iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** VIII **Month of publication:** August 2019

DOI: http://doi.org/10.22214/ijraset.2019.8008

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue VIII, Aug 2019- Available at www.ijraset.com

Performance Study of Archimedes Spiral Wind Turbine using Numerical and Experimental Analysis

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Abstract: In our research_a comparative analysis for aerodynamic characteristics and performance of Horizontal axis wind turbine blade adopting Archimedes Spiral principle had done. The Horizontal axis wind turbine blade is designed based on variety of design blade configurations and shape factors. The performance of Horizontal axis wind turbine blade is dependent on geometrical blade design and wind speed. Both numerical approach and experimental approach is verified. Both analytical and experimental approach are in good deal with the applied design configurations. It is observed that the power produced by the wind turbine is good at low wind speeds and power production increases when wind speed increases and this design is adoptive for house hold usage applications and suitable for urban areas where wind speed is low and influence of pressure and velocity distributions contribute to workability of the turbine in future if further wind speed is increased.
Keywords: Archimedes spiral wind turbine, CFD ANSYS CFX, Field test, Acrylonitrile Butadiene Styrene (ABS), Power production.

I. INTRODUCTION

The electric power plays a vital role in everyday life by human beings on the earth. In fact without power human cannot survive now days. Non-renewable sources of energy are fossil fuels, oil, natural gas, coal and nuclear energy. Renewable sources of energy include solar energy, wind energy, hydropower, geothermal energy and biomass energy. Non-renewable sources of energy are depleting due to their incapability of regeneration because these energy takes millions of years to form which are dead and decay of living organisms. Renewable sources of energy are not depleting in fact they can be produced by climatic factors. Among the renewable sources of energy, wind energy is relatively highly ripen technology with excellent mass production in the areas of power [1]. This wind energy is being vitally made use by the wind turbines which are designed and fabricated by the engineers. These wind turbines are divided into various categories like Horizontal axis wind turbine (HAWT) and Vertical axis wind turbine (VAWT). HAWT uses lift force and VAWT uses drag force present in wind kinetic energy [2]. The Archimedes wind turbine is designed mainly from bases of Archimedes principle which is mainly dependent of angular momentum conservation law. By this principle it is proved that the angular momentum conservation law uses both lift force and drag force which increases efficiency in comparison with other wind turbines. These two forces act on blade which causes rotational motion which is optimum at 60 blade angle. The advantage of using Archimedes wind turbine is that rotor cut off speed is low as compared to the other type of wind turbine, so that it is suitable for city areas along with sea areas as such speed of wind is low in city areas. There have been lot of works been done on design of Horizontal axis wind turbine blade and produced maximum output power at different wind speeds, different papers use different software in to produce power and compared with the experimental conditions depending upon the equipment used. In previous papers comparison have been done between experimental and simulation such that both has firm agreement. In 2016, Sashank Chaudhary and Shubham Jaiswal designed an Archimedes wind turbine and concluded that the designed turbine suits for low areas and he set up a yawing mechanism to harness maximum amount of wind energy [3]. Dr S. Srinivasa Rao et. Al [1,2] has done comparative analysis and concluded that the torque obtained from AAWT blade is more at low and average wind speeds. In 2014, Kim and Ho Seong Ji has designed an Archimedes spiral blade based on angular momentum conservation law. The results obtained by the numerical and experimental coincided. The PIV measurement agreed with unsteady state than steady state simulation [11]. This work provides a detailed description of design of a new Archimedes spiral rotor blade of diameter 0.25 m and length of 0.27 m which is modeled in the CREO parametric 2.0 versions which is design software and the designed turbine blade is analysed using CFD based software ANSYS CFX in ANSYS WORKBENCH 16.2 version. The CFX is used to predict the aerodynamic characteristics like lift, drag, torque and power of the turbine.

II. DESIGN AND FABRICATION OF ARCHIMEDES SPIRAL WIND TURBINE

The design of the Archimedes wind turbine is done by CREO parametric in such a way that spiral shape has to be formed this is initially done by producing two motions about a point such that a uniform motion in a fixed direction and a motion in a circle with constant speed. Fig 1 representing Archimedean spiral wind turbine of diameter 0.25 m and length 0.27 m length

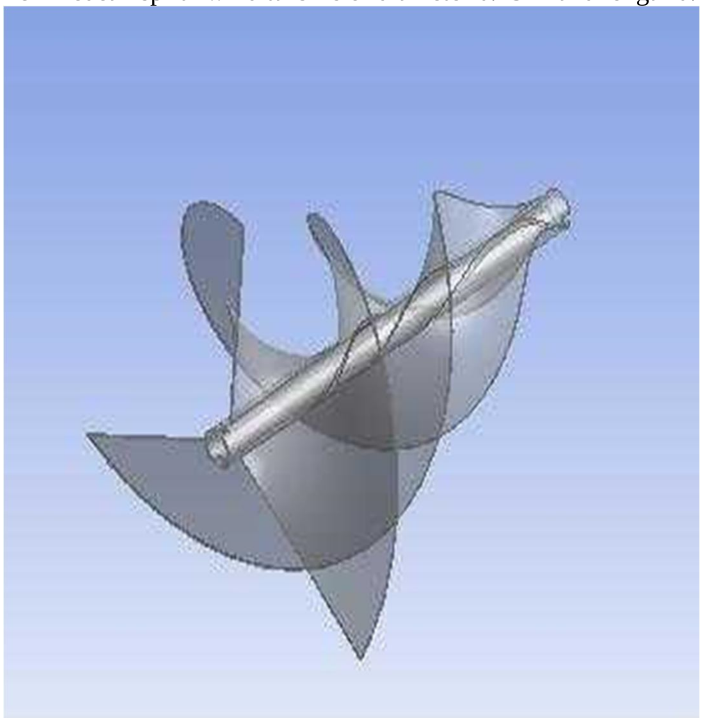

Fig 1 Archimedes spiral rotor blade

The material used for the turbine blade is ABS (Acrylonitrile Butadiene Styrene) which has high heat resistance, toughness and internal resistance. The shaft is assembled to the turbine blade in which its inner hole radius is 16 mm. The fabricated equipment is attached to the frame, base.

III. SIMULATION ANALYSIS AND EXPERIMENTAL ANALYSIS

A. Simulation Method

The analytical method is used here is CFD based ANSYS CFX and version is ANSYS Workbench 16.2. Usually this type of software is based on CFD and major application is solve problems that are encountered such as heat transfer, mass transfer and chemical reactions. The Reynolds Averaged Navier Stokes Equation (RANS) and finite volume method is based on CFX. Also CFX consists of various turbulence models such that SST k-ω and k-ε model which is a mere benefit for it such the two models such as k-ω represents k-turbulence kinetic energy and ω is the specific rate of dissipation and in k-ε represents such that k-turbulence kinetic energy and ε is the rate of dissipation of turbulent kinetic energy [1].

B. Mesh Generation

In CFD problems meshing is done which is usually defined as the tool which uses finite element method for finding the approximate solutions for the boundary value problems involving partial differential equations. FEM makes larger problem intosmaller and simpler parts called finite elements. The simpler equations which are responsible for the creation these finite elements are then assembled one by one into larger set of equations that model the entire problem. In finite element method multiple frames of reference is used to separate the rotary domain of spiral blade and stationary domain of imaginary wind tunnel. In our simulation meshing is generated and statistical results indicate that the stationary domain has 80223 nodes and 421073 elements and rotating domain has 12394 nodes and 40970 elements. The total domain of elements and nodes are 92617 nodes and 462043 elements.

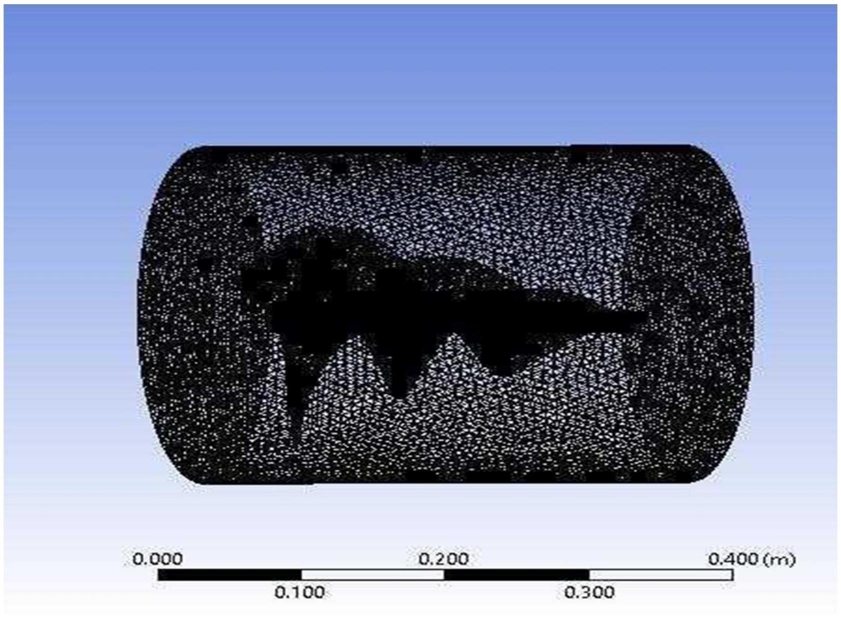

Figure 2 Meshing of Stationary and Rotating domain *3.1.2 Boundary Setup*

In ANSYS CFX analysis various conditions have been taken to predict power from the torque under different load conditions such as 50 grams, 100 grams, 150 grams and 200 grams. Various wind speed (m/s) and Turbine rotation (RPM) has been taken.

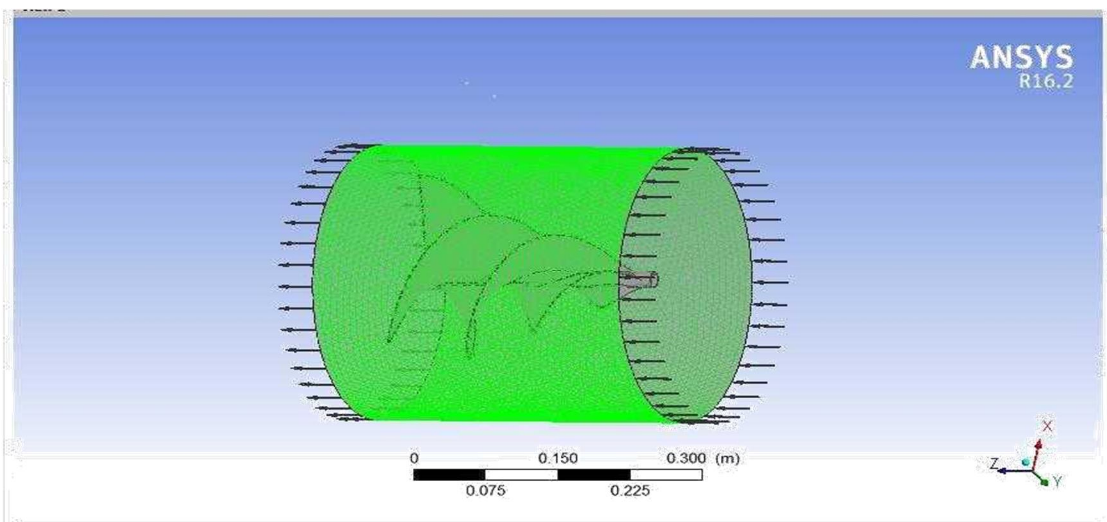

Figure 3 Boundary conditions setup at ANSYS CFX

Free slip boundary wall conditions have been applied at the top, bottom and side surfaces this means that there is no wind speed gradient normally and no flow across top, bottom and side surfaces.

C. Experimental Setup

1) *Selection of the Material:* The material used for the wind turbine rotor is ABS (Acrylonitrile Butadiene Styrene) which is a thermoplastic polymer and amorphous which is 0.25 m diameter and 0.27 m length. It has mechanical properties that are toughness, heat resistance and internal resistance. The turbine rotor inner hole is 0.016 m which is fit to the shaft. The base and the frame made of mild steel that can be welded. The two ends of shaft with turbine rotor are locked to the frame with the help of bearings which are 6202 ABC bearings. The Archimedes wind turbine rotor is assembled to frame and base which is welded.

2) *Experimental Setup:* The experiment is conducted on centrifugal blower test rig which has motor speed of 2880 RPM and motor capacity of 5 HP. The blower is made to run at various speeds such that at the outlet air at different speeds is obtained by regulating the blower valve. Initially, experiment is carried out at no load and various load conditions such that different weights which are tied to the rope that surrounds the pulley that is connected to the aluminium shaft. The weights starting from the 50 grams, 100 grams, 150 grams and 200 grams are tied to the rope which surrounds the disc of 0.47 m diameter which is made up of Acrylic glass such that it minimises losses due to inertia about rotor axis. The rope is tied to the rope brake dynamometer which shows deflection of spring are Starting from no load the wind velocity occurred at the outlet is measured by anemometer and turbine speed is measured by digital tachometer.

Figure 4 Experimental set up of wind turbine model assembly

Figure 5 Turbine model in front of Centrifugal blower test rig

IV. RESULTS

A. *Results from CFD analysis*

The results of CFD analysis indicate aerodynamic characteristics of turbine blade. The inlet wind speeds with different turbine speed of wide range on different load conditions have been accounted. Table 1 represents results of power from both CFD and experiment is indicated which are obtained at different inlet wind speeds and turbine rotational speed under different load conditions. Experimental and simulation results of power show an increasing tendency with increase in wind speed under different load conditions.

1) At Load of 50 Grams

Table 1: Comparison of Power produced by the turbine at different loads

S. NO	Wind Speed (m/sec)	Speed of the turbine Rpm	Power (Watts)		% Error
			Simulation	Experimental	
1	8.5	275.5	3.63	3.38	-7.39
2	10.8	487.9	10.33	12.01	13.91
3	13	680.7	20.82	25.13	17.14
4	15	989.7	40.23	42.62	5.61

At load of 100 grams

S. NO	Wind Speed (m/s)	Speed of the turbine Rpm	Power (Watts)		% Error
			Simulation	Experimental	
1	16.7	234.7	12	12.71	5.88
2	18.2	465.3	28.03	29.77	5.84
3	20.5	773.2	59.74	60.88	1.87
4	23	1204	117.23	118.51	1.08

b) At load of 150 grams

S.NO	Wind Speed (m/s)	Speed of the turbine Rpm	Power (Watts)		% Error
			Simulation	Experimental	
1	21.1	295	24.09	25.4	5.15
2	24.2	587	62.4	60.06	-3.86
3	25.4	758	88.78	89.53	0.83
4	27.3	1188	160.7	160.7	0

c) At load of 200 grams

S.NO	Wind Speed (m/s)	Speed of the turbine Rpm	Power (Watts)		% Error
			Simulation	Experimental	
1	28.3	906	131.906	133.775	0.01
2	29.5	1267	203.240	208.63	0.0256

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B. Comparison of Experimental and CFD Analysis

The result of power comparison between both simulation and experimental conditions as shown in the figure 5 such that both the power obtained from experimental and simulation agrees and both shows an increasing tendency. So, the results calculated from CFD analysis are power, velocity contour, pressure and streamlines.

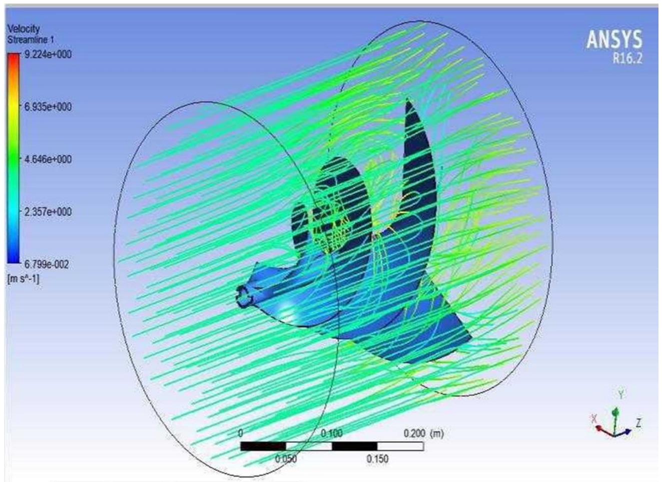
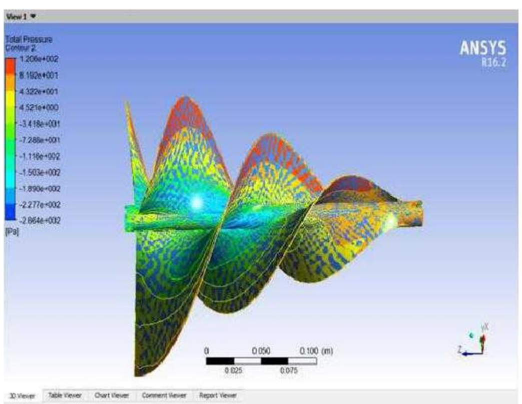


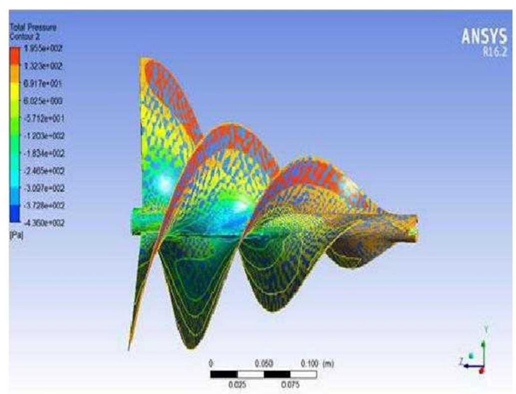
Figure 6 Streamlines

The figure 6 shows velocity streamlines in which the influence of wind speed velocity over the turbine to determine its uniform passage and swivels at some portion to be determined. For every increase in wind speed the increase in velocity occurred at the portion which are indicated in the red lines at some portion of the turbine.

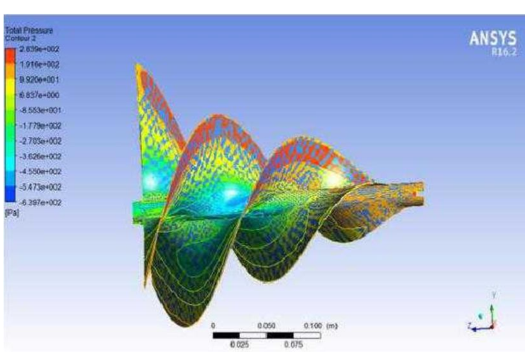
The pressure contours at various inlet wind speeds at different load At 50 grams load



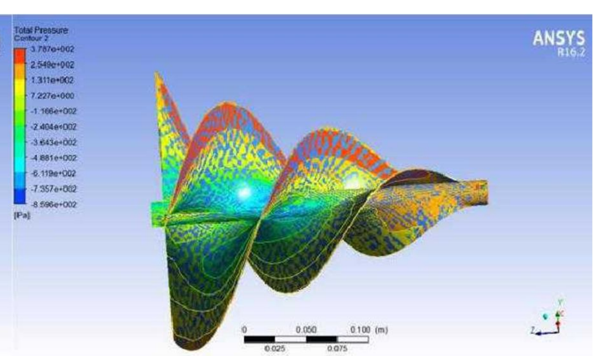
(a) 8.5 m/s



(b) 10.8 m/s



(c) 13 m/s



(d) 15 m/s

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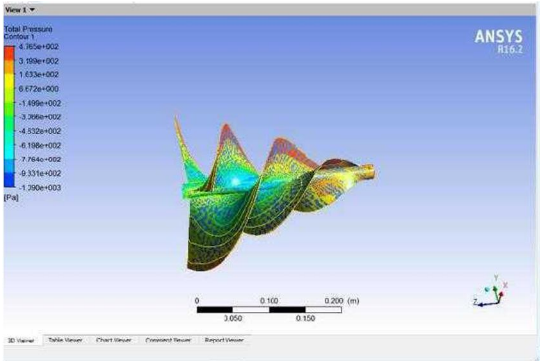
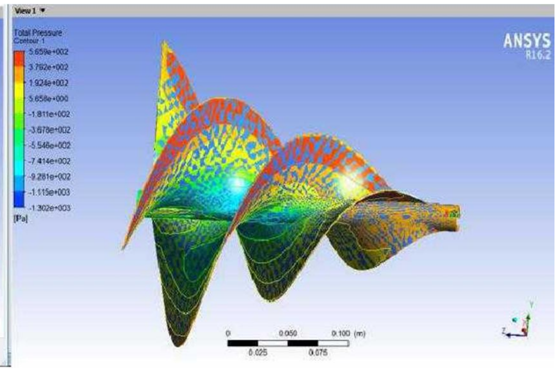
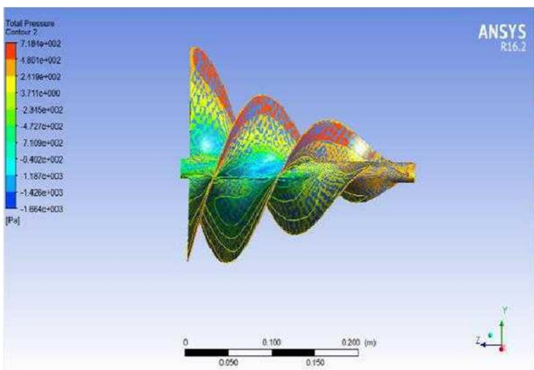
1) At 100 Grams Load



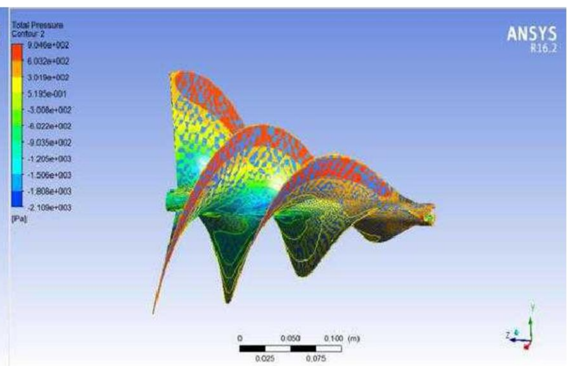
(a) 16.7 m/s



(b) 18.2 m/s

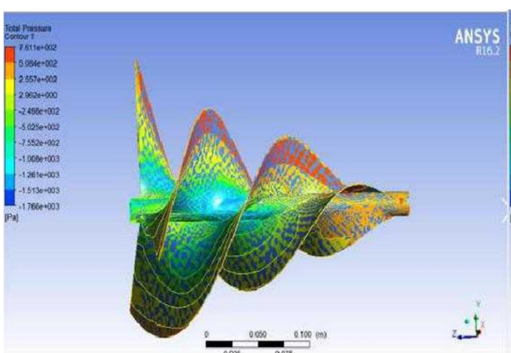


(c) 20.5 m/s

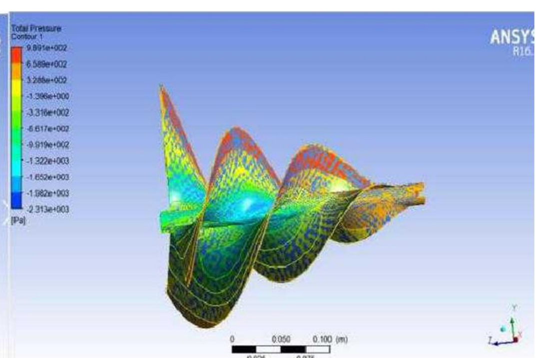


(d) 23 m/s

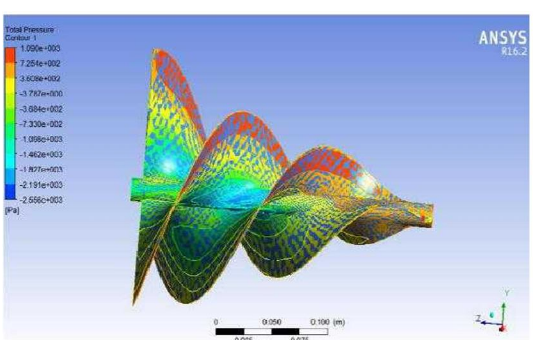
2) At 150 Grams Load



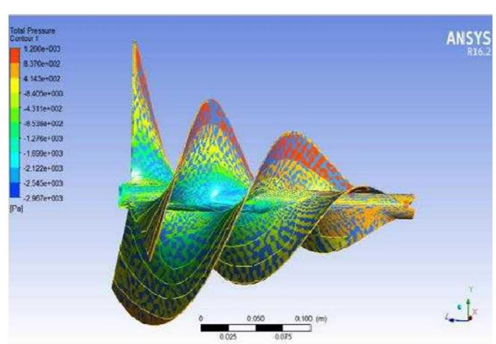
(a) 21.1 m/s



(b) 24.3 m/s

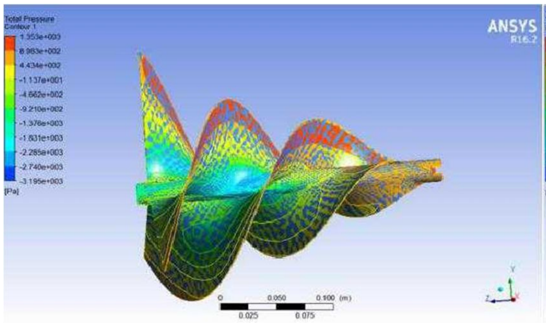


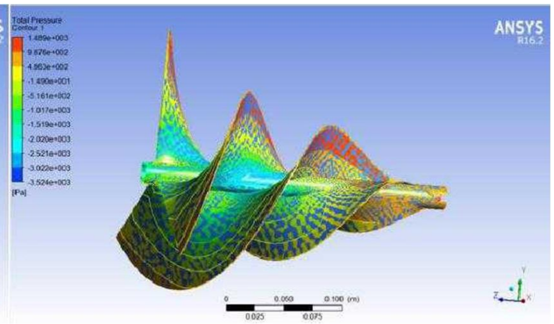
(c) 25.4 m/s



(d) 27.3 m/s

3) At 200 Grams

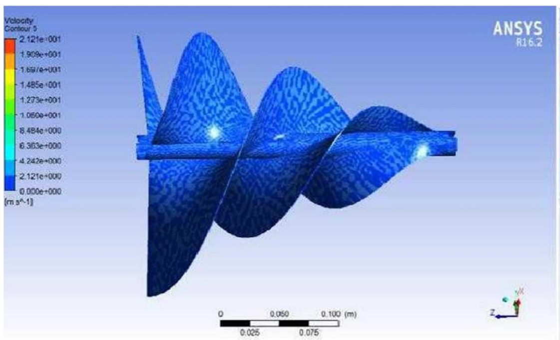


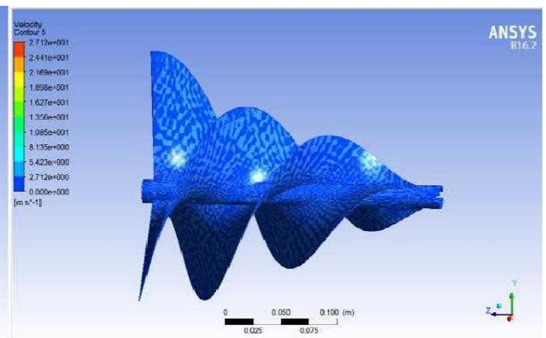


(a) 28.3 m/s (b) 29.5 m/s

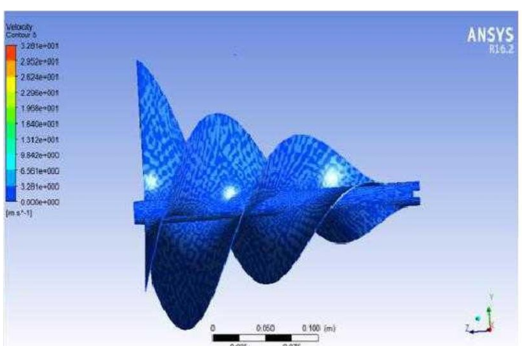
It is observed from all pressure contours that red colour presence on the surface of the turbine which indicates that pressure is increased at the surface of the turbine which is related to the structure and efficiency of the turbine such that the increase in pressure leads to damage of turbine in future which also depend upon material used ABS (Acrylonitrile Butadiene Styrene) and also it is observed that the pressure contour increases with increase in wind speed at particular load.

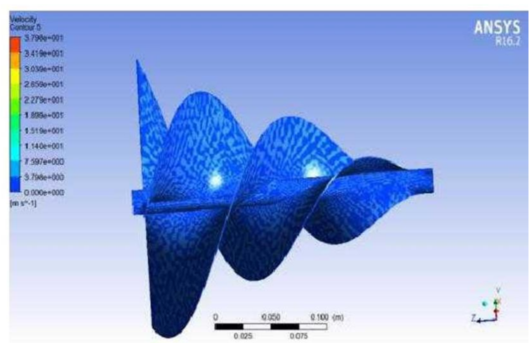
The velocity contours at various speeds under different load conditions At 50 grams load





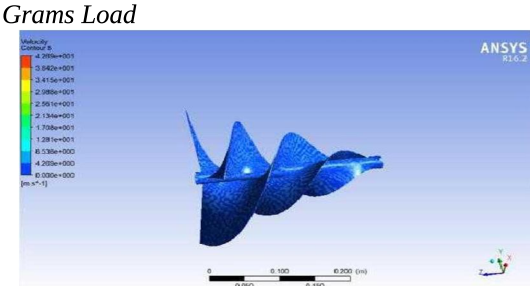
(a) 8.5 m/s (b) 10.8 m/s

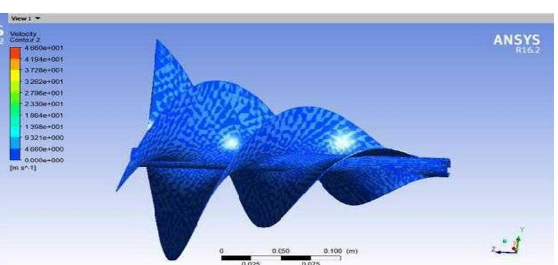




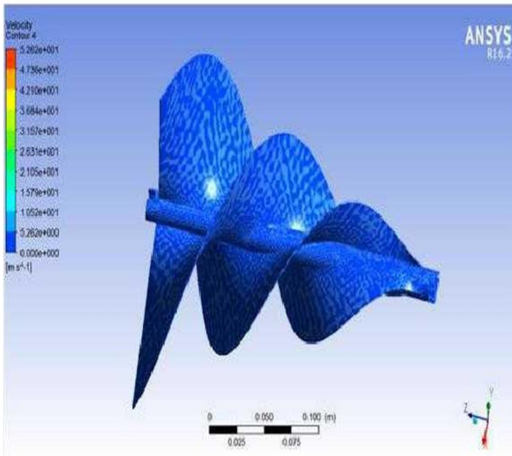
(c) 13 m/s (d) 15 m/s

4) At 100 Grams Load

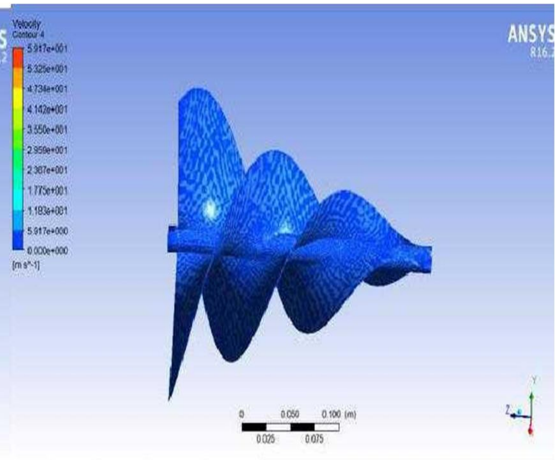




(a) 16.7 m/s (b) 18.2 m/s

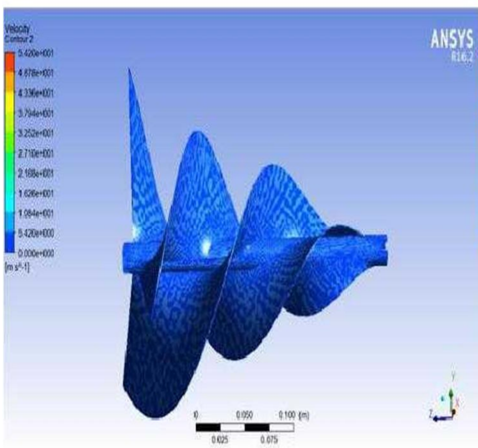


(c) 20.5 m/s

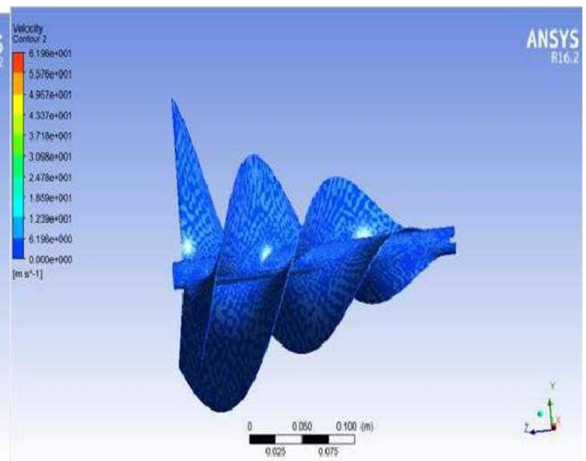


(d) 23 m/s

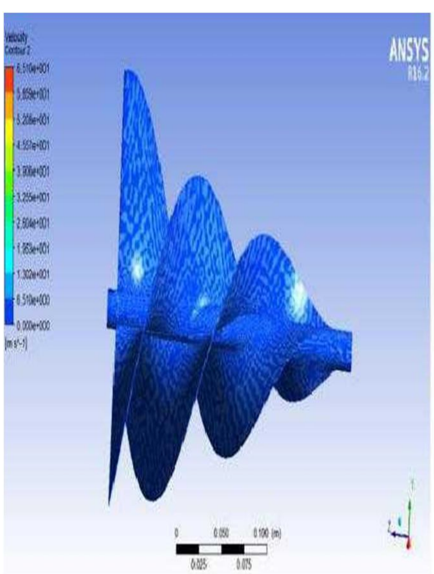
5) At 150 Grams



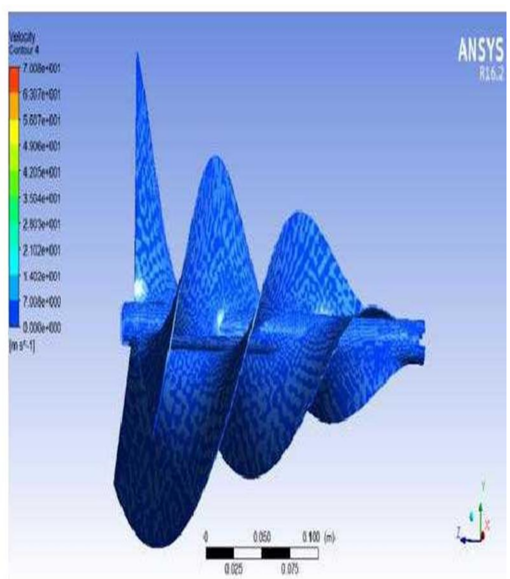
(a) 21.1 m/s



(b) 24.3 m/s

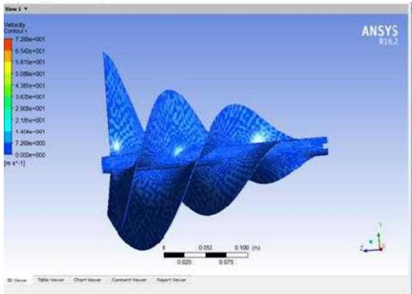


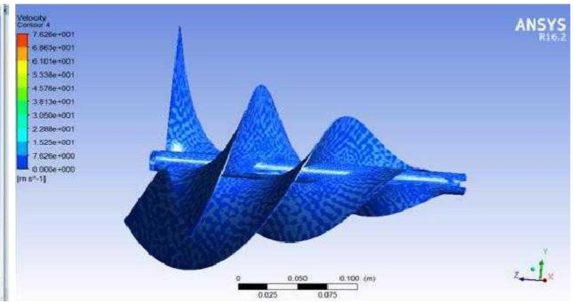
(c) 25.4 m/s



(d) 27.3 m/s

6) At 200 Grams Load





(a) 28.3 m/s (b) 29.5 m/s

The velocity contour indicates that the velocity at the centre of mass of the blade is more for a wind speed. So, as the wind speed increases the velocity or turbulence at the centre of turbine blade is also increased which is indicated in the red colour. The velocity contour concluded that velocity has not much influence in structural damage to the turbine.

V. CONCLUSIONS

The Archimedes spiral wind turbine of 0.25 m diameter and 0.27 m length is designed to predict aerodynamic characteristics such as power, torque, velocity distribution and pressure distribution. Initially the wind turbine is designed in CREO 2.0 parametric and analysed in CFD simulation like ANSYS CFX for determining power, velocity distribution, and pressure distribution and compared with the results obtained through field test in which both tests agree with each other. The following conclusions are drawn which are summarised as

A. This work provides that the ANSYS CFX is efficient software for producing power which undergoes high methods of resolution in determining fluid flow, power at different wind speed, pressure coefficient and velocity coefficient.
B. It produces maximum power of 118.51 watts under low speed and design configuration of the blade.
C. The material Acrylonitrile Butadiene Styrene (ABS) used as turbine blade material is best suited due to its impact resistance, strength and heat resistance.
D. As there is a use of tangential, radial and axial forces so it is unnecessary to use electric yawing equipment.
E. As per the CFD ANSYS CFX results this Archimedes wind turbine is better than HAWT in terms of promising power and due to the design parameters of the blade we can extract power under low speed.
F. ANSYS CFX agrees with experimental observations which are taken by the running centrifugal blower test rig.
G. The pressure contours indicate that highest pressure of magnitude is 1489.54 Pa is found on the surface of the blade tip and low pressures is found at the back thus resulting in lifespan of the wind turbine blade.
H. The velocity contour indicate that highest velocity is obtained as 76.26 ms^{-1} so there is low velocity distribution throughout the turbine blade and its life workability is safe under various conditions.

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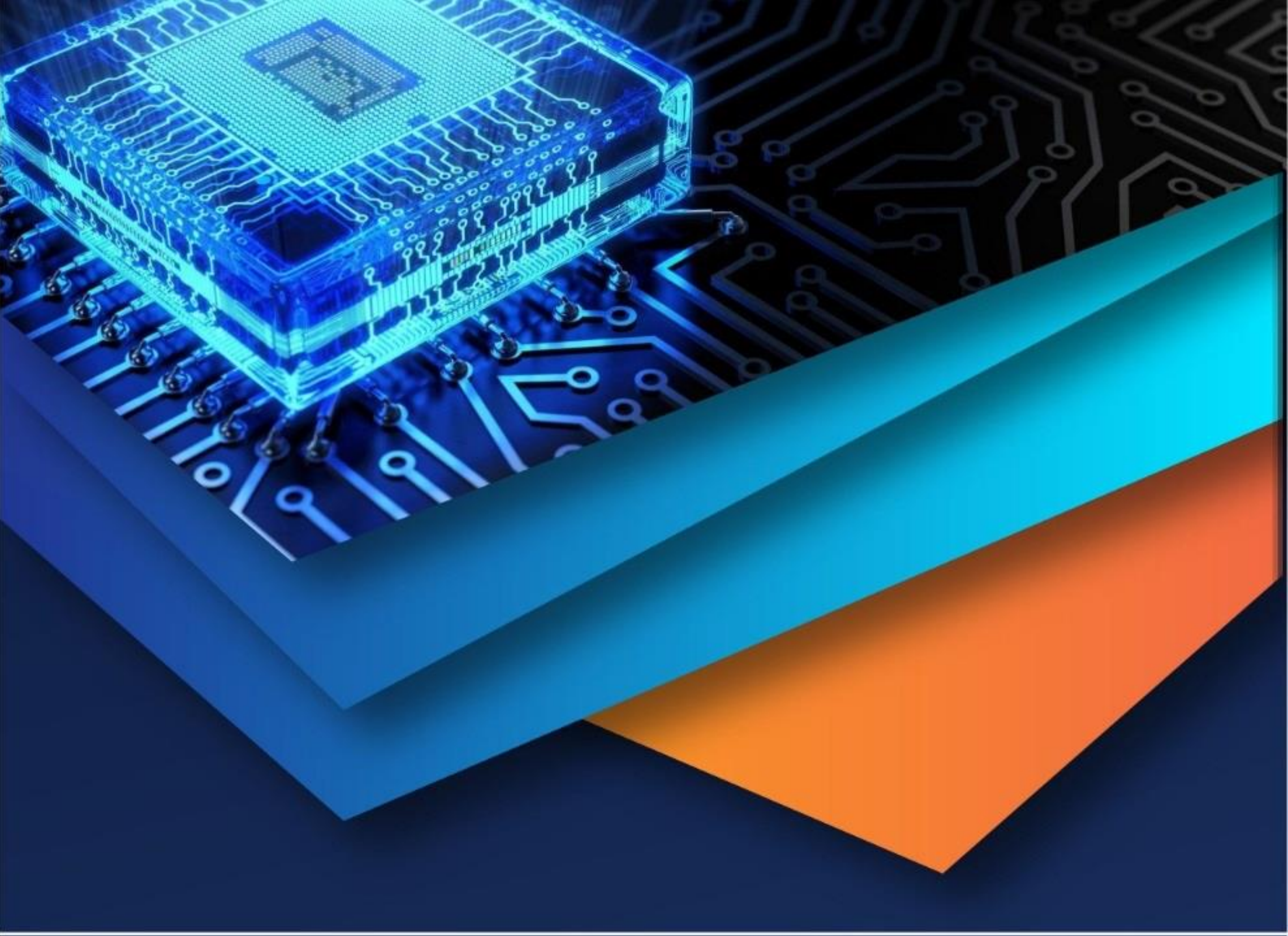

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