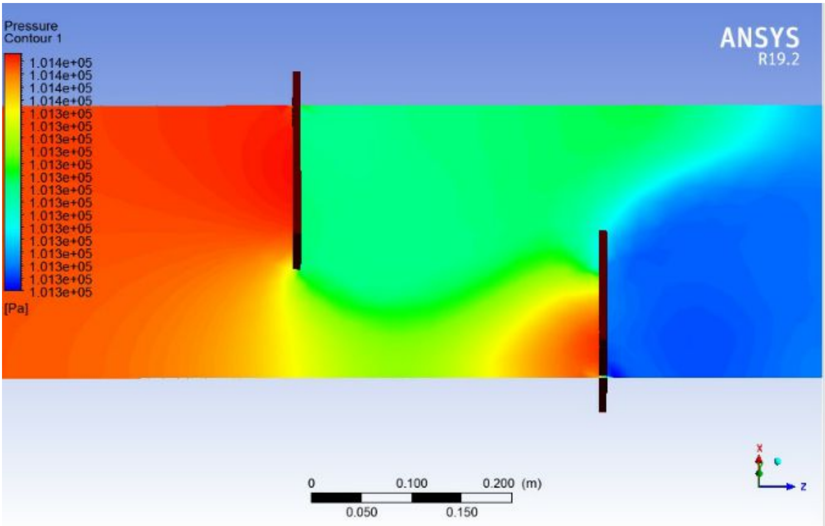


Fig 6.28 Pressure Distribution

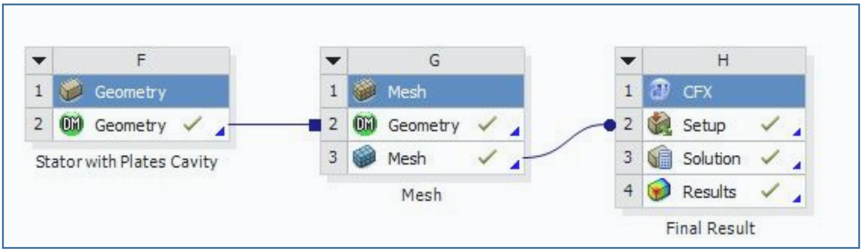


Fig 6.29 Summary of CFD 6.2 Analysis

6.3 CFD ANALYSIS OF ROTOR AND STATOR WITH STATIONARY DEFLECTOR PLATES

6.3.1 CREATION OF GEOMETRY & MESHING

The creation of geometry and meshing for rotor and stator is same as discussed in the earlier sections.

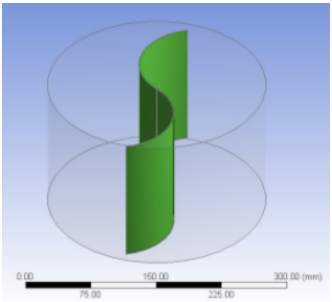


Fig 6.30 Rotor geometry

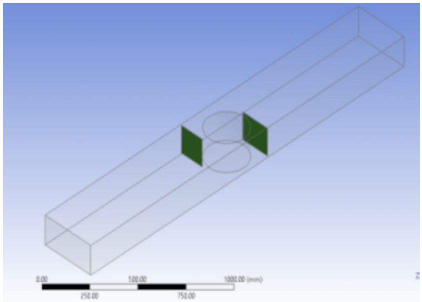


Fig 6.31 Stator geometry with deflector plates

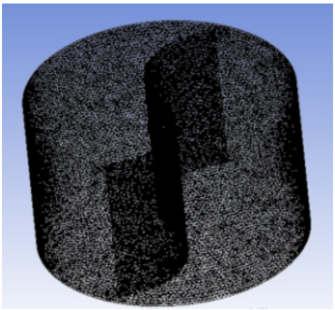


Fig 6.32 Rotor's Mesh

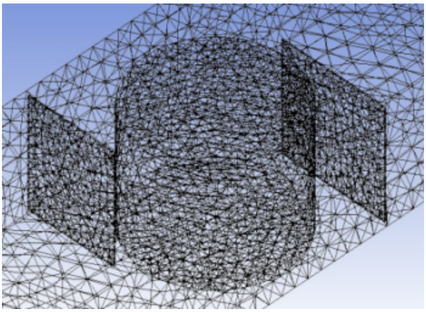


Fig 6.33 Stator's Mesh

6.3.2 PRE-PROCESSING

The Preprocessing of this channel is done through ANSYS CFX PRE setup module by importing the grid from the mesh.

[1] Rotor

At first a Rotor Domain is created and the corresponding rotor geometry is selected and assigned to this domain following which a water is designated as the working fluid with a reference pressure 0 atm and a buoyancy model is entitled to the current problem by giving an acceleration of 9.81m/s^2 in the negative Y - direction. The rotation axis is set along the Y - axis with an angular velocity of 0.001 RPM. There is no mesh deformation in this problem.

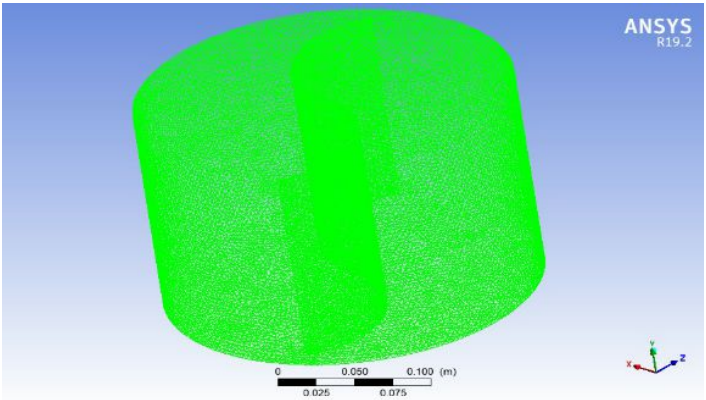


Fig 6.34 Rotor Domain

[2] Stator

In a similar manner a domain is created and is being assigned for the stator as well with the working fluid as water at 25º C with the consideration of Buoyancy by giving an acceleration of 9.81 m/s^2 in the negative Y direction. The domain motion is set to stationary and the reference pressure is set to 0 atm. There is no mesh deformation in this problem.

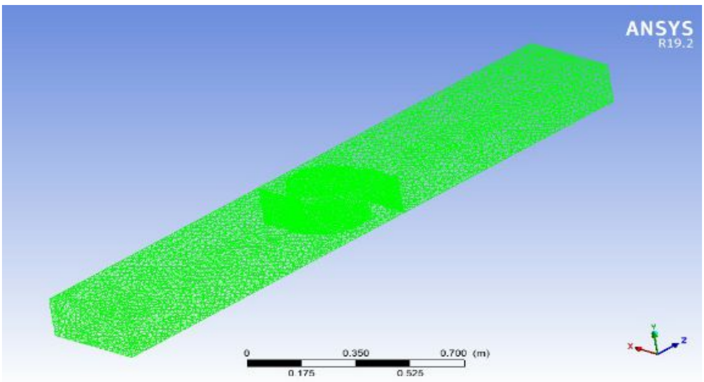


Fig 6.35 Stator's Domain

[3] Analysis Type

The analysis type is set to 'transient blade flow' with time integration as the Transient method. The transient Blade Row model is conducted with 100 time steps and each time step is 0.00131004s. The number of periods per run is set to 1.

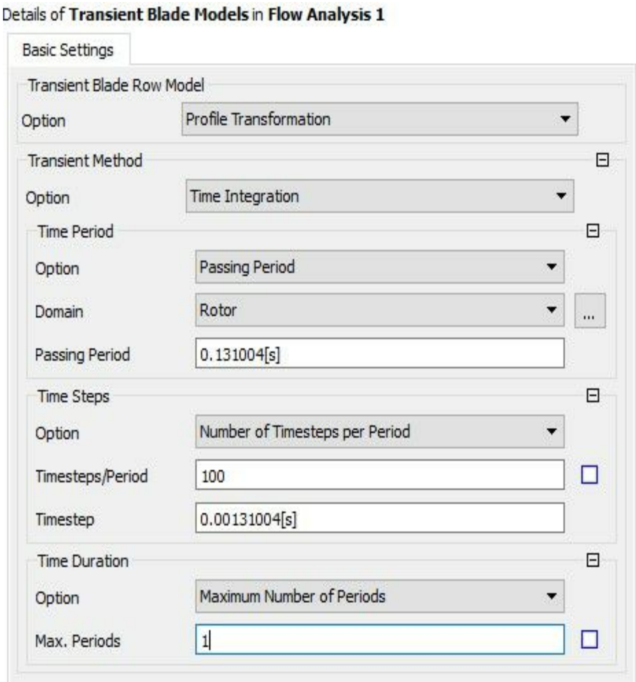


Fig 6.36 Analysis Type

The surfaces interacting between the rotor and stator are interfaced by the creation of domain interfaces and thereby matching the rotor's and stator's interacting surfaces in accordance to their respective geometries.

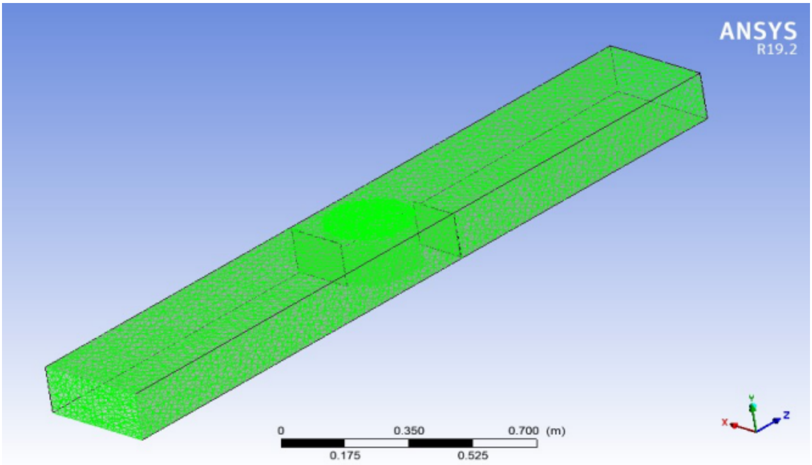


Fig 6.37 Interfacing the domains

[4] Boundary Conditions

The inlet face of the stator is given a velocity inlet of 2m/s and the outlet is given a relative pressure of 1 atm or a mass flow rate after the creation of boundaries in the stator. The boundaries in the stator once created have to assigned to the named sections of the stator. The other side of the stator are given ‘wall’ as their boundary conditions without any slip.

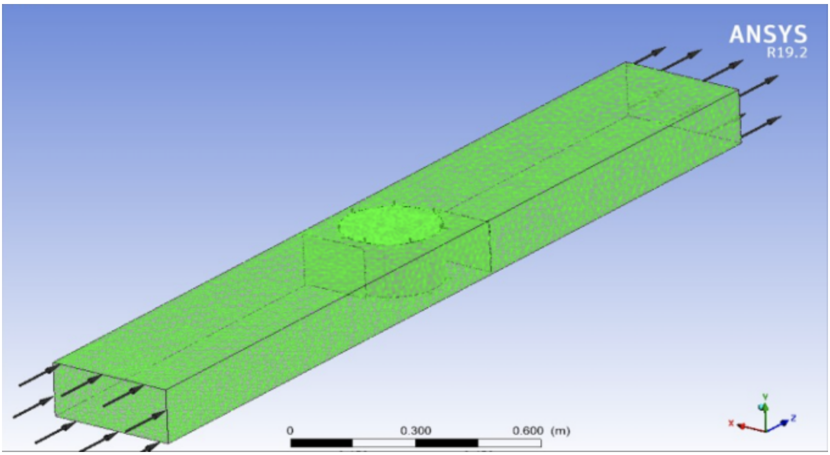


Fig 6.38 Application of BCs

[5] Solver Control

The solver is set to K-ε Turbulence model with a medium intensity of turbulence. The transient scheme is a Second Order backward Euler scheme.

[6] Initialization

The stator and rotor domains are initialized by specifying the initial velocity of flow i.e., 2m/s in the w (Z direction) and zero m/s in u and v. Also a relative static pressure of 1atm is kept without which the program cannot be compiled. The frame type in both stator and rotor is kept stationary.

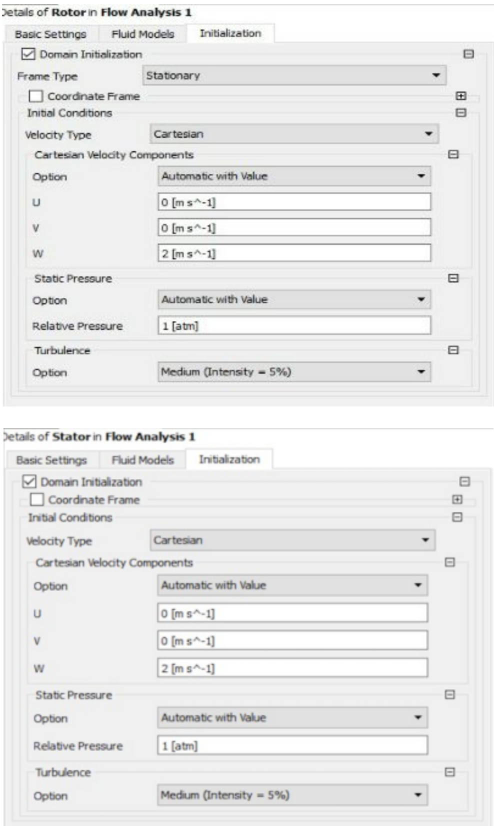


Fig 6.39 Initialization of rotor and stator

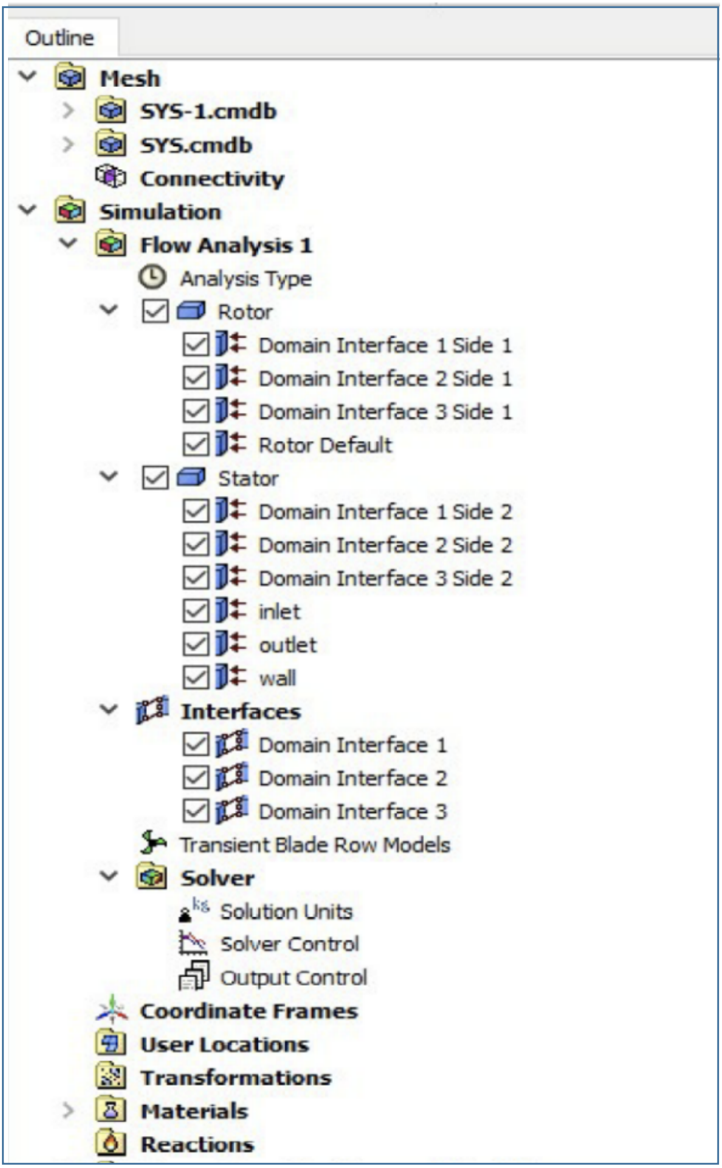


Fig 6.40 Outline of CFX-PRE

6.3.4 SOLUTION AND POST PROCESSING

The various contours of pressure, velocity and turbulence kinetic energies are indicated below.

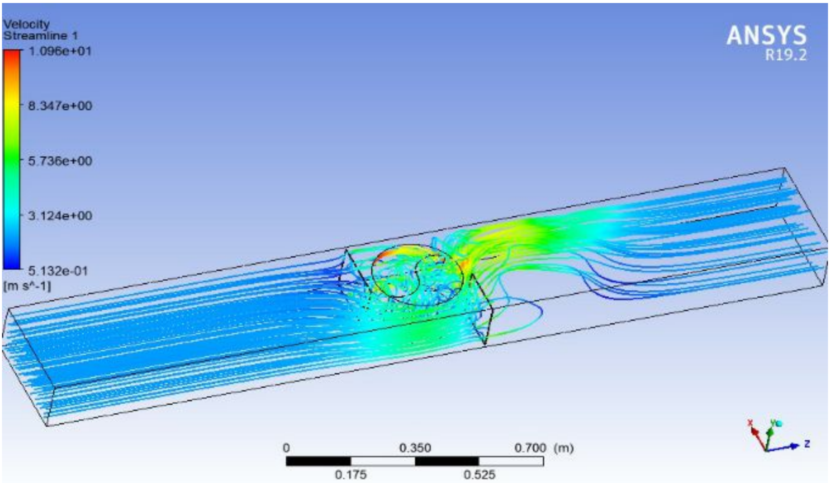


Fig 6.41 Velocity Streamline

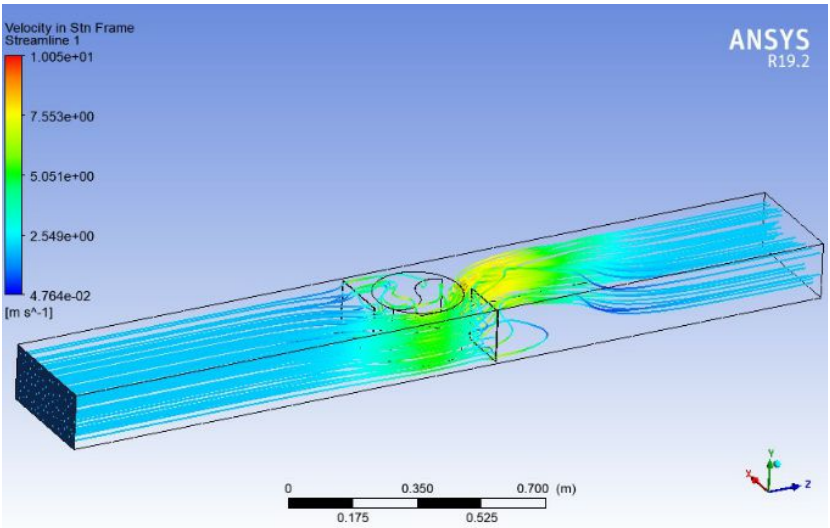


Fig 6.42 Velocity Streamline in Stationary frame

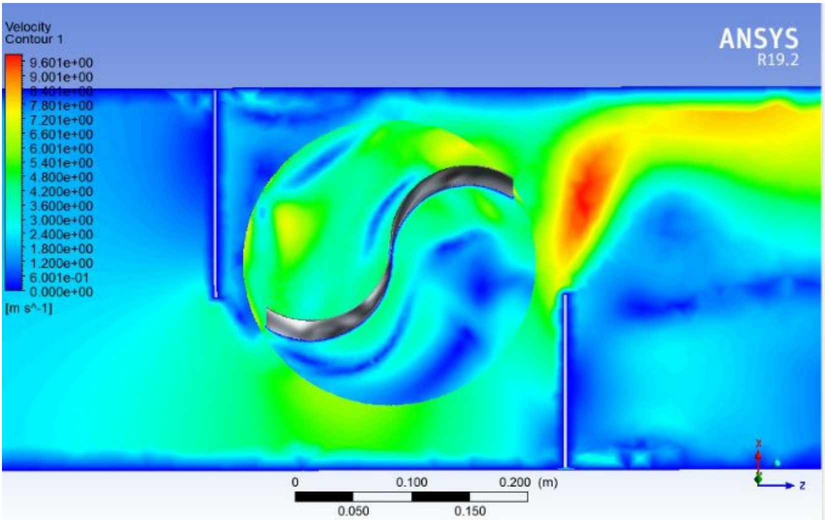


Fig 6.43 Total Velocity Distribution

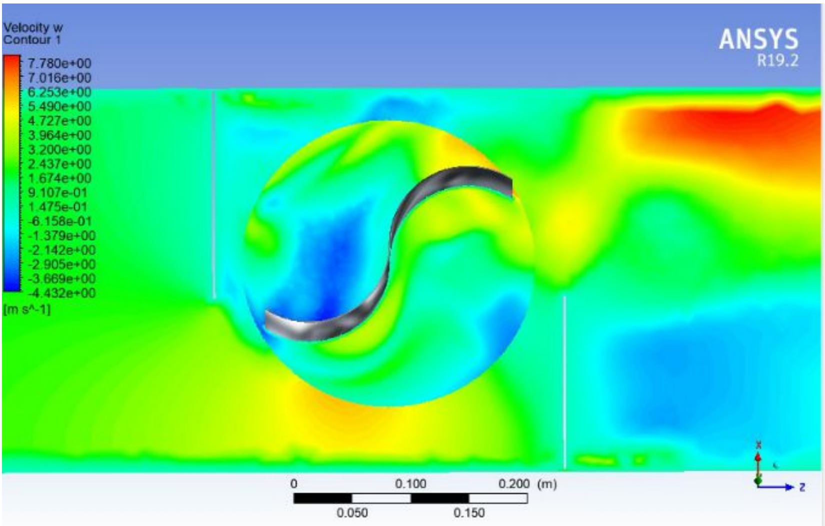


Fig 6.44 Velocity Distribution in Z-Direction

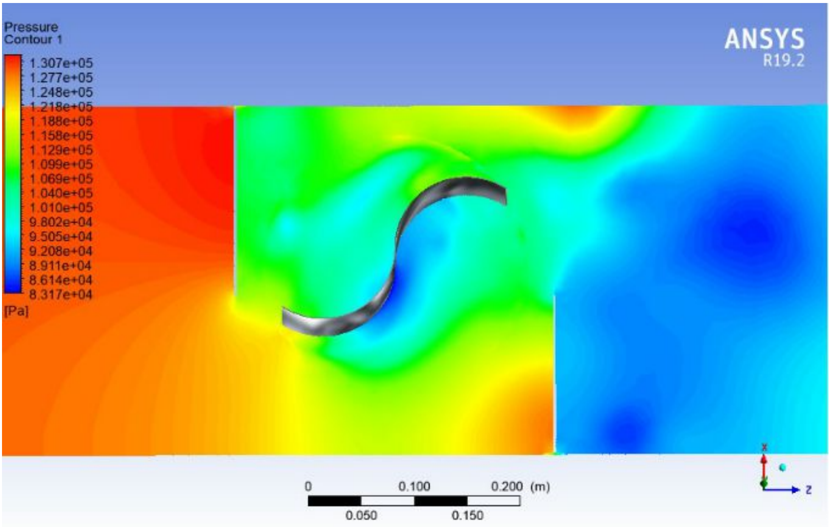


Fig 6.45 Pressure Distribution

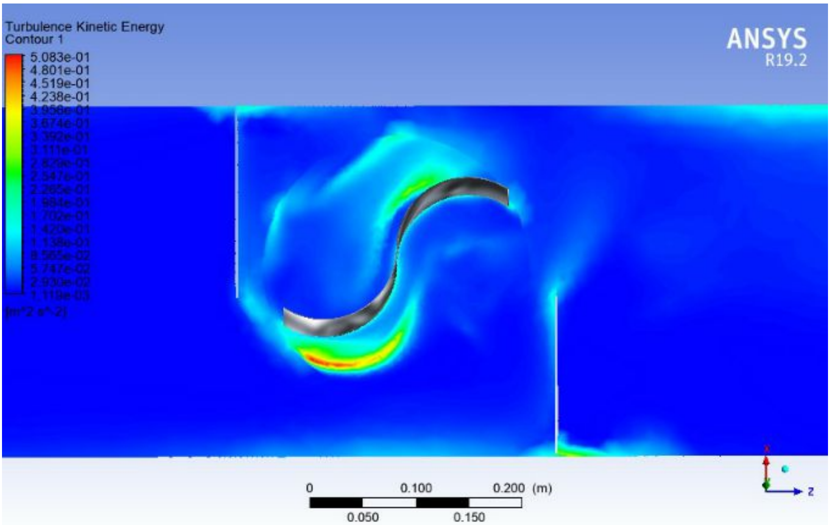


Fig 6.46 Turbulence Kinetic Energy contour

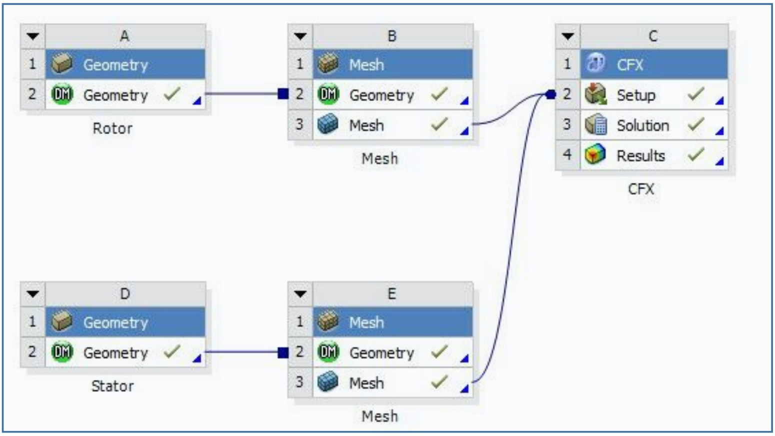


Fig 6.47 Summary of CFD 6.3 Analysis

Now the free stream velocity of the water flowing to the channel is kept at Reynold's number of 1.32 x 10^5 and the simulation was once again carried out on the basis of the criteria taken by by Kailash Golecha et.al and the results have been validated and tabulated in Table 9.1.

CHAPTER 7: CALCULATIONS

The energy flux of the flowing water is dependent on its density, cross sectional area of the channel and of course the velocity of the water. Therefore power produced by the turbine can be written as:

$$P = \frac{1}{2} \times \rho A v^3 \quad (1)$$

The torque obtained through the simulation can be verified using the below equation comprising of V_1 and V_2 which are upstream and downstream velocities of the flowing water and radius (r) of the rotor as 0.06795 m.

$$T = \frac{1}{2} \rho A r(V_1^2 - V_2^2) \quad (2)$$

Coefficient of torque (Ct) and coefficient of power (Cp) are given by:

$$Ct = 4T/\rho U^2 D^2 H \quad (3)$$

$$Cp = TSR \times Ct \quad (4)$$

The tip speed ratio can be calculated with U being the free stream velocity

$$TSR = \omega D/2U \quad (5)$$

Therefore Power can be written as:

$$P = T \times \omega. \quad (6)$$

Reynold's Number (Re) with μ being the dynamic viscosity of water can be written as:

$$Re = \rho UD / \mu \quad (7)$$

Based on the above mathematical formulae the results obtained by Kailash Golecha et.al were validated. Also keeping the rotational speed of the rotor to 2.79 rad/s the improvement in the performance due to deflector plates was gauged and has been tabulated.

CHAPTER 8: OPTIMIZATION OF POSITION OF DEFLECTOR PLATES

Similar to the earlier simulations performed, the process of optimization was done through CFD by positioning the deflector plates based on the data used by Kailash Golecha et.al, whose nomenclature and geometrical criteria have been given below.

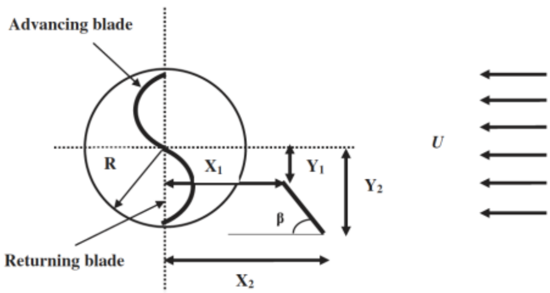


Fig 8.1 Savonius rotor with deflector plate shielding returning blade

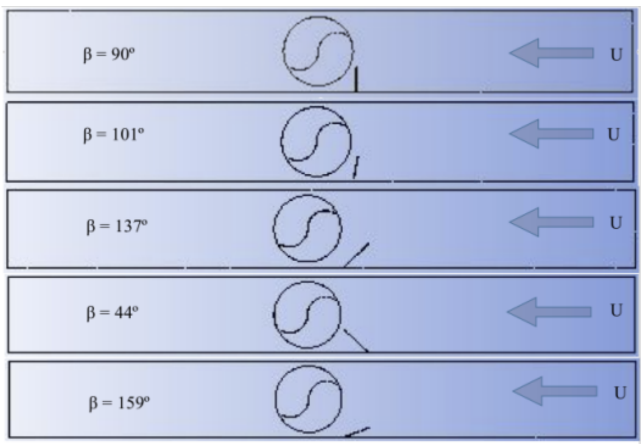


Fig 8.2 Various angular positions of deflector plates in the closed water channel

The geometries of the rotor and deflector plates for various positions have been constructed using parameters such as plate angle (β), X_1, X_2, Y_1, Y_2 positions and radius of rotor (R)

S.No.	X1 (mm)	X2 (mm)	Y1 (mm)	Y2 (mm)	β
1.	135	135	55	145	90º
2.	152	135	55	145	101º
3.	230	135	55	145	137º
4.	135	230	55	145	44º
5.	230	135	108	145	159º

Table 8.1 Criteria for positioning of deflector plate

The pre-processing of the turbine setup was performed using the ANSYS CFX-PRE module. The grids of both rotor and the stator (closed water channel with stationary deflector plates) have been assigned with rotor and stator domains and were then assigned boundaries and the following boundary conditions have been specified as shown in Table 8.2

Location	Boundary Condition
Inlet	Re 1.32×10^5 [12]
Outlet	Static pressure = 1 atm
Stator's Wall	NO SLIP wall conditions
Domain motion (Rotor)	Rotating (with almost zero angular velocity)
DomainMotion (Stator)	Stationary
Buoyant Model	9.81 m/s^2 along negative Y direction
Analysis Type	Transient Blade Row (with medium intensity)

Table 8.2 Boundary Conditions & Initial Conditions

The rotor and the stator domains have been properly interfaced (connected) and the problem was initialized with a Reynold's number 1.32×10^5 which serves as the free stream. A transient blade row model has been selected and K-ε turbulence model with an option of medium intensity of five percent has been assigned.

The solution and post processing of the above setup was done in ANSYS CFX post processor. The post processing depicted various contours based on a variety of parameters such as turbulence kinetic energy, eddy viscosity, pressure, rotational velocity etc,. of which the contours of velocity profiles for various plate angles are shown below.

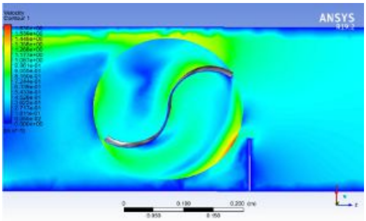


Fig 8.3 Velocity distribution at β = 90º

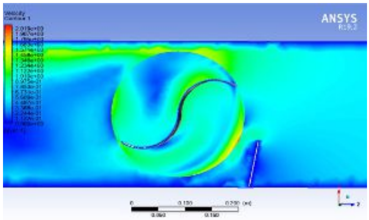


Fig 8.4 Velocity distribution at β = 101º

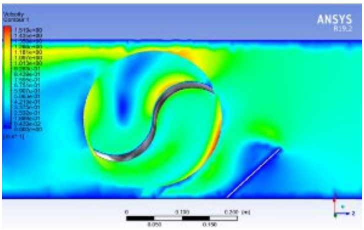


Fig 8.5 Velocity distribution at β = 137º

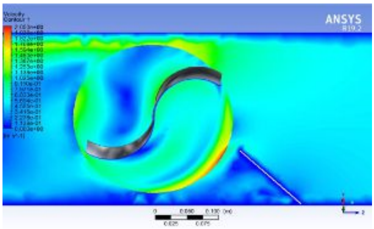


Fig 8.6 Velocity distribution at β = 44º

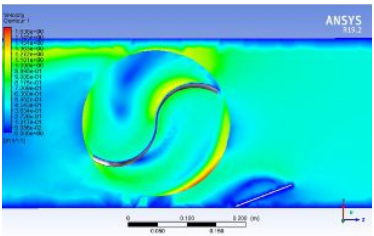


Fig 8.7 Velocity distribution at β = 159º

In almost all these profiles, the velocity along the flow increases and sometimes doubles because of the flow restrictions arising due to the presence of these deflectors. This increased up stream velocity causes the rotational speed of the turbine to increase generating a higher power as compared to a rotor without these plates situated.

CHAPTER 9: RESULTS

The results comparing the performances of the rotor in the presence of deflector plates with a rotor without these plates have been tabulated below.

PERFORMANCE PARAMETER	ROTOR WITHOUT DEFLECTOR PLATES IN THE CHANNEL	ROTOR WITH DEFLECTOR PLATES IN THE CHANNEL
Torque about Y axis	0.15 N-m	0.18 N-m
Torque (Experimental)	-	0.138 N-m
Coefficient of Power (Cp)	0.23	0.27
Cp (Experimental)	-	0.18
Rotational Speed of Rotor (kept fixed)	2.97 rad/s	2.97 rad/s

Table 9.1 Comparison of the performance of rotor with and without the presence of deflector plates in the channel with a flow of Re 1.32×10^5

Based upon the data set taken for experimentation by Kailash Golecha et,al the simulation was carried out for the given tip speed ratios and the coefficient of performance for each position was calculated and has been tabulated as shown below.

S.No.	β	TSR	T_{sim} (N-m)	T_{exp} (N-m)	$(Cp)_{sim}$	$(Cp)_{exp}$
1.	90°	0.76	0.180	0.138	0.27	0.18
2.	101°	0.82	0.148	0.149	0.24	0.21
3.	137°	0.79	0.178	0.118	0.28	0.16
4.	44°	0.89	0.121	0.111	0.21	0.17
5.	159°	0.62	0.182	0.169	0.23	0.18

Table 9.2 Comparison between simulated and experimental results to find out the optimized plate angle

The table above clearly shows that the computational results are slightly higher than the experimental results arising due to environmental and experimentation factors. It can also be observed that with an increase in TSR and for a plate angle of 101°, the coefficient of power obtained was 0.21 experimentally and 0.24 computationally thereby indicating maximized performance of the turbine w.r.t the other positions of the plates.

CHAPTER 10: CONCLUSION

The CFD simulation of the savonius rotor presented us with clear visual representations of flow pattern and property contours of water flowing in the channel. As it was earlier aimed, this paper gauges the performance of the SHKT under free and restricted flow circumstances. Based on the earlier experimental values the speed of the turbine was held constant and the torque and Cp were computed. The results were found to be in variation with experimentation on an average deviation of 0.06 albeit in close proximity to the experimental results. The optimization on positions, inclinations of the plates and the coefficient of performance were performed and the following conclusions can be drawn:

1. Positioning the deflector plates along the flow path showed an increase in the magnitude of the upstream velocity striking the blades of the turbine.

2. The flow restriction caused the input velocity to be double its initial value, thus enabling it to rotate faster.

3. Although there is no significant improvement in the turbine alone, by positioning the plates externally indicated the improvement in the turbine setup on the whole.

4. There is an improvement in the coefficient of power (Cp) by positioning deflector plates from 0.23 to 0.27.

5. The savonius rotor in a closed water channel comprising of a set of deflector blades positioned at varying angles of 90º, 101º, 137º, 44º and 159º shows an increased performance w.r.t to a rotor without any deflectors (by almost 50% in the case of β as 101º [10]).

6. Based on the tip speed ratios, boundary conditions and initial conditions assigned to the turbine setup, it can be observed that there is a considerable increase in the coefficient of performance with a deflector plate situated at an angle β as 101º operating with a TSR of 0.82 shows a coefficient of performance (Cp) of 0.24 which is marginally differing from the experimental value of 0.21.

Nevertheless, the scope for further improvisation in the performance thereby leading to effective and higher power extraction is still wide open for future research work and definitely takes us forward to cope up with the increasing power demand by means of achieving green energy.

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