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"JNANA SANGAMA", BELAGAVI-590018.

Report
on
PROJECT PHASE II

"VANE DESIGN OPTIMIZATION USING CFD"

Submitted in partial fulfillment for the award of bachelor degree
in

MECHANICAL ENGINEERING

Submitted By

NANDAN SESHADRI	**[1JB17ME039]**
PRAMOD S N	**[1JB17ME052]**
SAIVIDHAT D	**[1JB16ME071]**
SHASHANK P	**[1JB17ME069]**

UNDER THE GUIDANCE
of

Dr. Kiran Kumar P.
Professor

DEPARTMENT OF MECHANICAL ENGINEERING

SJB INSTITUTE OF TECHNOLOGY

B G S Health & Education City
Kengeri, Bangalore-560060.

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Sri Adichunchanagiri Shikshana Trust ®

SJB INSTITUTE OF TECHNOLOGY

BGS Health & Education City, Kengeri, Bangalore-560060.

DEPARTMENT OF MECHANICAL ENGINEERING

CERTIFICATE

Certified that this report is submitted in partial fulfillment for the award of **BACHELOR DEGREE** in **MECHANICAL ENGINEERING** as prescribed by **VISVESVARAYA TECHNOLOGICAL UNIVERSITY, Belagavi** by bonafide students of **SJB Institute of Technology**

1.NANDAN SESHADRI[1JB17ME039],

2.PRAMOD S N [1JB17ME052],

3.SAIVIDHAT D [1JB16ME071],

4.SHASHANK P [1JB17ME069],

On the work titled "VANE DESIGN OPTIMIZATION USING CFD" carried out in the Project Phase I (Course Code: 17MEP78) during 7th semester in the academic year 2020-21.

[Dr. KIRAN KUMAR P.] **PROFESSOR**	**[Dr. T. MADHUSUDHAN]** **PROFESSOR & HEAD**	**[Dr. AJAI CHANDRAN C.K.]** **PRINCIPAL**

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Nandan Seshadri, Pramod S N,

SaiVidhat D, Shashank P

ABSTRACT

The aim of this project is to study the various types of vanes and to optimize the design of the existing vanes to provide efficiency in the best possible way. Weighted average method is a type of method which has been used to determine the most efficient blade analytically considering various factors such as head, kinetic energy conserved, type of flow, efficiency, power. Modeling and structural analysis were performed to determine the structural limits using Solid Works software. Findings from the study revealed that the spiral type turbine was more efficient than the others. A conceptual model of the spiral turbine has been designed using the Solid Works software with a 2-D sketch showing the appropriate dimensions. Further the work will be carried using CFD for optimum vane blade design.

Keywords - Turbine, Vanes, Pelton, Kaplan, Spiral Turbine Solid Works, Computational fluid dynamics (CFD), Weighted average method

TABLE OF CONTENTS

LIST OF FIGURES

VANE DESIGN OPTIMISATION

CHAPTER 1

INTRODUCTION

A **turbine blade** is the individual component which makes up the turbine section of a gas turbine or steam turbine. The blades are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine blades are often the limiting component of gas turbines. To survive in this difficult environment, turbine blades often use exotic materials like and many different methods of cooling that can be categorized as internal and external cooling, and thermal barrier and coatings. Blade fatigue is a major source of failure in steam turbines and gas turbines. Fatigue is caused by the stress induced by vibration and resonance within the operating range of machinery. To protect blades from these high dynamic stresses, friction dampers are used.

TYPES OF VANES IN TURBINE

- FLAT PLATE VANES
- CURVED VANES
- SPIRAL VANES

Common application of a water turbine is the hydroelectric power plant situated in various cities that provide electricity to the modern era.

Water Turbines were developed in the 19th century and were widely used for industrial power prior to electric grids. Now they are mostly used for electric power generation. Water turbines are mostly found in dams to generate electric power from water potential energy.

Some of the common problems faced while designing a heat exchanger are:

- Hydro Power Plants usually need a very high amount of water flowing through it to produce a considerable amount of electricity. Due to the huge size the manufacturing, maintaining, operational cost of these turbines is very high.
- As most parts of the world are being powered by this facility the generated power has to be transmitted to households' factories situated far away from the power plant. The process of transmitting the electricity involves several steps such as using a step-up transformer to increase the voltage to 22000v and then stepping it down to the required voltage of 220-240v using a step-down transform this involves a huge power loss which reduces the efficiency.
- Another important factor to consider is that the generated power is only being transmitted to metropolitan cities such as Bangalore, Delhi, Hyderabad, Mumbai, etc. Small villages are still facing a huge issue to get electricity as it involves drawing up electric lines far from the source till the village where the population does not cross 100 because of the huge investment involved in building a source for electricity the government is incapable of helping the villagers.

Considering the disadvantages of all these types of vanes, in order to overcome the limitations, we have taken the micro water turbine.

- A micro hydro power plant is a type of hydro-electric power scheme that produces up to 100 KW of electricity using a flowing steam or a water flow. The electricity from such systems is used to power up isolated homes or communities and is sometimes connected to the public grid.
- Micro hydro systems are generally used in developing countries to provide electricity to isolated communities or rural villages where electricity grid is not available. Feeding back into the national grid when electricity production is in surplus is also evident in some cases. The micro hydro scheme design can be approached as per household basis or at the village level often involving local materials and labour.

- In 1995, the micro-hydro capacity in the world was estimated at 28 GW, supplying about 115 TWh of electricity. About 60% of this capacity was in the developed world, with 40% in developing areas.

- Micro hydro plants that are found in the developing world are mostly in mountainous regions for instance in some places in the Himalayas as well as in Nepal where there are around 2,000 schemes, including both mechanical and electrical power generation. In South America, there are micro-hydro programs in the countries along the Andes, such as Peru and Bolivia. Smaller programs have also been set up in the hilly areas of Sri Lanka, Philippines and some parts of China.

Fig 1.1: Micro spiral water turbine

ADVANTAGES

- Efficient energy source: It takes only a small amount of flow to make it work (as small as two gallons of water or a drop of as low as two feet) to generate electricity with the micro hydro, the produced electricity can be used as far as a mile away from the production site.

- Reliable electricity source: There is a constant and continuous electrical energy supply from a hydro power plant compared to other small scale renewable energy technologies. There are however peak energy seasons (mainly during winter) when large quantities of electricity are required.

- No reservoir required: Micro hydro are considered to run as a 'run-of-river' system, this means that when the water passes through the turbines it is diverted back to the river/ stream with relatively low impact on the surrounding ecology.

- Cost effective energy solution: A small hydro- power system can cost depending on the site electricity requirements and location. The operation and maintenance costs are relatively low as well compared to other technologies.

- Power for developing countries: Having low-cost versatility and long-life span, micro hydro can be used by developing countries in supplying electricity to small villages and communities.

- Integrate with the local power grid: If there is a surplus production of electricity, some companies can buy the electricity from you and integrate it to the grid. There could also be a possibility of supplementing your level of micro power with intake from the grid.

Environmental impact: The impact on the environment is minimized as compared to the traditional power stations that use fossil fuel.

APPLICATIONS

Power produced from a small hydro station can be used for various purposes, some of the uses have been classified as follows:

1. Productive Use: This is where the electricity generated is used to perform activities where money is exchanged for a service. Most of these scenarios take place in small businesses.
2. Consumptive Use: All the other used that the electricity can be used for are called consumptive use. They include using the electricity at the household or close to the household.

Besides the productive and consumptive use, a distinction can also be made between the use of power in a mechanical way or in the form of electricity.

	MECHANICS	ELECTRICITY
PRODUCTIVE USE	▪ Agro processing ▪ Timber sawing ▪ Textile fabrication ▪ Cooling ▪ Drying	▪ Mechanical uses with electricity as intermediate ▪ Heating ▪ Lighting ▪ Fertilizer production
CONSUMPTIVE USE		▪ Domestic lighting ▪ Cooking ▪ Cooling ▪ Radio and television

As the above illustration shows power that is generated by MPH is a convenient source of electricity to fuel anything from workshop machines to domestic lighting as the power can also be supplied to villages via portable rechargeable batteries and thus there are no expensive connection costs. Batteries can as well be charged and used to provide the local community with power. For industrial use however, the turbine shaft can be used directly as mechanical power as opposed to converting it into electricity via generator or batteries. This is suitable for agro-processing activities such as milling, oil extraction and carpentry.

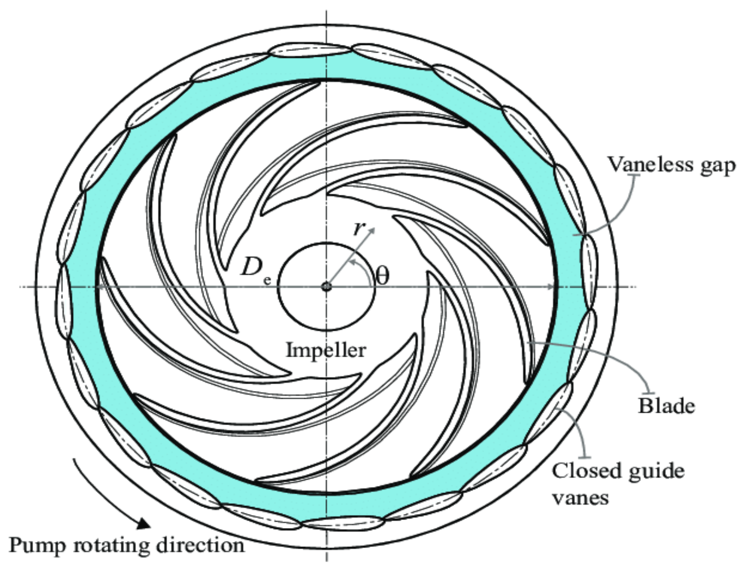


Fig 1.2 : Sectional view of a spiral vane

INTRODUCTION TO WEIGHTED AVERAGE METHOD:

- Weighted average is a calculation that takes into account the varying degrees of importance of the numbers in a data set. In calculating a weighted average, each number in the data set is multiplied by a predetermined weight before the final calculation is made.
  - Scaled Property $(\beta) = \dfrac{\text{Lowest value in the list}}{\text{Numerical value of the property}} \times 100$

    where β = scaled factor,

    α = weighted factor
  - Performance Index = $(\beta * \alpha)$
  - In weighted average method, the particular weight indexes are given with the preferences allotted to it for the required working conditions. It takes all the parameters into consideration and the total weighted average number is taken. In order to get the most efficient one from among all, the performance index is taken and the one which has high performance index among all the types available will be chosen as the most efficient one.
  - The weighted average method is so important in selecting the most efficient one among all the available ones. It emphasizes on all the parameters like cost-efficient, manufacturing cost, maintenance cost, tool cost, etc., and then by giving the weighted indexes for the preferred parameters required, it gives the most efficient one with high performance factor for the required working conditions.

    In general, for the efficient design we need to have low machine cost, high work output, low maintenance and the high performance index among the designs available for the weighted average method.

INTRODUCTION TO COMPUTATIONAL FLUID DYNAMICS(CFD)

- Computational fluid dynamics is used in our project to show the flow visualization of the water flowing through the vanes. Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to analyze and solve problems that involve fluid flows. Computers are used to perform the calculations required to simulate the free-stream flow of the fluid, and the interaction of the fluid (liquids and gases) with surfaces defined by boundary conditions. With high-speed supercomputers, better solutions can be achieved, and are often required to solve the largest and most complex problems. Ongoing research yields software that improves the accuracy and speed of complex simulation scenarios such as transonic or turbulent flows. Initial validation of such software is typically performed using experimental apparatus such as wind tunnels. In addition, previously performed analytical or empirical analysis of a particular problem can be used for comparison. A final validation is often performed using full-scale testing, such as flight tests.

OBJECTIVES

- To determine an efficient blade design for desired application.
- To perform weighted average method to select the most efficient vane design from the various types available.
- To perform structural analysis to calculate structural limits.
- To perform CFD analysis to showcase flow visualization.
- To publish a journal paper.

CHAPTER 2:

LITERATURE REVIEW

1. **Numerical Study of the Leakage Flow on a Novel Turbine Blade Tip; Dengyu Jiang, Hualing Luo, Xiang Zhang; 2014 Asia-Pacific International Symposium on Aerospace Technology**

In this paper, a squealer tip of a turbine blade helps in reducing leakage mass flow rate. This paper speaks in detail about how a novel turbine blade tip can improve the aerodynamic performance by associating with understanding of the leakage flow characteristic. CFD analysis is used to predict the reduction of leakage mass and increase in efficiency. The numerical investigation using CFD showed that-

1. The sharper squealer tip corner on the pressure side forces the leakage flow to turn by a larger which produces a large separation bubble which reduces efficiency.
2. CFD predicts that squealer tip shows 30% less leakage mass flow rate and 0.11% total isentropic efficiency increase for a single motor compared to baseline squealer tip case.

2. **Effect of blade angle on turbine efficiency of a Spiral Horizontal Axis Hydro Turbine; Wiroon Monatrakul and Ratchaphon Suntivarakorn; 2017 International Conference on Alternative Energy in Developing Countries and Emerging Economies**

This paper presents how efficiency of the turbine increases w.r.t the change in blade angle. Angles 15, 18, 21 and 30 are taken at velocities 1, 1.5, and 2 m/s for a 3-bladed axial turbine along with at 2 conditions: free flow and collection chamber and using CFD analysis. Thus, the paper helps a spiral blade angled around a turning axle. The study analyzed the optimal blade angle at 15, 18, 21 and 30 for 1, 1.5, 2 m/s water velocities at 2 conditions: free flow and collection chamber. The axial turbine performed 3 times higher than the free flow condition.

3. **Experimental and Numerical Analysis of Deformation in a Rotating RC Helicopter Blade; Pedro J. Sousa, Francisco Barros, Paulo J. Tavares and Pedro M. G. P. Moreira; International journal of turbomachinery, propulsion and power**

In this paper, since rotating structures are important for transportation and energy generation, it's important that it works without any problems. This paper focuses on using 3D digital image correlation to obtain apparent stillness of the blades when it's in motion to remove imprecision by acquiring data. This is applied to a RC helicopter and then compared to a computation model using CFD and FEA. Thus, the 3D digital image correlation plays a vital role in performing experimental numerical analysis of RC helicopter blade in operation. It helps in achieving both at great precision. The only limitation is the use of excess amount of light which is used to acquire clear images of rotating objects.

4. **Reducing Secondary Flow Losses in Low-Pressure Turbines: The "Snaked" Blade; Matteo Giovannini, Filippo Rubechini, Michele Marconcini, Andrea Arnone and Francesco Bertini; International journal of turbomachinery, propulsion and power**

This paper talks about the impact of a secondary flows on aerodynamic of a low-pressure turbine (LPT) using innovative design called "snaked" blade design which provides a more design concept was patented by Avio Aero. This involves reshaping the stator blade at the end-wall region t oppose the flow turning deviation. The stator redesign is applied to the whole LPT in order to improve overall turbine performance. The snaked blade is designed to reduce secondary losses. IT is designed to close the end-wall region to improve exit swirl distribution. A uniform exit flow is obtained at exit to improve downstream blade condition. The effectiveness of the concept is justified using CFD where desired results are obtained.

5. **Body Force Modelling of the Aerodynamics of a Low-Speed Fan under Distorted Inflow; Emmanuel Benichou, Guillaume Dufour, Yannick Bousquet, Nicolas Binder, Aurélie Ortolan, and Xavier Carbonneau; International journal of turbomachinery, propulsion and power**

This paper emphasis on the use of body force modelling (BFM) on turbomachinery to accurately predict engine performance with affordable CPU resources. This method is used to examine a low-speed cooling fan with inflow distribution. This method is independent of CFD as it relies on semiempirical loss model. This is used to asses against the unsteady Reynolds-averaged Navier strokes (URANS) which in turn helps in providing early design phase of an innovation propulsion system at a low CPU cost. BFM was carried out on a cooling fan. BFM and URANS show good results for distortion. The body for simulation shows main flow behavior with low CPU cost than URANS by a factor of 40. This provides an innovative approach against CFD and shows BFM as a powerful tool. This research project is used to represent more propulsion function with more realistic distortion pattern.

6. **Performance Investigation and Optimization of a Vertical Axis Wind Turbine with the Omni-Direction-Guide-Vane; Y. C. Lima, W. T. Chong, F. B. Hsiao; 7th Asian-Pacific Conference on Aerospace Technology and Science**

This paper aims to present an approach on optimizing the design of the guide-vane in order to maximize the performance of the vertical axis wind turbine. An analytical model based on the continuity equation for assessing the impact of each design parameter of the guide-vane to the turbine performance. A 2-level full factorial design was further utilised for the verification of analytical findings with the aid of computational fluids dynamics simulation. Three parameters, i.e., two guide vanes angles and ratio of turbine diameter to distance between two guide vanes was selected for the initial design of experiment screening process. The results suggested that the optimum point exists at the corner point. It is worth to highlight that the analytical model overestimates the performance at larger vane angle since only one-dimension steady flow is assumed. A single directional flow guide-vane that surrounds a vertical axis wind turbine designed to improve the turbine performance. An analytical study has indicated that vane angles and the ratio of turbine diameter to distance between two guide vanes are more crucial to turbine performance if diameter ratio of turbine to guide-vane is fixed. A two-level full factorial designed to the screening process for the identification of the critical factors for turbine performance. From two level full factorial, it further divulges that the strong interaction effect was observed at guide-vane angles, guide-vane angle with ratio of turbine diameter to the distance of guide-vanes compared to the main or individual effects

7. **Design and analysis of a sliding vane pump for waste heat to power conversion systems using organic fluids; Giuseppe Bianchi, Fabio Fatigati, Stefano Murgia, Roberto Cipollone; Applied Thermal Engineering**

In this paper, the current research work assesses the relevance of pumping work in energy recovery systems based on bottoming Organic Rankine Cycles and presents the development of a sliding vane pump prototype for small-scale units. The device was developed. In an organic Rankine cycle-based power unit for waste heat to power conversion in compressed air applications in which the heat source was a compressor lubricant while the heat sink was tap water. Tests performed with R236fa as working fluid at different pressure rises (3.9–9.7) and revolution speeds (500–1300 RPM). The experimental dataset was to validate a numerical one-dimensional CFD model of the sliding vane pump. The modelling platform further exploited to retrieve performance maps of the pump, angular vane pressure evolution as well as to break down leakage and friction losses. The effects of geometrical features on the pump performance as eventually investigated through variations of the aspect ratio. A general conclusion that can be drawn from this study and literature is that showed better machine efficiencies decreasing the stator diameter. It is the fact that changes in aspect ratio of a sliding vane machine can affect its efficiency either way. In fact, although the physics is the same, the baseline geometrical configuration involves variation of the geometrical dimensions that can mislead the theoretical predictions. Hence each case should be analysed with a detailed model-based approach.

8. **Design Optimization of A Small Scale High Expansion Ratio Organic Vapour Turbo Expander for Automotive Application; Qiyu Ying, Weilin Zhuge, Yangjun Zhang, Lei Zhang; IV International Seminar on ORC Power Systems, ORC2017 13-15 September 2017, Milano, Italy**

In this paper, a single-stage radial-inflow organic vapor turbo expander with pressure-ratio up to 8 is preliminarily designed, and its performance and internal flow are numerically studied. The performance is simulated with three-dimensional *computational fluid dynamic* (CFD) method at operating conditions. Several geometry modifications are conducted in order to learn their influence on turbine performance. Shock waves and trailing edge losses are observed as main losses in the nozzles. In addition, flow separations are the main losses in the rotors. Turbine blade is accordingly optimized after the analysis, and the nozzle total pressure loss coefficient decrease clearly, meanwhile a rise of 3.4% on turbine efficiency can be obtained. Shock waves and reflected waves are suppressed, and a more uniform stream at nozzle outlet can be observed. The result is concluded by observing the thermal analysis through temperature distribution and heat flux values are more for honey comb structure.

9. **A three-dimensional CFD modeling methodology applied to improve hydraulic components performance; Emma Frosina; ATI 2015 - 70th Conference of the ATI Engineering Association**

In this paper, a three-dimensional CFD methodology to improve the performance of hydraulic components that solves numerically the fundamental conservation equations of mass, momentum and energy and includes accurate physical models for turbulence and cavitation. The paper presents results obtained on variable displacement vane pump and on a vane pump power split transmission, both pumps are used for mobile application. Analyzing the results of this paper it is possible to appreciate the transversality of the adopted methodology. The flexibility the presented methodology makes this approach very interesting in the Hydraulic field offering the opportunity of solve completely different issues in many applications. This paper shows a methodology used to study hydraulic components like pumps. The first model was made to investigate the cavitation phenomena to improve the displacement control by a reduction of the forces acting on the ring. For this reason the model has an accurate cavitation sub-model.

10. **Optimal Aerodynamic Design of a Transonic Centrifugal Turbine Stage for Organic Rankine Cycle Applications; Giacomo Persico, Vincenzo Dossena, Paolo Gaetani; IV International Seminar on ORC Power Systems, ORC2017, 13-15 September 2017, Milano, Italy**

This paper presents the results of the application of a shape-optimization technique to the design of the stator and the rotor of a centrifugal turbine conceived for Organic Rankine Cycle applications. Centrifugal turbines have the potential to compete with axial or radial-inflow turbines in a relevant range of applications, and are now receiving scientific as well as industrial recognition. The design of optimal blades for centrifugal ORC turbines demands the application of high-fidelity computational tools. In this work, the optimal aerodynamic design is achieved by applying a non-intrusive, gradient-free, CFD-based method implemented in the in-house software FORMA was applied to optimize the shape of the stator and the rotor of a transonic centrifugal turbine stage, which exhibits a significant radial effect, high aerodynamic loading, and severe non-ideal gas effects. The optimization of the single blade rows allows improving considerably the stage performance, with respect to a baseline geometric configuration constructed with classical aerodynamic methods. Furthermore, time-resolved simulations of the coupled stator-rotor configuration shows that the optimization allows to reduce considerably the unsteady stator-rotor interaction.

11. **Modelling the Energy Extraction from In-stream Water by Multi Stage Blade System of Cross Flow Micro Hydro Turbine; Shahidul, M. I, Syed Tarmizi,S.S, Abdullah Yassin, Al Khalid Othman, Hushairi Zen, Ting Ching Hung, and Lee Man Djun; ELSEVIER -2014**

This journal paper, displays the extraction habitat of a multi stage Micro Hydro Turbine, especially when it is put to work at a low IN- Stream water body. The simulation has been completed using ANSYS CFD software which is the fundamental of designing a software. The essential component involved in designing the turbine were blade area, blade stage, turbine operation. The study did reveal that the turbine has initiated to extract energy from the water at a velocity of 0.4 m/s at an rpm of 35. The inlet velocity of water was 1.1 m/s, the velocity drop along the blade was found to be 26.6% eventually giving an efficiency of 48.3 %. It was then found to be that the energy extraction was comparatively higher when multiple stages were influenced. The findings of the study indicate that by using a multi stage MHT (micro hydro turbine) has the power to contribute higher percentage of energy from an instream water source and therefore increase the turbine performance. Of- course, higher extraction performance would contribute to increase environmental sustainability, thus society would be benefited by using developed model.

12. **Performance Analysis of Mini Centrifugal Pump with Splitter Blades; T. Shigemitsu, J. Fukutomi, T. Wada, H. Shinohara; International Journal of Thermal science – Springer -2013**

In this paper, the Design method for a mini centrifugal pump has not been established the reason being that the internal flow condition for these small- sized fluid has not been clearly specified. The semi-open impeller for the mini centrifugal pump with 55mm impeller diameter was taken to consideration for its simple design and friendly maintenance. Splitter blades are taken into account in the research to improve the performance and internal flow condition of a mini centrifugal pump having large blade outlet angle. The performance test is conducted with these rotors in order to investigate the effect of the splitter blades on the performance and internal flow condition. A three-dimensional steady numerical flow analysis is conducted to analyze rotor, volute efficiency and loss caused by the vortex. Furthermore, the performance analysis of the mini centrifugal pump with and without the splitter blades are conducted. To conclude, the rotor, volute of the mini centrifugal pump with or without splitter blades were evaluated by the numerical analysis result. Further the bond between performance and flow condition was investigated. There were two types of blades used in the analysis is was found to be that the flow condition at the outlet of the rotor became uniform for type 2 due to the action of splitter blades and hence having higher volute efficiency with a lower vortex efficiency.

13. **Structural Design and Manufacturing Process of a Low Scale Bio-Inspired Wind Turbine Blades; Camilo Herreraa, Mariana Correaa , Valentina Villada, Juan D. Vanegas , Juan G. Garc´ıa, C´esar Nieto-Londo noa, Juli´an Sierra-P´erez; ELSEVIER 2019**

In this paper, a wind turbine is blade design inspired by a tree seed called Triplaris Americana. The analysis of seed’s curvature and airfoil along the wingspan helped in the designing of the blade which resulted in a non-conventional horizontal axis wind turbine composed of three blades. Composite materials were used in designing resulting in six zones. Finally, a manufacturing simulation by means of vacuum assisted resin infusion was performed. Four injections strategies were proposed with three of them considered successful based on a complete mold filling and time limit imposed by the polymerization time of the resin. In general, the bio-inspired wind turbine performance overcome the various commercials wind turbine performance overcome the different types of commercial wind turbines regarding to the power coefficient and hence the energy conversion factory. The use of runners helped the resin to reach zones that were difficult given the mold complexity, avoiding the formation of dry zones that are undesirable. Even this high permeability channels reduced the overall filling time which implies that the pressure requirements can be reduced. This particular geometry showed that the wind turbine has a great potential to generate electricity in areas where there is a low wind speed.

14. Blade Design and optimization of a horizontal axis tidal turbine; Fu-wei Zhu, Lan Ding, Bin Huang, Ming Bao, Jin-Tao Liu; ELSEVIER-2020

In this paper, a device which converts kinetic energy of water into electrical energy is known as Tidal Turbine. The theory used in this paper is Blade Element Momentum Theory (BEM). Even though there is an enormous amount of tidal power the actual operation of tidal power plant is not effective because of its drawbacks in the field of conversion of energy efficiency and the production cost. The optimization of the power coefficient, the main index of hydraulic performance of tidal turbine. The altered results are being verified in the ocean. The results show that after optimizing the length of the blade chord and pitch angle distribution, the power coefficient of the turbine increases by 2% and the optimal tip speed ratio range is also expanded. The power flow turbine is well discussed in the paper including the chord length and pitch angle distribution of the blade are optimized by genetic algorithm, so as to optimize the hydraulic performance. The blade angle is changed with change in the blade pitch angle when there is a flow, hence the blade pitch angle must be optimized in respect to the lift and drag ratio of the airfoils. The main power generation position of the blade is concentrated at about 75% of the blade span which would help to capture more wind with the increase of chord length.

15. **Structural Design of a 10mw wind turbine blade; Kevin Coxa, Andreas Echtermeyer; ELSEVIER-2012.**

In this paper, the structural prospective of a blade which is 70 m long in an upwind, horizontal axis wind turbine developed in this paper using a high wind speed location. The blade was subjected to a FEA studies which will determine the ability if the blade to withstand the extreme load condition which has been defined in the offshore wind standard. Detailed analysis of the structural components and ply layups are been presented in the paper along with the maximum and minimum values of strains and deflections. The blade of 70 m was designed to withstand the EOG and EWM load cases with materials strains, tips, deflection and the critical buckling load used as failure criteria. The blade was designed by layering 0-degree carbon fiber pipes to contribute to the buckling resistance. In relation to this method, a composite ply layup deflection was developed yielding a total blade weight of 2498 kg. Other techniques were introduced to determine potential for further blade optimization.

16. **Multiphase flow modeling and optimization for online wash systems of gas turbines; E.M. Wahba, H. Nawar; Applied Mathematical Modelling**

In this paper, compressor blades dirt will cause loss in power and efficiency. Therefore, online wash systems are used to remove dirt without having to shut down the gas turbine. The developed approach is used to optimize the design of the online wash system for the General Electric MS5002 gas turbine model. In this study, a CFD-based design optimization procedure is developed for gas turbine online wash systems. As a result, there is comparatively less power loss and high efficiency.

17. **Computational fluid dynamics simulation of the effect of guide-vane angles on the performance of the exhaust air energy recovery turbine generator; S. C. Poha, S. Y. Sima, W. T. Chonga, A. Fazlizana, S. Y. Yip, W. P. Hew, W. Z. W. Omar, Z. M. Zain; The 6th International Conference on Applied Energy – ICAE2014**

In this paper, an exhaust air energy recovery turbine generator is designed to recover part of the energy in the discharged air from an exhaust air system. The design is a combination of H-rotor vertical axis wind turbines, guide-vanes and a diffuser. The exhaust air energy recovery turbine generator can be used to recover waste energy from the discharged wind of an exhaust air system for urban areas. In this study, the exhaust air energy recovery turbine generator is another green technology that can recover waste energy from the discharged wind of an exhaust air system. Guide-vanes at optimized angles serve the purpose to change the direction of airflow for better angle of attack of the turbine blades and hence improve the turbine performance.

18. **Experimental and CFD ANALYSES of a highly- loaded gas turbine blade; Tommaso Bacci, Andrea Gamannossi, Lorenzo Mazzei, Alessio Picchi, Lorenzo Winchler, Carlo Carcasci, Antonio Andreini, Luca Abba, Stefano Vagnoli; 72nd Conference of the Italian Thermal Machines Engineering Association, ATI2017**

In this paper, the metal temperature is more important than anything else to ensure better life span of gas turbine hot gas path components. Changing mainstream and coolant mass flow rates it was thus possible to characterize the thermal response at different operating conditions. The metal temperature of 30% is reduced to 5% where coolant turbulence plays a minor role. In this study, the increase in the cooling flow and the reduction of the mainstream lead to a reduction of the metal temperature, even though this process becomes steadily less efficient the coolant flow is increased. Numerical results have proved the robustness of the γ-Reθt transition model.

19. **Fluid-dynamic design and characterization of a mini-ORC turbine for laboratory experiments; M. Pini, C. De Servi, M. Burigana, S. Bahamonde, A. Rubino, S. Vitale, P. Colonna; IV International Seminar on ORC Power Systems, ORC2017.**

In this paper, organic Rankine Cycles power systems of low power capacity are receiving recognition for distributed and mobile energy generation applications. It's to cope with very large volumetric flow ratio with limited fluid-dynamic penalty. The detailed design and the characterization of the fluid dynamic performance of a mini-ORC radial inflow turbine have been documented in this paper. The results of this work outlined that current design rules for radial-inflow turbines are arguably not applicable to mini-ORC turbines.

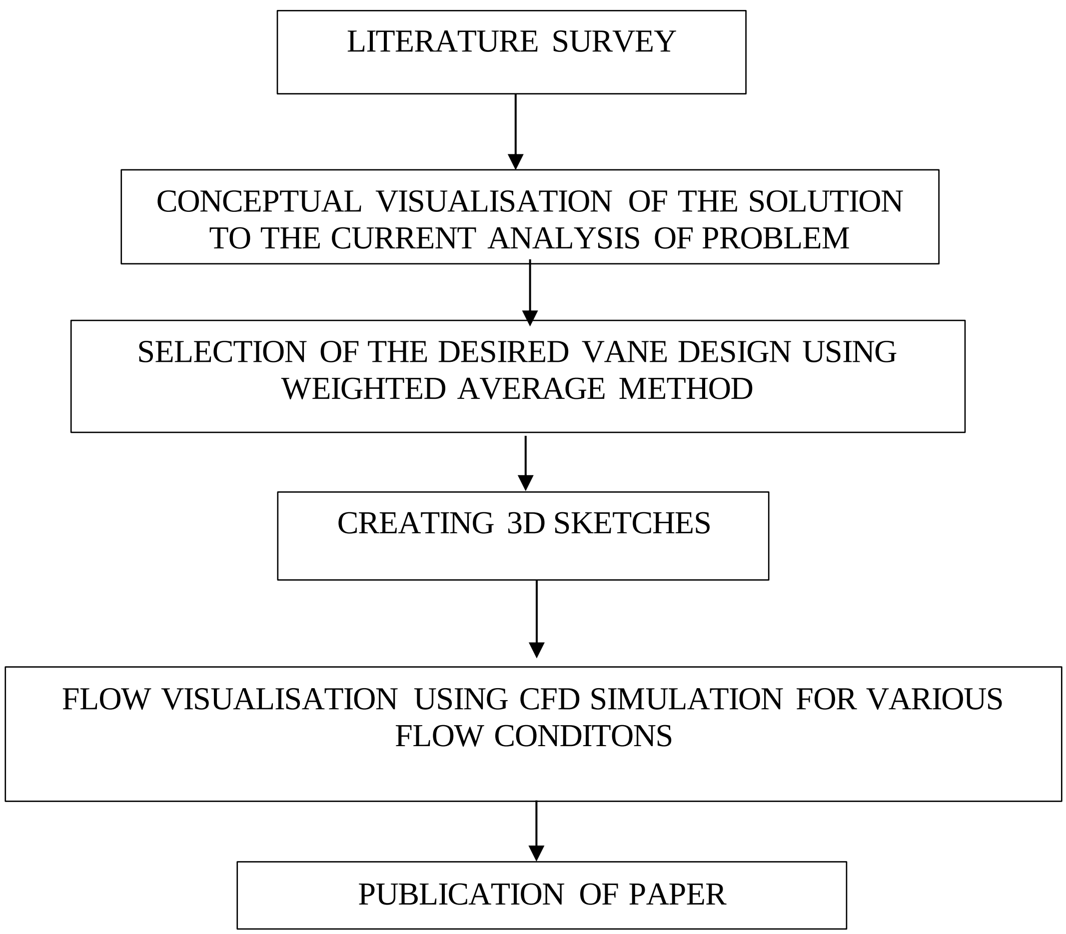
20. Investigation of a Steam Turbine with Leaned Blades by Through Flow analysis and 3D CFD Simulation; Xiaodong Wang, Shun Kang and Ke Yang; NUMECA-BEIJING Fluid Engineering Co. Ltd, Beijing, 100081, China

In this paper, the blade lean angle on the flow performance in the design process of a one-stage turbine with large diameter/height ratio, a through-flow tool of Ax STREAM is used to make the investigation. Some results for five typical lean angles are compared with the data of a 3D CFD simulation performed with FINE/TURBO software. The blade profiles of stator and rotor were optimized through Ax STREAM. So, in this design, leaned blade was used in stator to improve the performance of stage.

CHAPTER 3

METHODOLOGY

Turbine is a rotary engine that converts the energy of a moving stream of water, steam or gas into mechanical energy. The basic element in a turbine is a wheel or rotor with paddles, blades or buckets arranged on its circumference in such a way that the moving fluid exerts a tangential force that turns he wheel and imparts energy to it. This mechanical energy is then transferred through a drive shaft to operate a machine, compressor, electric generator or propeller. In a Pelton Turbine, water impeaches on the blades of the turbine making the wheel to rotate (due to force of the falling water) producing torque and power through the runner to rotate the alternator/generation at a particular speed thereby producing power. The procedure to take up the project is shown in the flowchart below.



PROGRESS OF WORK

- Literature survey completed.
- Conceptual design of 3D model completed.
- Final Synopsis completed.
- Obtained an efficient design (spiral vanes) as per requirements using weighted average method.
- Publication of review paper in iManagers journal of material science is completed.

PROGRESS CHART

Sl no	Tasks	4 weeks	8 weeks	12 weeks	16 weeks	20 weeks	24 weeks	28 weeks	32 weeks	36 weeks	40 weeks	44 weeks
1	Project definition											
2	Literature review											
3	Final synopsis											
4	Project progress phase 1 (50%)											
5	Exams											
6	Paper publication											
7	Project progress phase 2 (100%)											
8	Report submission											

SELECTION OF VANE USING WEIGHTED AVERAGE METHOD

By using weighted average method, various parameters are taken into consideration and the Weighted indexes are given as follows. For the required minimum head and the total kinetic energy conserved. The spiral vane is the most efficient. So further, the design and the analysis of the spiral vane are conducted.

VANE	HEAD	TYPE OF VANE BLADE	K.E CONSERVED	EFFICIENCY	POWER
PELTON	HIGH (150m)	RADIAL	LOW	50-60%	73KW
KAPLON	LOW (10-70m)	AXIAL	MEDIUM	70-93%	5-200MW
SPIRAL	VERY LOW (5m)	AXIAL	HIGH	70-90%	350KW

PROPERTY	WEIGHT INDEX
HEAD	**5**
K.E CONSERVED	**4**
TYPE OF FLOW	**3**
EFFICIENCY	**2**
POWER	**1**

$$\beta=(1/5)*100$$

$$\beta=20$$

$$\wp=(5*20)$$

$$\wp=100$$

Here, for the working circumstances the highest preference or high weighted index is given to the head and then for the total kinetic energy conserved, type of flow, efficiency and power. For the minimum head required and the high total kinetic energy conserved, the spiral vane design comes out as the most effective among the Pelton and the Kaplan. Hence, the spiral vane with highest performance index is chosen as the most efficient and further design and the structural analysis are conducted in order to optimize the vane.

CHAPTER 4

4.1 DESIGN OF THE EQUIPMENT

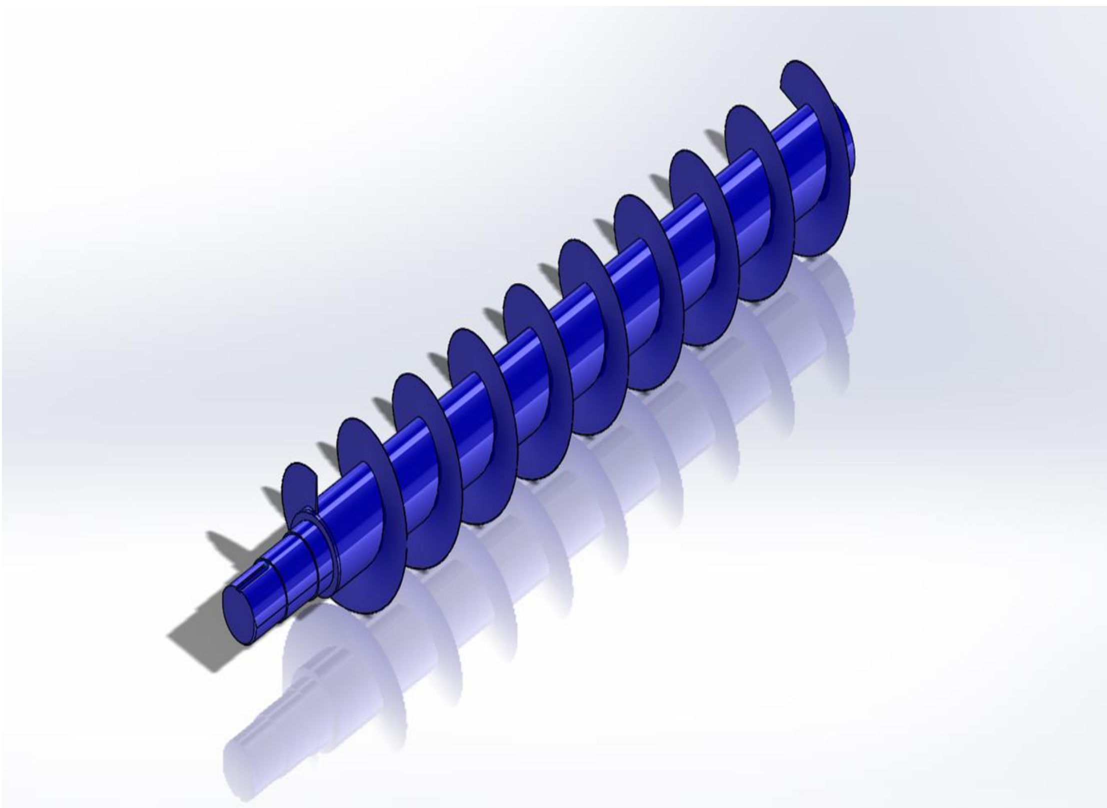


FIG 4.1.1 SHAPE OF SCREW TURBINE

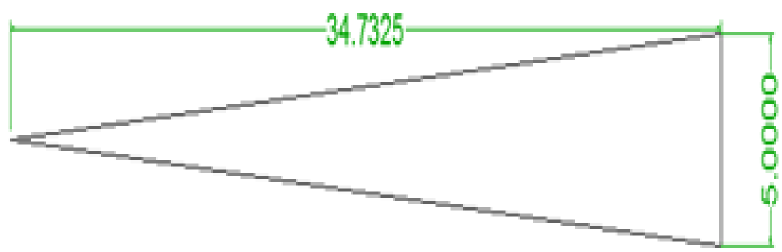


FIG 4.1.2 CROSS SECTION OF THE SCREW BLADE

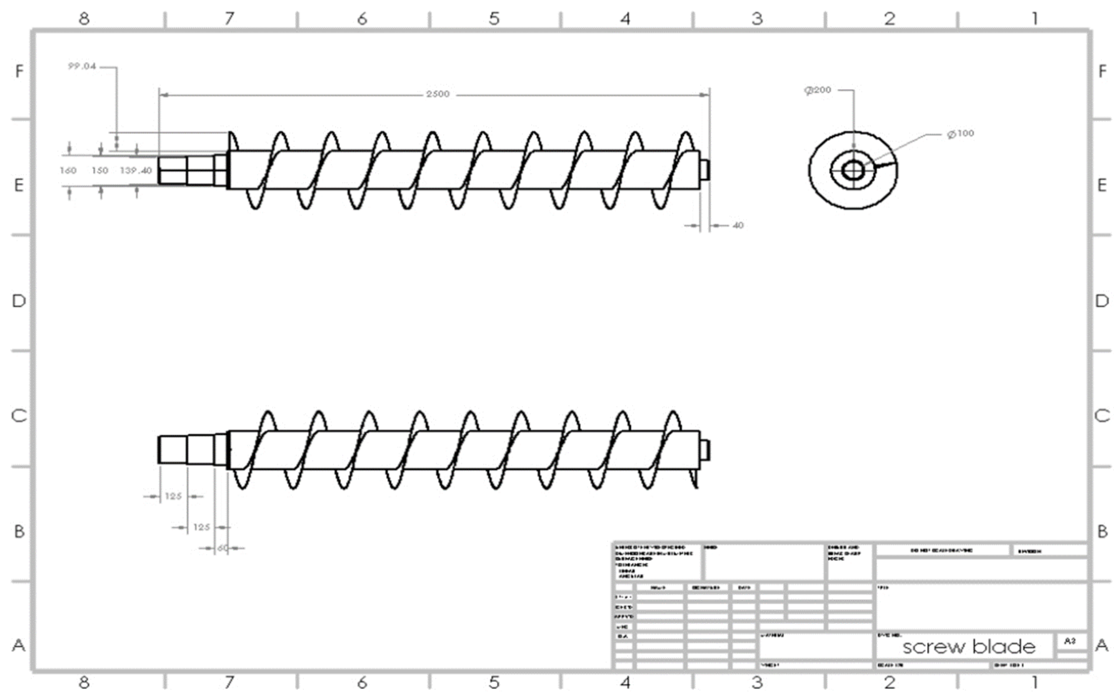


FIG 4.1.3 CROSS-SECTIONAL VIEW OF SPIRAL BLADE

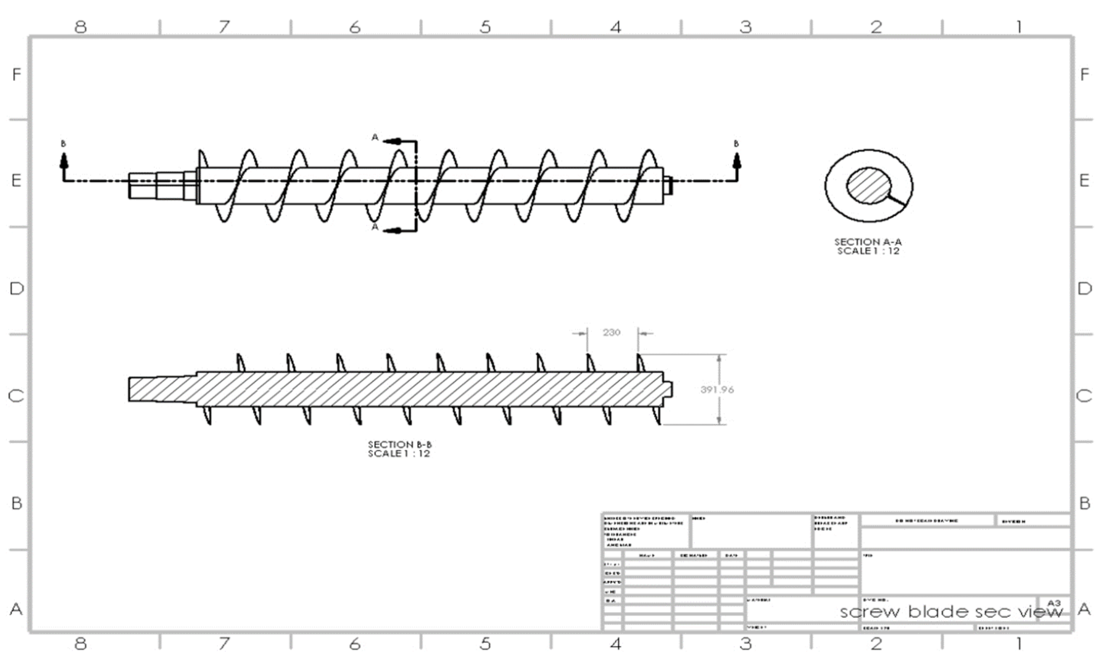


FIG 4.1.4 CROSS-SECTIONAL VIEW OF SPIRAL BLADE

4.2 MESHING

- Meshing is a part of the engineering simulation manner where complex geometries and models are divided into simple elements that can be used as discrete local approximations.
- Meshing is one of the key components to obtaining accurate results from a FVM model. The elements in the mesh must take many aspects into account to be able to discretize results accurately.
- The trade-off is that the higher the accuracy, the larger the simulations become and thus solve times are extended.

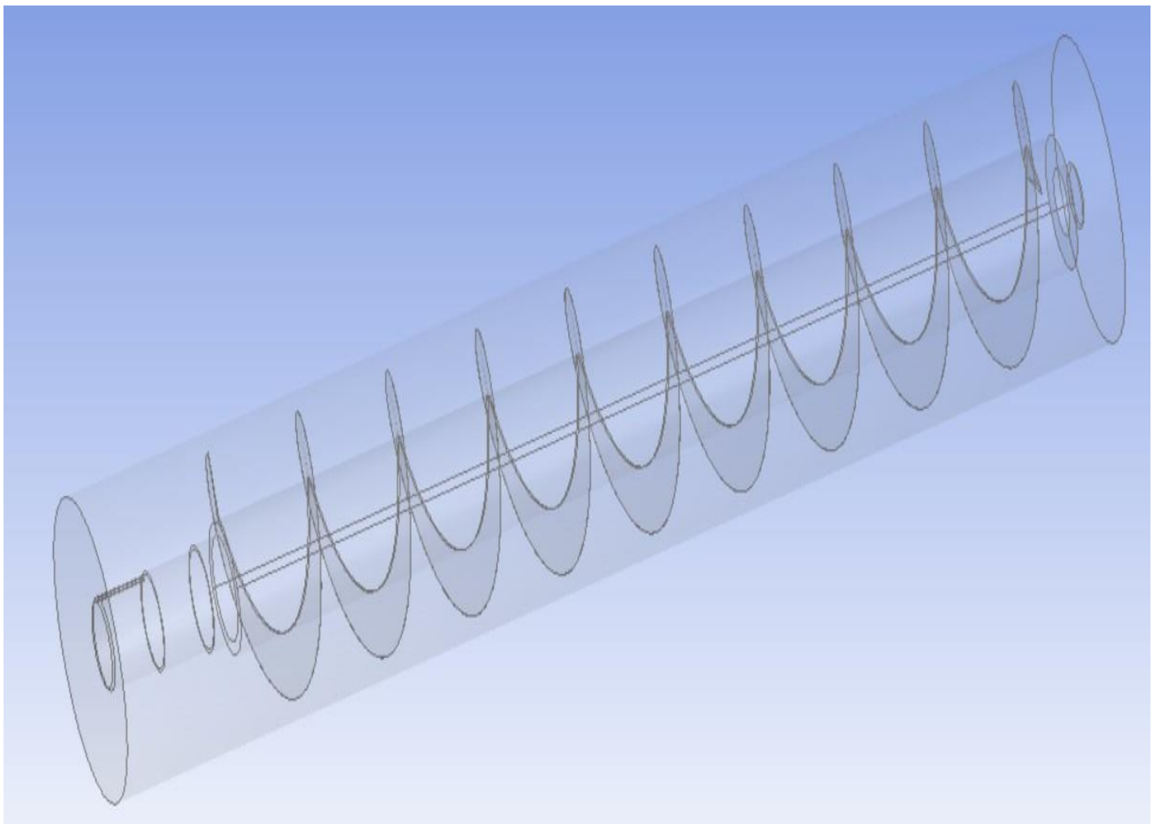


FIG 4.2.1 SCREW TURBINE WITH THE TROUGH

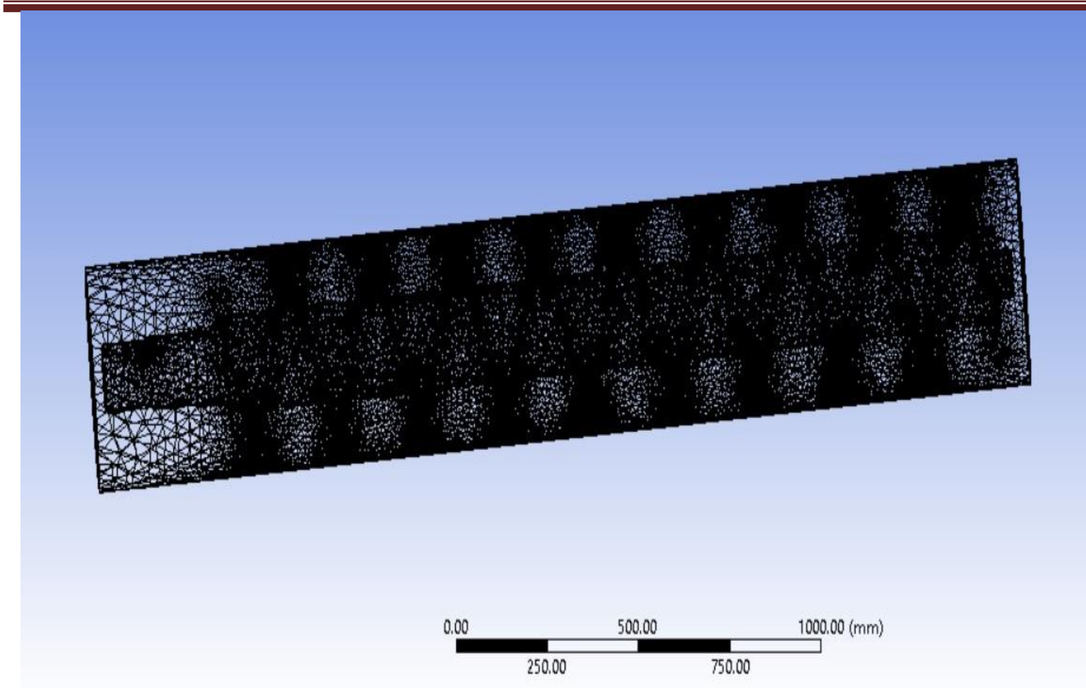


FIG 4.2.2 MESHED WIRE FRAME MODEL

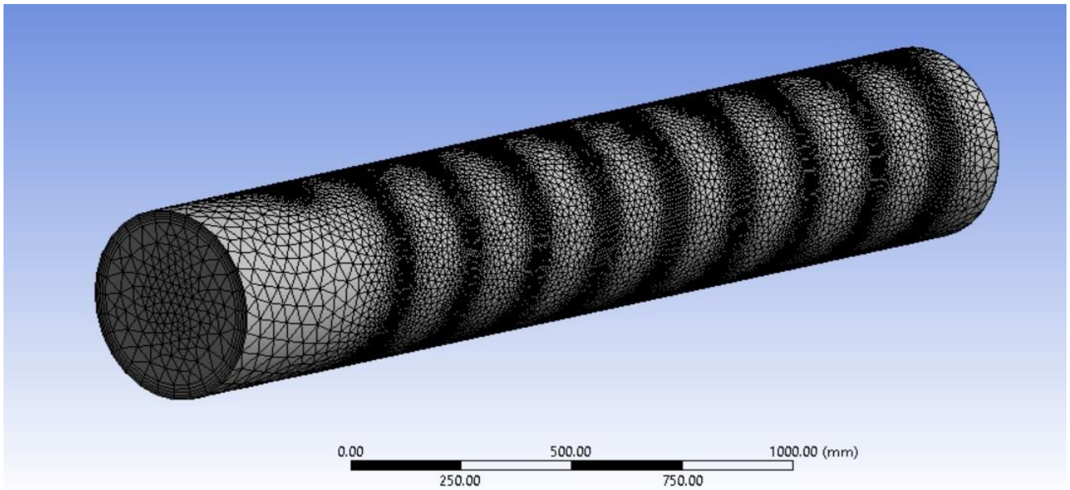


FIG 4.2.3

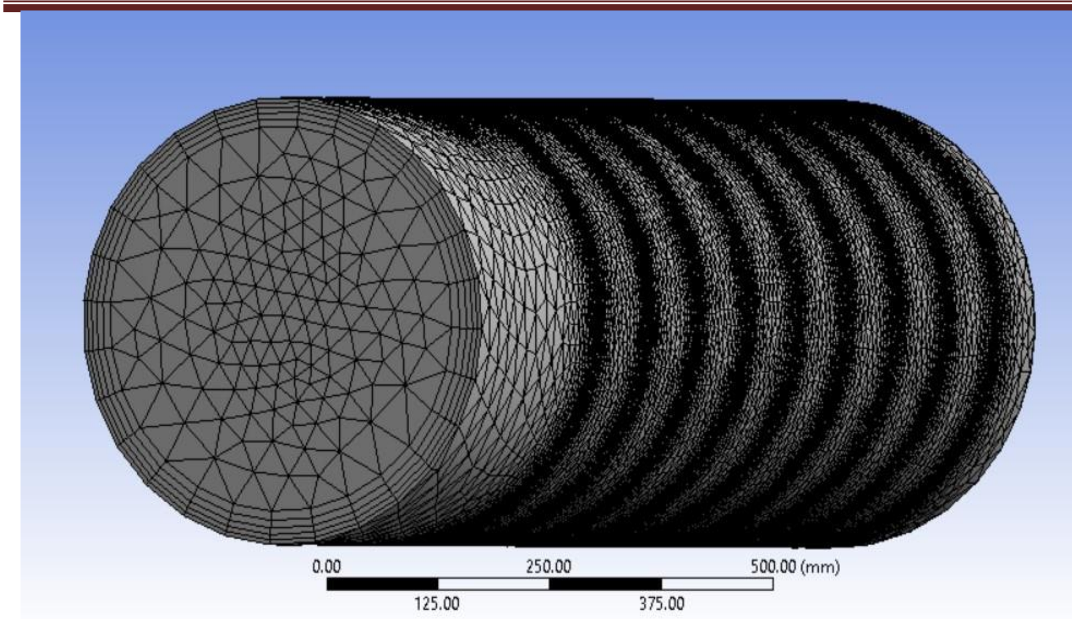


FIG 4.2.4 INFLATION VIEW

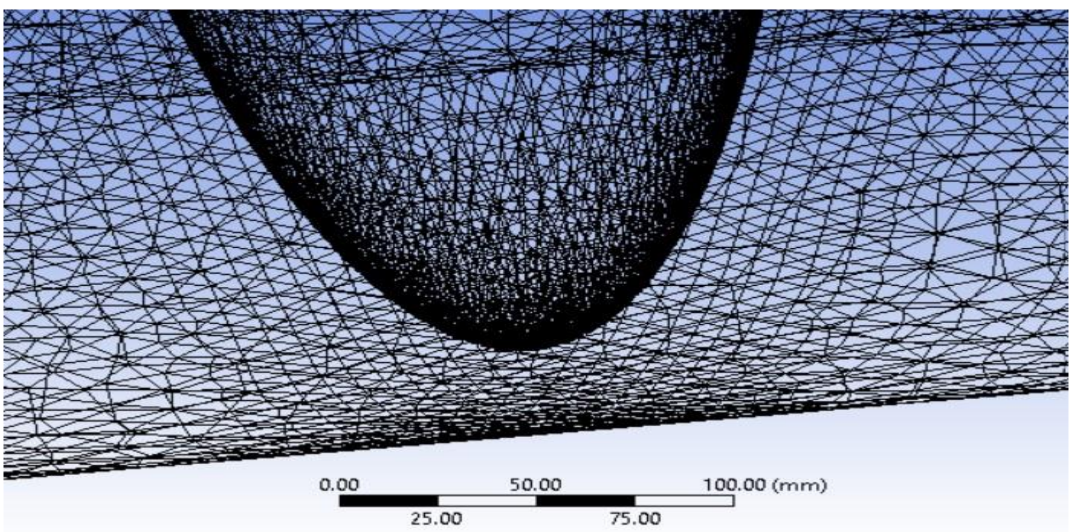


FIG 4.2.5 ZOOM-IN VIEW OF THE MESHING

Details of "Patch Conforming Method" - Method

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Tetrahedrons
Algorithm	Patch Conforming
Element Order	Use Global Setting

Quality	
Check Mesh Quality	Yes, Errors
Target Skewness	Default (0.900000)
Smoothing	High
Mesh Metric	None

Details of "Inflation" - Inflation

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Boundary Scoping Method	Geometry Selection
Boundary	1 Face
Inflation Option	Smooth Transition
Transition Ratio	Default (0.272)
Maximum Layers	5
Growth Rate	1.2
Inflation Algorithm	Pre

Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
Element Size	130.0 mm
Export Format	Standard
Export Preview Surface Mesh	No

4.3 COMPUTATIONAL FLUID ANALYSIS OF SPIRAL TURBINE FOR VARIOUS FLOW VISUALIZATION

- Computational fluid dynamics (CFD) is a science that, with the help of digital computers, produces quantitative predictions of fluid-flow phenomena based on the conservation laws (conservation of mass, momentum, and energy) governing fluid motion.
- Computation fluid dynamics (CFD) is an engineering tool used to simulate the action of thermo-fluids in a system. It is used by many industries in their development work to analyze, optimize and verify the performance of designs before costly prototypes and physical tests.
- The most important thing to be done in the computing process is the modeling of turbulent structures in the flow field. This turbulent structure occurs at various timescales and lengths, creating a model that can analyze all these possibilities is not easily practicable.
- There are different turbulence models available for turbulent flow simulation. The model used in this study is a variant on the standard k-epsilon model called the renormalized group k-epsilon model.

Navier-Stokes Equation

- This equation can be used for weather modeling, ocean currents, water flow in pipes and airflow around the aircraft wing. The Navier-Stokes equation in complex and simplified form can help in the design of power plants, turbines and many other things. In terms of the inertial reference, the general form of the fluid motility equation is

$$\rho \left(\frac{Dv}{Dt}\right) = -\nabla p + \nabla . T + f$$

- (1) T is a symmetrical tensor except when the fluid is composed of degrees of freedom that rotate like a vortex. In general, (in three dimensions) T has the form of the equation:

$$T = \begin{pmatrix} \sigma_{xx} & \tau_{xy} & \tau_{xz} \\ \tau_{yx} & \sigma_{yy} & \tau_{yz} \\ \tau_{zx} & \tau_{zy} & \sigma_{zz} \end{pmatrix}$$

Where σ: normal stress and τ: tangential stress (shear stress)

k-ε (k-epsilon) Turbulent Model

- The k-epsilon turbulence model uses turbulent flow analysis characterized by the field of fluctuation velocity. This turbulent flow occurs due to high velocity flow and irregular movement of fluid particles, thus causing turbulence or unregulated effects. Many mixed fluctuations on the move such as momentum, energy, and concentration species have caused moving speed also to fluctuate. The K-Epsilon model adds two transport equations, which are based on k and ε variables . Equations with variable k ie,

$$\rho \frac{Dk}{Dt} = \frac{\partial}{\partial x_i}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_i}\right] + G_k + G_b - \rho\epsilon - Y_M$$

Boundary Conditions:

- The outer wall of the mesh is kept stationary whereas the complete volume is rotated.
- The height of the head is varied to get the required power output.
- The rotational velocity of the blade is set at 25 rpm.
- The flow occurs in the positive z direction in this model from inlet to outlet. The inlet is assumed to have uniform flow across the surface.
- The volume flow rate at inlet is 1.13 l/s.
- The outlet boundary condition is zero pressure. Assuming that water at the outlet will be in contact with the atmosphere, the outlet pressure is considered as atmospheric.
- Fluid Viscosity is 0.001003 kg/ms
- Fluid Density, ρ is 998.2 kg/m3
- Solid (aluminum) Density, ρ 27.00 kg/m^3

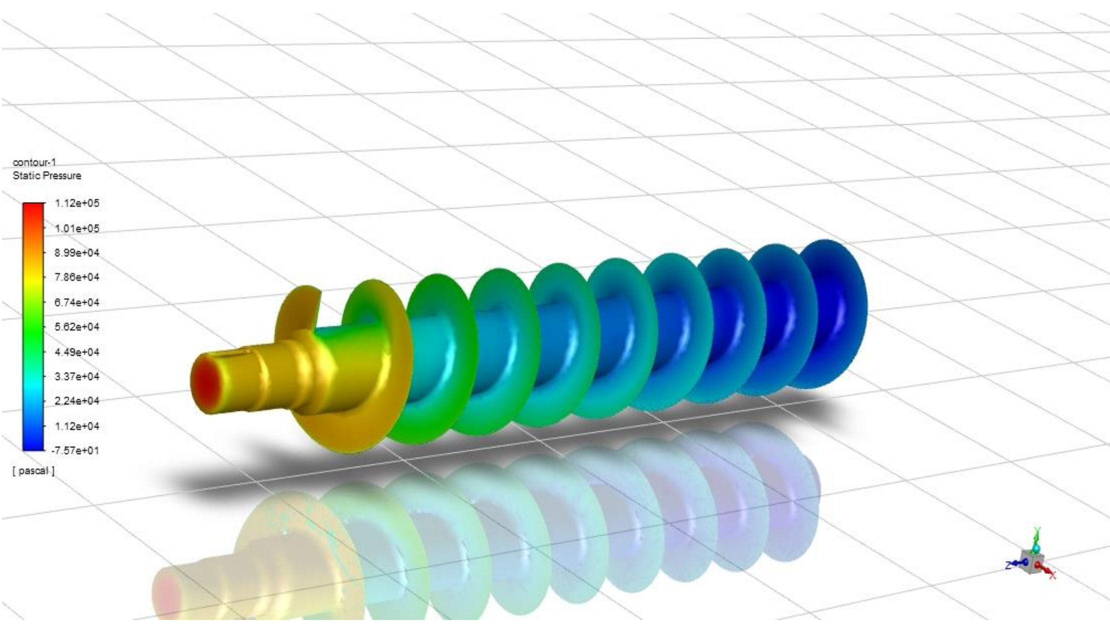


FIG 4.3.1 CFD MODEL OF SCREW BLADE

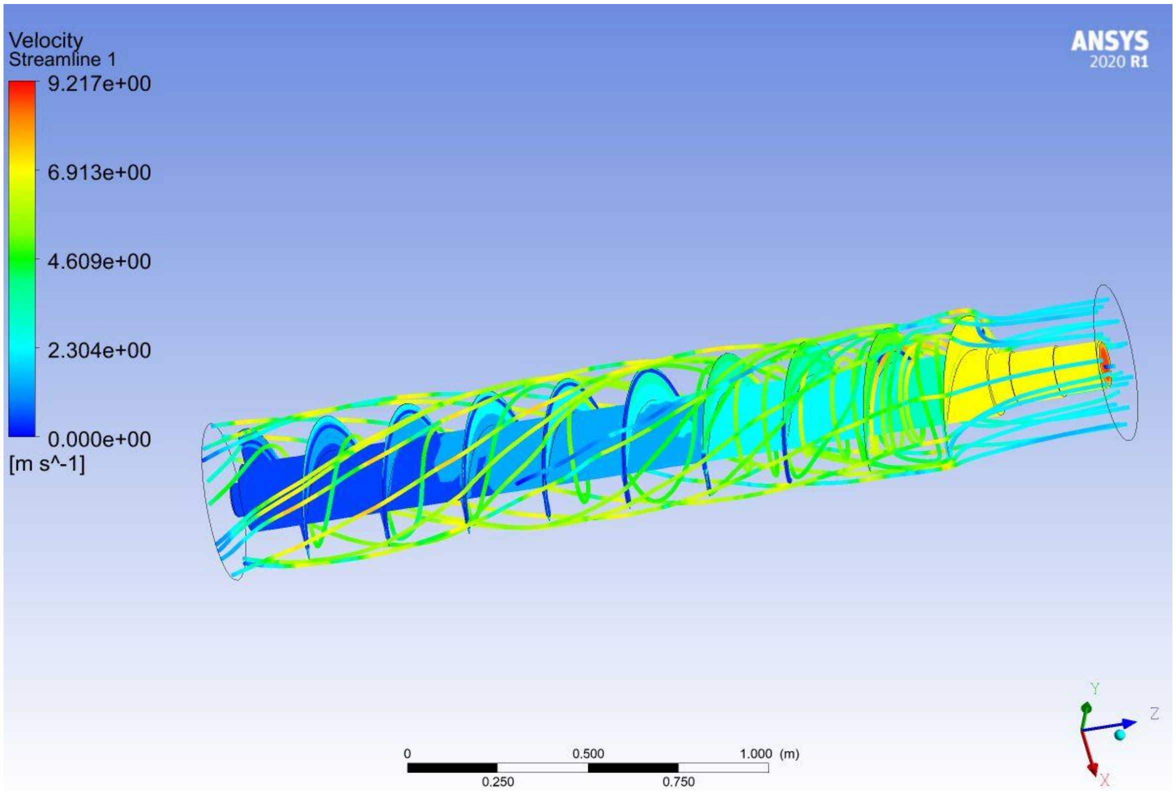


FIG 4.3.2 VELOCITY CONTOUR OF SCREW BLADE

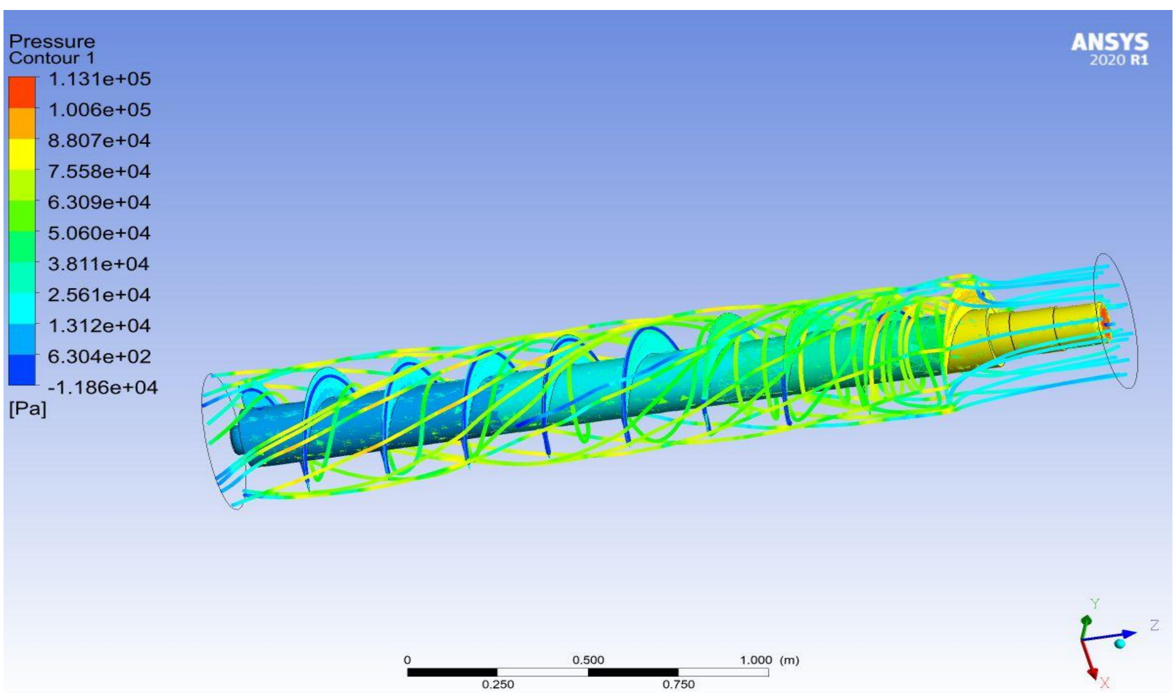


FIG 4.3.3 PRESSURE CONTOUR OF SCREW BLADE

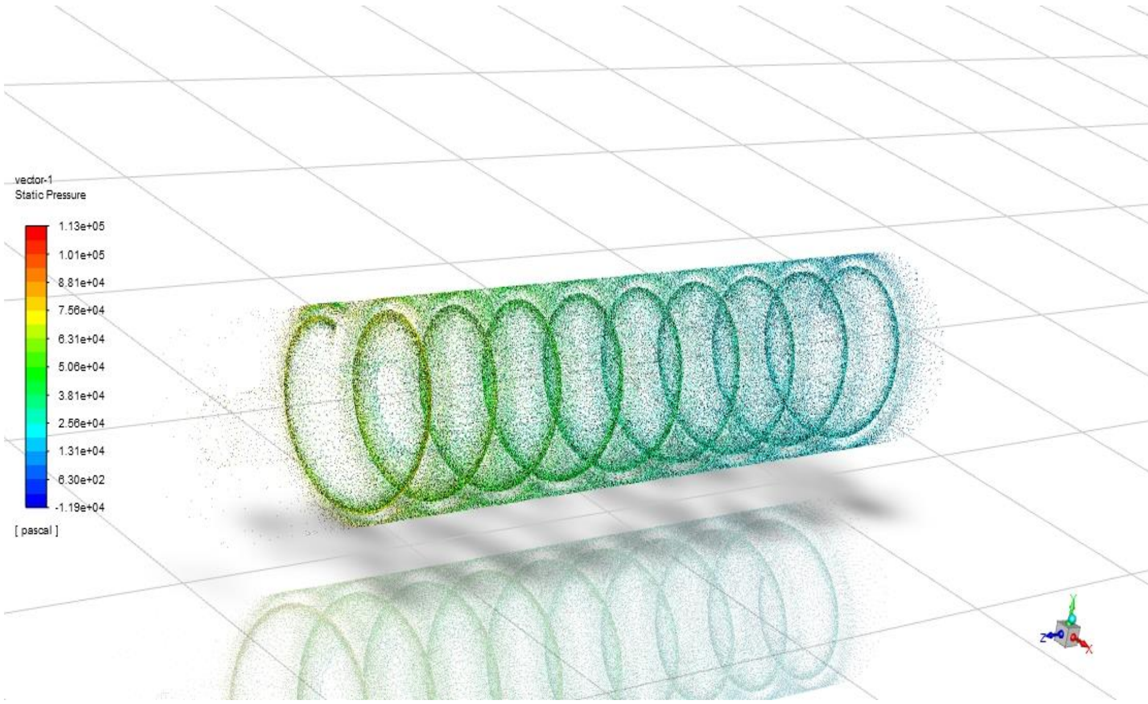


FIG 4.3.4 STATIC PRESSURE CONTOUR OF SCREW BLADE

CFD RESULTS

- The computaional fluid analysis of the spiral blade has been performed using ANSYS FLOW workbench.
- The results have been obtained and tabulated in a table as shown below.

Test Number	Head difference	Torque Value (Nm)	Power (W)
1	0.2	1.4359	3.7592
2	0.4	2.8599	7.482
3	0.6	4.2697	11.178
4	0.8	5.6704	14.845
5	1	7.0788	18.532
6	1.2	8.4974	22.246

FIG 4.3.5 TABLE SHOWING VARIATION OF POWER WITH HEAD

- The power of the turbine can be given as ,

  P(Wt)=2πNT/60

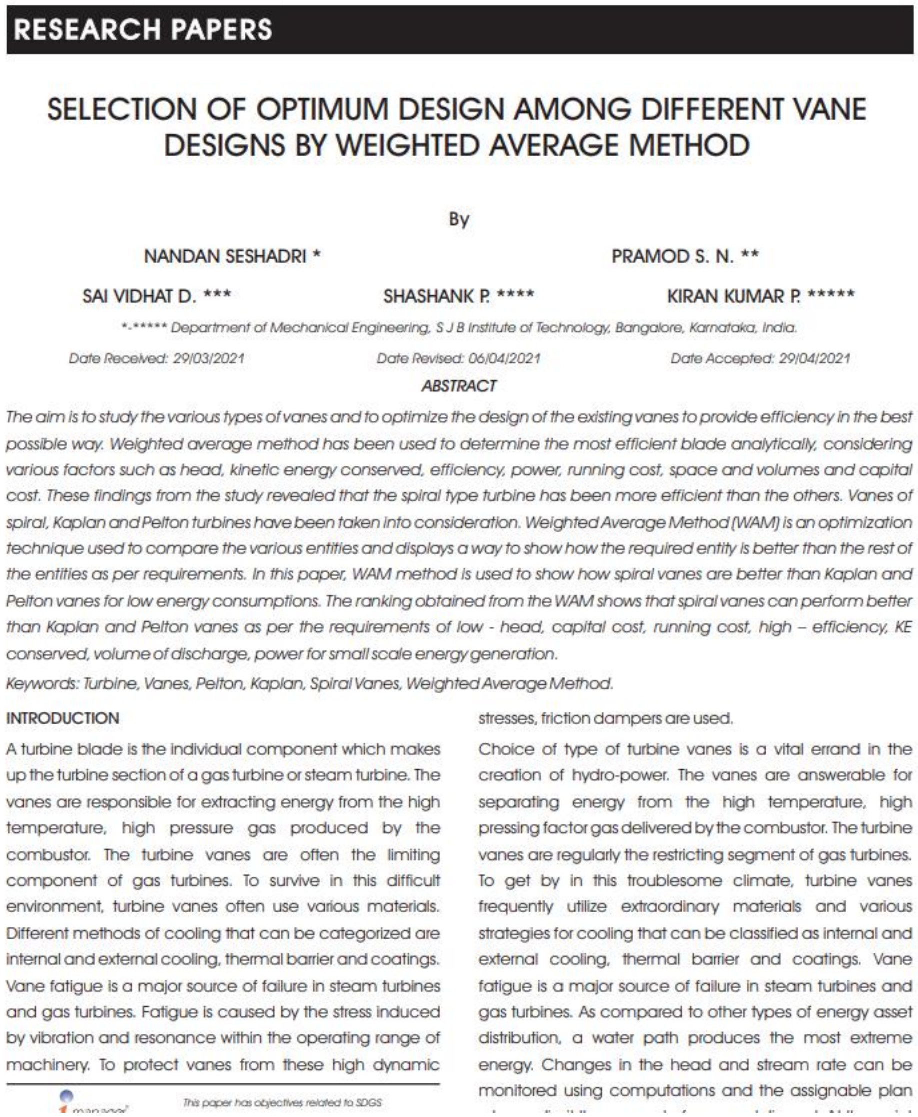
  Where P=power in watts

  N=speed in RPM

  T=torque in N/m s

- The results are obtained suggests that the design of the spiral turbine is well suatable for the purpose of micro-size power production.

4.4 PUBLICATION OF RESEARCH PAPER



RESEARCH PAPERS

SELECTION OF OPTIMUM DESIGN AMONG DIFFERENT VANE DESIGNS BY WEIGHTED AVERAGE METHOD

By

NANDAN SESHADRI * PRAMOD S. N. **

SAI VIDHAT D. *** SHASHANK P. **** KIRAN KUMAR P. *****

*-***** Department of Mechanical Engineering, S J B Institute of Technology, Bangalore, Karnataka, India.

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ABSTRACT

The aim is to study the various types of vanes and to optimize the design of the existing vanes to provide efficiency in the best possible way. Weighted average method has been used to determine the most efficient blade analytically, considering various factors such as head, kinetic energy conserved, efficiency, power, running cost, space and volumes and capital cost. These findings from the study revealed that the spiral type turbine has been more efficient than the others. Vanes of spiral, Kaplan and Pelton turbines have been taken into consideration. Weighted Average Method (WAM) is an optimization technique used to compare the various entities and displays a way to show how the required entity is better than the rest of the entities as per requirements. In this paper, WAM method is used to show how spiral vanes are better than Kaplan and Pelton vanes for low energy consumptions. The ranking obtained from the WAM shows that spiral vanes can perform better than Kaplan and Pelton vanes as per the requirements of low - head, capital cost, running cost, high – efficiency, KE conserved, volume of discharge, power for small scale energy generation.

Keywords: Turbine, Vanes, Pelton, Kaplan, Spiral Vanes, Weighted Average Method.

INTRODUCTION

A turbine blade is the individual component which makes up the turbine section of a gas turbine or steam turbine. The vanes are responsible for extracting energy from the high temperature, high pressure gas produced by the combustor. The turbine vanes are often the limiting component of gas turbines. To survive in this difficult environment, turbine vanes often use various materials. Different methods of cooling that can be categorized are internal and external cooling, thermal barrier and coatings. Vane fatigue is a major source of failure in steam turbines and gas turbines. Fatigue is caused by the stress induced by vibration and resonance within the operating range of machinery. To protect vanes from these high dynamic stresses, friction dampers are used.

Choice of type of turbine vanes is a vital errand in the creation of hydro-power. The vanes are answerable for separating energy from the high temperature, high pressing factor gas delivered by the combustor. The turbine vanes are regularly the restricting segment of gas turbines. To get by in this troublesome climate, turbine vanes frequently utilize extraordinary materials and various strategies for cooling that can be classified as internal and external cooling, thermal barrier and coatings. Vane fatigue is a major source of failure in steam turbines and gas turbines. As compared to other types of energy asset distribution, a water path produces the most extreme energy. Changes in the head and stream rate can be monitored using computations and the assignable plan

This paper has objectives related to SDGS

FIG 4.4.1 AN OVERVIEW OF RESEARCH PAPER

- A review paper based on the selection of the most suitable blade design using weighted average method among the different vane designs has been published.
- The review paper has been published in the i-Manager's Journal of Mechanical Engg. Website.
- The title of the review paper is as follows **"SELECTION OF OPTIMUM DESIGN AMONG DIFFERENT VANE DESIGNS BY WEIGHTED AVERAGE METHOD".**

CHAPTER 5:

CONCLUSION

The spiral vanes are selected based on the conclusion drawn from the literature survey and by using weighted averaged method. The spiral vane are very efficient for low cost, low maintenance applications and as well as play a vital role in domestic purposes as running water of high kinetic energy isn't required to get the blades running to generate power from the generator attached the blades. The design and analysis of the spiral vane has been completed. The design of the spiral blade is done using SOLIDWORKS and the CFD simulation for various flow conditions are shown using ANSYS software.

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Project Phase II Outcomes

Course outcome defines what students will be capable of doing after acquiring the knowledge or skills on successful completion of this course

CO. No.	**Description of Course Outcomes** On successful completion of the course students will be able to;	**PO & PSO Mapped**
CO1	Review the research literature, identify and analyse the complex engineering problems, formulate the sustainable conclusions or solutions using the basic principles of applied mathematics, science and engineering	PO1, PO2, PSO1
CO2	Design proper methodology to derive the solutions for the existing or anticipated complex engineering problems in concern with the issues of public health, safety, societal, cultural and environmental areas	PO3 PSO1
CO3	actice and establish the professional engineering methodology for sustainable development in the society to address the complex engineering problems associated with societal and environmental factors	PO6, PO7
CO4	Form internal and external group to work together as a team in the project under consideration under multi-disciplinary settings	PO9
CO5	Communicate effectively addressing the complex engineering activities with documentation, reports and proper presentation tools	PO10

PROGRAM EDUCATIONAL OBJECTIVES	
PEO1	Progress their career as a **professional** in mechanical engineering and interdisciplinary fields.
PEO2	Become successful **entrepreneur** with **social responsibilities** and **ethical values.**
PEO3	Pursue **higher education** and involve in **research** of allied areas in mechanical engineering.

PROGRAM OUTCOMES	
PO1	**Engineering knowledge:** Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
PO2	**Problem analysis:** Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
PO3	**Design/development of solutions:** Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.
PO4	**Conduct investigations of complex problems:** Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
PO5	**Modern tool usage:** Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.
PO6	**The engineer and society:** Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
PO7	**Environment and sustainability:** Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
PO8	**Ethics:** Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO9	**Individual and team work:** Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO10	**Communication:** Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.
PO11	**Project management and finance:** Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
PO12	**Life-long learning:** Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change
PROGRAM SPECIFIC OUTCOMES	
PSO1	Apply the Knowledge & Skill of Mechanical Engineering on Design, Manufacturing and Thermal platforms to address the real-life problem of the society.
PSO2	Design and implement new ides with the help of CAD/CAM and Industrial Automation tools.

College Vision

To become a recognized technical education center with global perspective.

College Mission

To provide learning opportunities that fosters students' ethical values, intelligent development in science and technology and social responsibility so that they become sensible and contributing members of the society.

Department Vision

To become a center of excellence and a platform in diversified fields for the aspirants in Mechanical Engineering.

Department Mission

- To impart comprehensive education in the field of Mechanical Engineering to produce highly accomplished graduates
- To endow technical & soft skill trainings to foster professionalism and ethical values among students
- To induce innovative thinking among students through projects and research work