Design And Fabrication Of Flapping Panel Horizntal Axis Magnus Wind Turbine For Power Generation

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Abstract-

In a developing nation like India, electricity has become one of the most important basic needs nowadays. Coal and gasoline based power generation capacity stands at 71% in India, which contributes to a considerable part of air pollution. There are various renewable energy sources which are pollution free, one among them is the wind energy. So the main objective of the project is to facilitate pollution free power generation for individual purpose. In order to understand the problem and working, a horizontal axis wind turbine is introduced. The advantage of using a magnus wind turbine over a conventional wind turbine is that, the turbine has ability to produce power at lower wind velocities. The magnus wind turbine is designed using solidworks software and analysed using ansys tools. The blades are attached to the shaft and the rotor is connected to the permanent magnet electricity generator (PMG). The PMG converts the Kinetic energy of the rotor shaft into electrical energy.

Keywords—Turbine, Magnus, Renewable energy, Power generation

INTRODUCTION

A wind turbine converts the wind's kinetic energy into electrical energy. Wind turbines are manufactured in a wide range of vertical and horizontal axis. The smallest turbines are used for applications such as battery charging for auxiliary power for boats or caravans or to power traffic warning signs. Larger turbines can be used for making contributions to a domestic power supply while selling unused power back to the utility supplier via the electrical grid. Arrays of large turbines known as wind farms are becoming an increasingly important source of intermittent renewable energy and are used by many countries as part of a strategy to reduce their reliance on fossil fuels. One assessment claimed that as of 2009, wind had the "lowest relative greenhouse gas emissions, the least water consumption demands and the most favorable social impacts" compared to photovoltaic, hydro, geothermal, coal and gas.

WORKING PRINCIPLE OF WIND TURBINE

There is an air turbine of large blades attached on the top of a supporting tower of sufficient height. When wind strikes on the turbine blades, the turbine rotates due to the design and alignment of rotor blades. The shaft of the turbine is coupled with an electrical generator. The output of the generator is collected through electric power cables.

When the wind strikes the rotor blades, blades start rotating. The turbine rotor is connected to a high-speed gearbox. Gearbox transforms the rotor rotation from low speed to high speed. The high-speed shaft from the gearbox is coupled with the rotor of the generator and hence the electrical generator runs at a higher speed. An exciter is needed to give the required excitation to the magnetic coil of the generator field system so that it can generate the required electricity. The generated voltage at output terminals of the alternator is proportional to both the speed and field flux of the alternator. The speed is governed by wind power which is out of control

. Hence to maintain uniformity of the output power from the alternator, excitation must be controlled according to the availability of natural wind power. The exciter current is controlled by a turbine controller which senses the wind speed. Then output voltage of electrical generator (alternator) is given to a rectifier where the alternator output gets rectified to DC. Then this rectified DC output is given to line converter unit to convert it into stabilized AC output which is ultimately fed to either electrical transmission network or transmission grid with the help step up transformer. An extra units is used to give the power to internal auxiliaries of wind turbine (like motor, battery etc.), this is called Internal Supply Unit.

There are other two control mechanisms attached to a modern big wind turbine.

- Controlling the orientation of the turbine blade.
- Controlling the orientation of the turbine face.

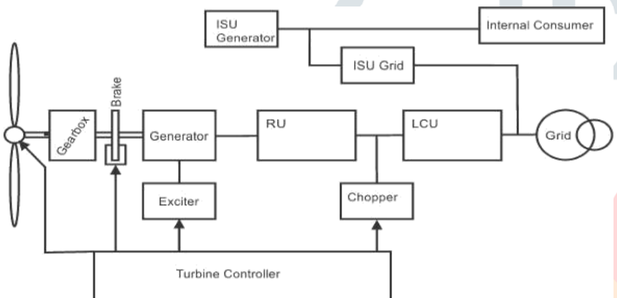

Figure 1.1 An Internal Block Diagram of a Wind Turbine

HORIZONTAL AXIS WIND TURBINE

Horizontal axis wind turbine (HWAT) have the main rotor shaft and electrical generator at the top of the tower , and may be pointed into or out of the wind. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator.

The orientation of turbine blades is governed from the base hub of the blades. The blades are attached to the central hub with the help of a rotating arrangement through gears and small electric motor or hydraulic rotary system. The system can be electrically or mechanically controlled depending on its design. The blades are swiveled depending upon the speed of the wind. The technique is called pitch control. It provides the best possible orientation of the turbine blades along the direction of the wind to obtain optimized wind power.

The orientation of the nacelle or the entire body of the turbine can follow the direction of changing wind direction to maximize mechanical energy harvesting from the wind. The direction of the wind along with its speed is sensed by an anemometer (automatic speed measuring devices) with wind vanes attached to the back top of the nacelle. The signal is fed back to an electronic microprocessor-based controlling system which governs the yaw motor which rotates the entire nacelle with gearing arrangement to face the air turbine direct along the direction of wind.

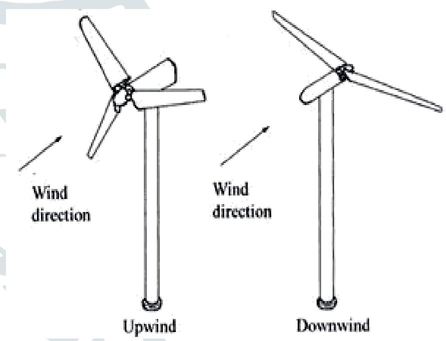

Figure 1.2 Flow of Wind

LITERATURE SURVEY

A literature survey was made on the various construction techniques that have been used in the construction of Wind turbines. Some of the surveys have been listed below.

1. Giudice and La Rosa, have presented a MWT prototype that is also developed MWT prototype utilizes 4 smooth surface rotating cylinder blades and it is designed to harvest energy from water channels like drainage and irrigation. They have concluded that the Chiral Rotor prototype has a great prospect toward hydroelectricity as an alternative to wind energy harvester. shows the Chiral Rotor prototype with 4 short rotating cylinder blades. Moreover, they emphasize that, the Chiral Rotor prototype use smooth surface on the cylinder blades due to the absence of knowledge and research regarding the surface roughness effect on rotating cylinder blades. Meanwhile, It have investigated a prospect of 3 cylinder blades shaped like Savonius wind turbine with endplates and concluded it as one of the possible combinations.

2. N M Bychkov, A V Dovgal and V V Kozlov, have clearly presented a research about The Magnus force, occurring on a rotating cylinder due to asymmetry of flow separation from its surface, may be an order of magnitude higher than lift of a blade. Thus, in the case of Magnus WT, one expects the increased driving force of the windwheel as well as other operational benefits.

3. Robert E. Akins, Dale E. Berg, W. Tait Cyrus, he conducted a research about the blades of magnus wind turbine There are several shortcomings of traditional blade turbines which are presently used. The major of them is their low efficiency at the most repeatable wind velocities V < 6 to 7 m/s that is due to small lift coefficient of a blade, Cy ≤ 1. Under such conditions, the power coefficient of WT drops rapidly to zero at about V = 4 m/s On the other hand, the Magnus WTs can be exploited in a wide range of wind velocities, that is, from 2 to 40 m/s instead of 5 to 25 m/s acceptable for the blade turbines. A reduced rotation velocity of the Magnus wind wheel which is 2 – 3 times lower comparing to the blade one ensures its high ecological and operational safety. Also, an advantage of the Magnus WT is aerodynamic self-regulation of the wind wheel rotation preventing from its excessive spin up and destruction due to centrifugal forces. In particular, at wind velocities higher than about 35 m/s, the self-regulation results in diminution of the Magnus force with the wind wheel self-braking. Several attempts to design WTs on the Magnus effect have been undertaken since 1924 – 1926 (Flettner, Kazhinsky, etc.) [1]. In 1929 – 1934 a project of high-capacity WT "Madaras" was developed [2]. By several reasons, these projects were not completed. The first actual WT on the Magnus effect with a non-optimal number of cylinders i = 3 at their aspect ratio λ = 6 was constructed in the USA, 1984, the wind wheel design being similar to that of traditional blade WTs. The studies on Magnus WT in the Institute of Theoretical and Applied Mechanics SB RAS were focused, at first, on aerodynamics of high-aspect-ratio (up to λ = 40) rotating axis symmetric bodies and cylinders. Afterwards, aerodynamic characteristics of WTs with the aspect ratio of rotating cylinders λ = 3.5 - 10.7 [3, 4], λ = 11.5 and 14 were examined in details. As a result, it was found that the efficiency of WT gets higher with growth of λ and i. Also, it was shown that the maximum power coefficient of the Magnus WT can be achieved starting from V = 1 to 2 m/s instead of V close to 8 m/s for the blade turbines, thus, increasing daily operation of the WT and power production.

4. M. Ragheb, his research was based on the wind tunnel tests The experimental runs were performed in T-324 wind tunnel of the Institute of Theoretical and Applied Mechanics SB RAS. The WT model was mounted in 3.6 x 3.6 m and 2.1 x 2.1 m cross sections of the facility at the oncoming flow velocities up to 4.5 m/s and 15 m/s, respectively. The wind wheel diameter varied as D = 1.26, 1.9 and 2.0 meters at the diameter d of rotating cylinders in the range from 0.05 to 0.09 meters. The cylinders were equipped with end plates as large as ds = 2d, that is, at their relative diameter C = 2. The number of cylinders which were set into rotation up to 8000 rpm individually by electric motors was in the range from i = 2 to 6. Isolated rotating cylinders with d = 0.15 m were examined in 1 x 1 m test section of the wind tunnel at V = 10 to 70 m/s and the oncoming-flow turbulence level ε = 0.04 %.configuration and their kinematic characteristics as well as on the operational range of wind velocity.

5. Marzuki et al, have investigated the torque performance impact of sandpaper surface roughness types on MWT with 5 rotating cylinder blades. The finding highlights that, as the surface 5 AEROTECH VII - Sustainability in Aerospace Engineering and Technology IOP Publishing IOP Conf. Series: Materials Science and Engineering 405
(2018) 012011 doi:10.1088/1757-899X/405/1/012011 roughness is changed from smooth to rough sandpaper, the torque produced by the MWT significantly increases up to 5 times compared to that with smooth surface. The MWT model without and with sandpaper enhancement inside wind tunnel. Meanwhile, researchers Sakipova et al. [12, 30] have investigated the performance of MWT with porous surface roughness with 3 cylinder blades and later on with 2 cylinder blades as shown in Figure 8. In an analysis of the effect of porosity surface on the rotating cylinder, Kussaiynov et al.
[31] have found that it gives a notable improvement of lift force around 1.5 times in comparison to the smooth surface cylinder.

6. A. Massaguer, E. Massaguer, T. Pujol, M. Comamala, and J. Velayos, have researched about the impact and effect of Magnus wind turbine uses rotating cylinders instead of conventional horizontal axis blades. These cylinders rotate around their own axes and create a rotational force according to Magnus effect. Although this kind of wind turbines have many benefits over conventional axis blades and can exhibit different blade characteristics, it is not clearly demonstrated which the most efficient blade geometry is. This paper focuses on assess the influence of the blade shape on the Magnus force, using particle image velocimetry.

7 Shivprakash Bhagwatrao Barve, through his research he found out that, High rotor efficiency is desirable for increased wind energy extraction and should be maximized within the limits of affordable production. Energy carried by moving air is expressed as a sum of its kinetic energy. The magnitude of energy harnessed is a function of the reduction in air speed over the turbine. 100% extraction would imply zero final velocity and therefore zero flow. The zero flow scenario cannot be achieved hence all the winds kinetic energy may not be utilised. This principle is widely accepted and indicates that wind turbine efficiency cannot exceed 59.3%. This parameter is commonly known as the power coefficient Cp, where max Cp = 0.593 referred to as the Betz limit. The Betz theory assumes constant linear velocity. Therefore, any rotational forces such as wake rotation, turbulence caused by drag or vortex shedding will further reduce the maximum efficiency.

MAGNUS WIND TURBINE

Magnus wind turbine uses rotating cylinders instead of conventional horizontal axis blades. These cylinders rotate around their own axes and create a rotational force according to Magnus effect .Magnus wind turbines can overcome most of existing turbines limitations used nowadays, such its low efficiency at the most repeatable wind velocities V < 7 m/s due small blade lift coefficient. Under such conditions, the power coefficient of traditional wind turbines drops rapidly to zero at about V = 4 m/s. On the other hand, the Magnus wind turbines can be exploited in a wide range of wind velocities, that is, from 2 m/s to storm winds. It is one of the cheapest and most abundant sources of renewable energy. On the other hand, the energy density is small, since the power generated is dependent on the size of the turbine, the wind direction and wind speed. However It is one of the cheapest and most abundant sources of renewable energy.

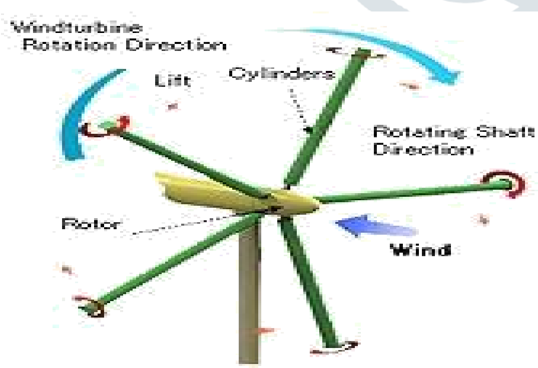

Figure 3.1 Magnus Wind Turbine

MAGNUS EFFECT

The Magnus effect is named after Heinrich Gustav Magnus, the German physicist who investigated it. The force on a rotating cylinder is known as Kutta–Joukowski lift, after Martin Kutta and Nikolai Zhukovsky (or Joukowski), who first analyzed the effect.German physicist, Magnus, described the effect in 1852.However, in 1672, Isaac Newton had described it and correctly inferred the cause after observing tennis players in his Cambridge college.In 1742, Benjamin Robins, a British mathematician, ballistics researcher, and military engineer, explained deviations in the trajectories of musket balls in terms of the Magnus effect.The magnus effect is an observable phenomenon that is commonly associated with a spinning object moving through a fluid. The path of the spinning object is deflected in a manner that is not present when the object is not spinning. The deflection can be explained by the difference in pressure of the fluid on opposite sides of the spinning object.

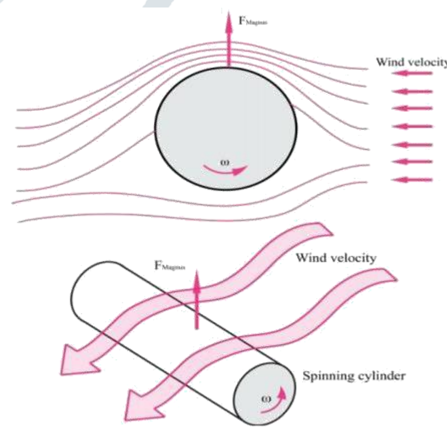

Figure 3.2 Magnus Effect on Cylindrical Object

PHYSICS BEHIND MAGNUS EFFECT

An intuitive understanding of the phenomenon comes from Newton's third law, that the deflective force on the body is a reaction to the deflection that the body imposes on the air-flow. The body "pushes" the air in one direction, and the air pushes the body in the other direction. In particular, a lifting force is accompanied by a downward deflection of the air-flow. It is an angular deflection in the fluid flow, at of the body.

FLETTNER ROTOR SHIP

A rotor ship is a type of ship designed to use the Magnus effect for propulsion. The ship is propelled, at least in part, by large vertical rotors, sometimes known as rotor sails. German engineer Anton Flettner was the first to build a ship which attempted to tap this force for propulsion, and ships

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using his type of rotor are sometimes known as flettner ship.

PRINCIPLE OF OPERATION

A rotor or Flettner ship is designed to use the Magnus effect for propulsion. A Magnus rotor used to propel a ship is called a rotor sail and is mounted with its axis vertical. When the wind blows from the side, the Magnus effect creates a forward thrust. Thus, as with any sailing ship, a rotor ship can only move forwards when there is a wind blowing. Due to the arrangement of forces, a rotor ship is able to sail closer to the wind than a conventional sailing ship. Other advantages include the ease of control from sheltered navigation stations and the lack of furling requirements in heavy weather.

However if the ship changes tack so that the wind comes from the other side, then the direction of rotation must be reversed or the ship would be driven backwards. The wind does not power the rotor itself, which must have its own power source to spin it up. Like other sailing ships, rotor ships often have a small conventional propeller as well, to provide ease of manoeuvrability and forward propulsion at slow speeds and when the wind is not blowing or the rotor is stopped. In a hybrid rotor ship the propeller is the primary source of propulsion, while the rotor serves to offload it and thus increase overall fuel economy.

Figure 3.3 Flettner

Ship FLETTNER AIRPLANE

A flettner planeis a type of rotor airplane which uses a Flettner rotor to provide lift. The rotor comprises a spinning cylinder with circular end plates and, in an aircraft, spins about a spanwise horizontal axis. When the aircraft moves forward the Magnus effect creates lift.Anton Flettner, after whom the rotor is named, used it successfully as the sails of a ship. He also suggested its use as a wing for a rotor airplane.

The Butler Ames Aerocycle was built in 1910 and tested on board a warship. There is no record of it having flown. The Plymouth A-A-2004 was built for Zaparka in 1930 by three anonymous American inventors, and was reported to have made successful flights over Long Island Sound.

An inherent safety concern is that if power to the rotating drums was lost—even if thrust was maintained—the aircraft would lose its ability to generate lift as the drum slowed down and it would not be able to sustain flight.

DESIGN AND ANALYSIS OF HORIZONTAL AXIS MAGNUS WIND TURBINE

4.1 SOFTWARE USED FOR DESIGNING – SOLIDWORKS

SolidWorks is a solid modeller, and utilizes a parametric feature-based approach which was initially developed to create models and assemblies. Building a model in SolidWorks usually starts with a 2D sketch. The sketch consists of geometry such as points, lines, arcs, conics, and splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity, and concentricity.

In an assembly, the analog to sketch relations are mates. Just as sketch relations define conditions such as tangency, parallelism, and concentricity with respect to sketch geometry, assembly mates define equivalent relations with respect to the individual parts or components, allowing the easy construction of assemblies. Finally, drawings can be created either from parts or assemblies. Views are automatically generated from the solid model, and notes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes.

4.2 DESIGN CALCULATION

- The wind turbine works on the principle of converting kinetic energy of the wind to mechanical energy. The kinetic energy of any component is given by,

$$K.E=½mv^2$$

- Where m, mass = volume * density. m= ρAv
- V, velocity of wind in m/s.
- The power of the wind turbine can be calculated by,

$$P= ½ρAV^3$$

- For 100 Watt power, calculating the design parameters of turbine,

P= 100 watts.

$P= \frac{1}{2}\rho AV^3$

- V, assuming wind velocity 5 m/s
- ρ, Density of air (1.225 kg/m3)
- $P= \frac{1}{2}\rho AV^3$

$100 = \frac{1}{2} X 1.125 X A X (5)^3$

- On solving the above equation,

$A= 1.5m^2$

$A = D X H (m^2)$

- D= diameter of the blade
- Taking diameter as 1 meter, height of turbine can be calculated as,

H= A/D = 1.5/1 = 1.5m

H =1.5m; D=1m

Design of shaft:

Length of shaft = 500mm

Diameter of shaft = 20mm

Shear stress = 32Mpa

Torque T = $(\pi/16) X d^3 X \zeta$

Torque T = $\frac{\pi}{16} X (20)^3 X (32)$

Torque T = 50.265 KN-mm

Turbine design calculations

Power =1/2 X ρ X A X u^3 X η

Power = 0.5 X 1 X 500 X 10^{-3} X 500 X 10^{-3} X4^3X1

Power = 8W

Speed of rotation N= (Velocity X 60) / (radius X 2π)

Speed of rotation N= (4 X 60) / (0.5 X 2 π)

Speed of rotation N = 76.39 rpm Angular Velocity ω =u / R Angular velocity ω = 4/ 0.5

Angular Velocity ω = 8 rad/s

Resultant blade velocity $V_R=\sqrt{(r\ \omega \sin \Theta)^2 + (r\ \omega \cos \Theta + u_x)^2}$

$V_R=\sqrt{(0.5 X 8 X \sin 60^0)^2 +[(0.5 X 8 X \cos 60^0)+ (2.608)]^2}$

Resultant blade velocity V_R= 5.76 m/s

4.3 PART MODELLING

4.3.1 MODELLING OF BLADE

The blade is modelled according to the dimensions using "solidworks" software.

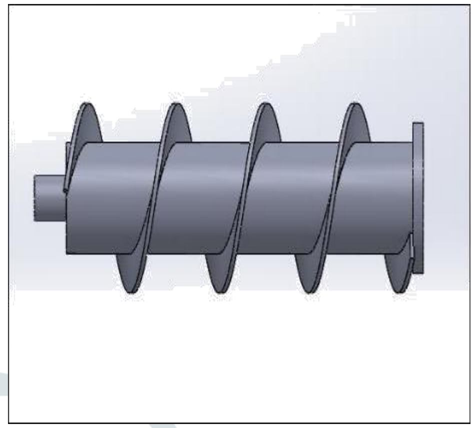

Figure4.1 Modelling of BLADE

4.3.2 FRAME

The frame is the important part to keep the blades and rotor in place. This frame is designed or modelled according to the required dimensions using "solidworks" software.

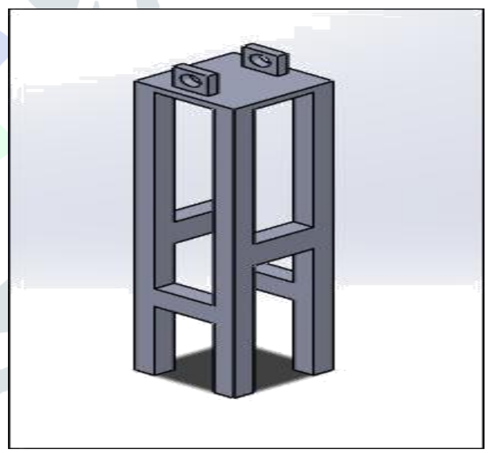

Figure 4.2 Frame

4.3.3 MODELLING OF ROTOR

The rotor is the important part to keep the blades in place. This frame is designed or modelled according to the required dimensions using "solidworks" software.

4.3.6 ASSEMBLING OF TURBINE BLADES AND THE FRAME

The frame is kept as base and all other parts such as shaft, bearings, blades and connecting

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rod and blade tip pin are assembled according to the required model.

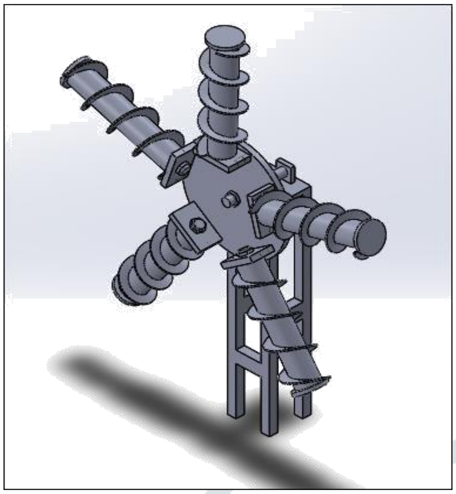

Figure 4.3 Assembling of Turbine blades and frame

4.4 SOFTWARE USED FOR ANALYSIS – ANSYS FLUENT

Ansys is an American based software development company, which develops engineering simulation software. Ansys software is used to design products and semiconductors, as well as to create simulations that test a product's durability, temperature distribution, fluid movements, and electromagnetic properties. Most Ansys simulations are performed using the Ansys Workbench software, which is one of the company's main products. Typically Ansys users break down larger structures into small components that are each modeled and tested individually. A user may start by defining the dimensions of an object, and then adding weight, pressure, temperature and other physical properties. Finally, the Ansys software simulates and analyses movement, fatigue, fractures, fluid flow, temperature distribution, electromagnetic efficiency and other effects over time.

Fluent software contains the broad, physical modeling capabilities needed to model flow, turbulence, heat transfer and reactions for industrial applications. These range from air flow over an aircraft wing to combustion in a furnace, from bubble columns to oil platforms, from blood flow to semiconductor manufacturing and from clean room design to wastewater treatment plants. Fluent spans an expansive range, including special models, with capabilities to model in-cylinder combustion, aero-acoustics, turbomachinery and multiphase systems. Fluent also offers highly scalable, high-performance computing (HPC) to help solve complex, large-model computational fluid dynamics (CFD) simulations quickly and cost-effectively.

4.4.1 VELOCITY FLOW ANALYSIS

The velocity flow analysis has been made for the blade considering the average velocity between o to 5m/s.

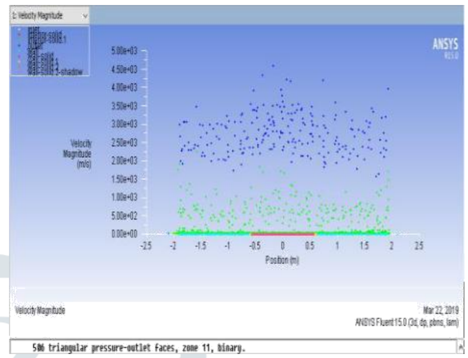

Figure 4.4 Velocity Magnitude graph

4.4.2 PRESSURE FLOW ANALYSIS

The pressure flow analysis for the blade is performed using the ansys fluent software, for the boundary condition of $1.015X10^5$ Pascal and temperature 310K.

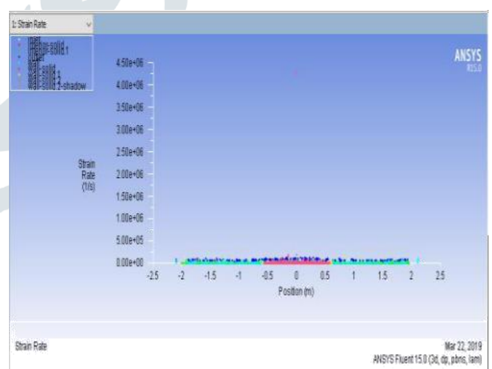

Figure 4.5 Strain rate

FABRICATION OF THE HORIZONTAL AXIS WIND MAGNUS WIND TURBINE

5.1 MATERIALS USED

5.1.1 MILD STEEL: Mild steel, also known as plain-carbon steel and low-carbon steel, is now the most common form of steel because its price is relatively low while it provides material properties that are acceptable for many applications. It is iron containing a small percentage of carbon, strong and tough but not readily tempered. Mild steel contains approximately 0.05–0.25% carbon making it malleable and ductile. Mild steel has a relatively low tensile strength, but it is cheap and easy to form; surface hardness can be increased through carburizing. .

5.1.1.2.1 MACHINING

The machinability of mild/low carbon steel is graded at 78%.

5.1.1.2.2 WELDABILITY

Mild/low carbon steel can be instantly welded by all the conventional welding processes. Welding is not recommended for AISI 1018 mild/low carbon steel when it is carbonitrided and carburized.

Low carbon welding electrodes are to be used in the welding procedure, and post-heating and pre-heating are not necessary. Pre-heating can be performed for sections over 50 mm. Post-weld stress relieving also has its own beneficial aspects like the pre-heating process.

5.1.2 GLASS FIBER

Glass fiber is a material consisting of numerous extremely fine fibers of glass. Glassmakers throughout history have experimented with glass fibers, but mass manufacture of glass fiber was only made possible with the invention of finer machine tooling. In 1893, Edward Drummond Libbey exhibited a dress at the World's Columbian Exposition incorporating glass fibers with the diameter and texture of silk fibers. Glass fibers can also occur naturally, as Pele's hair.

Glass wool, which is one product called "fiberglass" today, was invented in 1932–1933 by Russell Games Slayter of Owens-Corning, as a material to be used as thermal building insulation.Glass fiber has roughly comparable mechanical properties to other fibers such as polymers and carbon fiber. Although not as rigid as carbon fiber, it is much cheaper and significantly less brittle when used in composites. Glass fibers are therefore used as a reinforcing agent for many polymer products; to form a very strong and relatively lightweight fiber-reinforced polymer (FRP) composite material called glass-reinforced plastic (GRP), also popularly known as "fiberglass". This material contains little or no air or gas, is more dense, and is a much poorer thermal insulator than is glass wool.

5.1.2.1 ADVANTAGES AND LIMITATIONS

The advantages of fiber glass is that it could be easily be moulded into any shape, thus the mechanical strength that is so strong and stiff for its weight that it can out perform most of the other materials. Fibreglass last a long time,it can be coloured,shinny or dull.it is low maintenance,anti-magnetic,fire reistant,good electrical insulator and weatherproof. FRP allows the alignment of the glass fibres of thermoplastics to suit specific design programs. Specifying the orientation of reinforcing fibres can increase the strength and resistance to deformation of the polymer. Glass fibres are strongest and most resistive to deforming forces when the polymers fibres are parallel to the force being exerted, and are weakest when the fibres are perpendicular.

The disadvantages is that it needs to be re-gel coated about every five years and can result in airbrone fibres which may be an issue to asthma sufferers.Weak spots of perpendicular fibres can be used for natural hinges and connections, but can also lead to material failure when production processes fail to properly orient the fibres parallel to expected forces. When forces are exerted perpendicular to the orientation of fibres, the strength and elasticity of the polymer is less than the matrix alone.

5.3.8 FINAL ASSEMBLY OF THE TURBINE

Figure 5.1 Magnus Turbine

- Thus the blades, frame, and connecting rods are fabricated and assembled together.
- The blade has been kept in the top of the frame with a height of one meter.

CONCLUSION

It can reduce the dependence on fossil fuels further it helps us to have a pollution free environment. Decentralized system- suitable in rural areas and individual purposes. Can be used as backup systems during natural disasters and power cuts. The unique characteristics of magnus wind turbine is that it starts rotating even at low speeds, which makes this HAWT a better turbine when compared to others and also with its power obtained at any cause of rotation makes it perfect one for power generation. The blade pitch angle has a great influence on the self-starting behaviour of the turbine, higher values of the blade pitch angle are favorable for a low speed wind startingHence through these techniques, the HAWT is made to work at normal conditions of wind at 4 m/s and it produces an actual power of 8W at 76 rpm.Showcases the turbine as safe & successful turbine.

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