BLADELESS VORTEX WIND TURBINE

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelors of Mechanical Engineering

by

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ABSTRACT

The energy crisis in Pakistan and the green energy crisis in the world is the necessary push towards the research and development of the new and better ways of energy production for the future energy production as well as the reduction of the use of fossil fuels for energy production for a better clean and green world to come. Renewable energy sources are the best sources for the problem at hand. We have the options of solar and wind as the best competitors after hydroelectricity, which requires bigger investment and large operational region and matters with the location/region of world. So among solar and wind we selected wind for our problem. The project we decided on is a new idea in the wind energy harvesting devices. It is the vortex bladeless turbine; it is beneficial for occupying less space than before wind turbines. The method for designing the vortex turbine is from the research of the project Vortex Horizon H2020. We will design a vortex bladeless turbine which can be used for the solution of the clean green renewable energy for Pakistan energy crisis without causing any pollutants release in the environment. The results of the research and study and producing such device will fulfill the small energy gaps left in the main grid for seamless energy supply and also it can be used in the remote regions of the nation where electricity cannot reach because of the long lines to be placed for main grid supply.

Key words: Bladeless Vortex, VIV, Wind Turbine, Vorticity, Vortex Shedding, Renewable Energy

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There is much efforts being made in this project by all of us but without teamwork and devotion of each individual member it would not have been possible.

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ABBREVIATIONS

CFD	Computational Fluid dynamics
VIV	Vortex Induced Vibration
LES	Large Eddy Simulation
RAM	Random Access Memory
VAWT	Vertical Axis Wind Turbine
HAWT	Horizontal Axis Wind Turbine

NOMENCLATURE

fr	Frequency of vortex
$\mathrm{D(Y)}$	Diameter variation with y axis
d	Diameter at L/2
H	Distance between ground and anchor
$V_{\infty}(y)$	Fluid velocity
X(y)	Oscillation amplitude
S_t	Strouhal number
L	Length of the Mast
W	Weight of mast
E	Elastic modulus
I	Moment of inertia
s	stress
y	deflection
a	Constant
R_e	Reynolds number

For Spring:

D	Outer diameter
d	Inner diameter
K	Spring constant
N	Number of turns
L_{ih}	Length inside hooks

CHAPTER 1: INTRODUCTION

Background:

Wind has been a source of energy not in present but also for several centuries ago for certain civilizations. About 1000 years ago, the vertical axis mill existed in Persia for the grinding stone for milling purpose. Also in the 12^{th} century, the horizontal axis mill was present, which is the example use of wind energy. It was also used in the 19^{th} century in America for water pumping utilization. The size of the wind mills or turbines have only usually been increasing even within a decade difference, the main reason been the use of the renewable energy crisis and the pollution produced by the use of the coal, oil, petroleum and other burnable materials. The old windmills have been using for applications such as grinding of wheat and also water irrigation as well as water pumping. Wind energy has also been the only way of sailing in the boat.

In the 1970s, the use of wind as the energy source for electricity generation was thought and finally introduced. The major catalyst for this decision would have been the oil crisis of European countries in 1972. The small scale commercial wind turbines for the electricity production were made until 1992. The scale of the large wind turbines had been increased up to 10 times as before in 2002. Then the progress in the wind energy plans had boasted with Denmark providing a large percentage of energy from wind source as well as the USA and other countries in the world sought out the renewable, green and clean energy source for electricity generation. Then offshore wind turbines were to come in existence as the solution of wind source where the wind was not present for minimal requirement of wind turbine plant installation.

Motivation:

The wind energy in this era is being used mainly for the purpose of the energy production. Hence in order to generate more energy, the size of the wind turbines has been increasing even when compared to the ones existing about a decade ago. This trend has been still going on in order to produce larger turbines so more energy of wind can be captured. The design of the wind turbines in the beginning may seem easy but it's not especially when the target in of higher efficiency. The efficiencies of the renewable energy devices have been increased significantly in recent years. Nowadays the use of wind energy turbine is a better choice if the region has a windy climate. The wind turbines are the other option to the fulfillment of requirement of the renewable energy leaving solar energy. The wind turbines are first divided in different types of power production mechanisms which include the rotational energy from wind and the resonance due to vortex shedding in vortex turbines etc.

The two basic types in which the wind turbines are divided are vertical or horizontal orientation. The conventional wind turbines consist of blade which is very difficult and costly manufacture. Bladeless design is not just easy to manufacture but it is also efficient and have following advantages over conventional blade design.

- Easy to manufacture and replace.
- As they are small in size so they are easy to transport.
- Can easily be introduced to a system.
- Uses less material and which isn't costly resulting in less cost overall.
- Can operate in low cut in speed unlike conventional vertical and horizontal turbines.
- Doesn't harm any living creatures.

- Doesn't involve complex gear reduction mechanisms to increase or reduce the turbine speeds.
- Less operational cost.
- Low end industries can afford this method of power generation.

Considering all the reasons above we chose this project as it has great benefits and has relatively more room to improvisation and design optimization as this method of energy generation is quite recent.

Problem statement:

As one can easily see that system susceptible to vibration are generally unstable and quire often cause many accidents and casualties but we are using vortex induced vibrations(VIV) to generate a renewable and sustainable energy sources which is produced by relative motion of the coil attached with the mast that is oscillating relative magnet attached to the base.

Objectives:

The main objectives of our project is given below

- The 1st objective was to conduct an extensive of research regarding Vortex Bladeless Turbine.
- The 2nd objective was to come up with a design to work on.
- The 3rd objective was to perform calculation regarding that design and improve it.
- The 4th objective was to perform simulation on the design and improvise it.

- The 5th objective was to use the simulation results and optimize the original design parameters and then finalize the design.
- The 6th objective is to fabricate the final and optimized design.
- The 7th objective is to test the fabricated design and rectify its failure if any.
- The 8th objective is to obtain the results are document it.

We have so far cleared five of our objective and are yet to complete three remaining objectives. We are halfway in completing our fabrication phase and will then conduct extensive series of tests soon.

CHAPTER 2: LITERATURE REVIEW

The field of the wind power generation has only undergone further promotion and enhancement in its efficiency as well as the scope and need for the alternative to general power production sources from fossil fuels. In order to build our own wind turbine for the motive of electric power generation, we definitely need more knowledge and insight of the wind power generation industry as well as in the manufacturing of the wind harvesting device and the elements effecting the wind power generation for each class of power generation systems.

First of all we looked for different types of wind turbines which are being used and also developed for this particular objective. We came across these two basic types of wind turbines being used nowadays:

Figure 1 Basic two types of wind turbines

These are the two basic types of the wind turbines which are being operated on different scopes based on the basis of the requirement also on the maximum output possible in the region these are being employed. The turbines also differ from the small scale turbines to large scale turbines.

Small scales are typically less than **50 kW** but can reach as much as **250 kW.**

Large scales can be at least **660 kW** to the largest ones as **9.5 MW.**

But before we study the wind turbines we come across the general limitation for all wind turbines and wind energy harvesting systems.

Betz Limit or Betz Law:

A German physicist **Albert Betz** concluded in **1919** that no wind turbine can convert more than **16/27 (59.3%)** of the kinetic energy of the wind into mechanical energy turning a rotor. To this day, this is known as the **Betz Limit or Betz' Law**. The theoretical maximum power efficiency of any design of wind turbine is **0.59,** which means that no more than **59%** of the energy carried by the wind can be extracted by a wind turbine. This is called the **power coefficient** and is defined as:

$$C_{p_{max}} = 0.59$$

Other than this, the value of C_p is different for each turbine designed. In general cases, the C_p value after all engineering considerations comes to be around **0.35 to 0.45.** After even further technical considerations i.e. of gearbox, bearings and generator etc. the result becomes that only **10-40%** of the wind energy actually gets converted into the electricity being generated by the generator.

When designing a wind turbine, all the types of the wind turbines is compared on the basis of various elements including the Betz limit i.e. power coefficient. Hence the one with the most power production capacity under given conditions is chosen for the task at hand.

Vertical Axis Wind Turbine (VAWT):

This is one of the most common used wind turbines as mentioned early. In this mechanism, the rotor axis is parallel to normal of the ground. The wind direction is in traverse to the rotor shaft axis. The wind energy moves the rotor in the rotation about its vertical axis. The gearbox (if any) is connected to the shaft of the VAWT rotor and then it is further joined to the generator on the same shaft or maybe any other shaft in parallel. The two main types of the VAWT are as following:

1. Darrieus Wind Turbine
2. Savonius Wind Turbine

Advantages:

The VAWT has its own advantages over the other HAWT and unconventional turbines, some of them have been mentioned below:

- They are omnidirectional which usually does not need to track wind direction
- They have less complicated mechanisms than the HAWT
- They can be grouped together, covering less area for same power generation
- They perform better than the HAWT in turbulent and gusty winds, which helps in maintaining overall power generation
- The gearbox replacement and the maintenance is much more easy and more efficient as compared to HAWT
- The VAWTs can also be placed below the HAWTs in a wind farm as the supplement for the existing farm
- Lower wind startup speed

Disadvantages:

- The dynamic stall due to the quick change in the angle of attack

- The blades of a VAWT are prone to fatigue due to the wide variation in applied forces during each rotation causing the blades to twist and bend, therefore breaking them apart
- The VAWTs have proven statistically less reliable than HAWTs
- The VAWTs are generally less efficient overall as compared to the HAWTs

The applications of the VAWT range from home systems to official systems and also are used in industries as well as the research department.

Horizontal Axis Wind Turbine (HAWT):

The most commonly utilized wind turbine from small to large scale is the horizontal axis wind turbine (HAWT). It is being used around the world as the major renewable energy source and also several future projects for wind energy harvesting are under development. In this wind turbine, the wind is applied along the axis of the rotor which is horizontal or tangential to the ground. When it comes to the big wind applications, we would usually encounter with this wind turbine. The major advantage this turbine has is of higher efficiency compared to all of its counterparts. It definitely produces more electric power than those of vertical axis wind turbine or any other for an appropriate given wind speed. Types of HAWT on basis of generation system:

1. **Asynchronous (Induction) Generator**

This type of wind turbine is noted for its lower and almost constant turning speeds and also requires a gearbox. It converts the electricity by balancing the generators turning speed and does not require an inverter. These are usually the ones we see in large wind farms.

2. **Synchronous Generator**

This type of wind turbine is characterized by its higher turning speeds with higher wind speeds. This utilizes an inverter for constant electric energy supply to the main electric grid. There is no use of a gearbox generally.

Advantages:

- The towers of the HAWT are usually of higher heights allowing higher altitudes hence higher wind speeds which in turn results in more power generation. It can increase the power generation up to 30% for higher altitudes as wind speed also increases with altitude
- Higher efficiency than the other counterparts available
- The HAWT has variable blade pitch which helps in order to obtain more wind power by maintaining the best angle of attack

Disadvantages:

- High construction and installation costs are required. Large machinery is required for this purpose
- Massive tower construction in itself and the installation of the components (gearbox, shafts, brake assemblies etc.) is extremely careful work involving lifting and fitting
- Due to its large stature it is obstructive to the landscape and disturbs beautiful views.
- They have fatigue and structural failure problems
- Needs extra yaw mechanisms to make it in face to the wind direction
- Also require the mechanisms of braking in case of excessive rotational speeds

- They are susceptible to cyclic stresses and vibrations increasing the probability of failure
- They cause wake which can be disruptive to natural wind currents

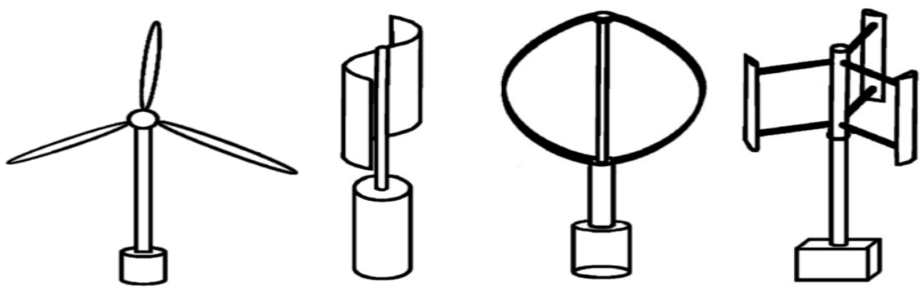


Figure 2 Models of VAWT and HAWT

Both of the basic types of wind turbines have a same power obtained from wind model. The power obtained from wind is given by:

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

By including the power coefficient, the actual power available to us through the wind turbines becomes:

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

Unconventional Wind Turbines:

There are quite a number of wind turbines which are based on different principles and mechanisms for the very same purpose of power generation. Note that they do have applications or are either in research or in development stage. They are actually not as efficient as the HAWT on the same scale. But, if any of the unconventional wind turbines would compete or surpass the HAWT in terms of ease and power generation, they would become the future of the wind turbine power generation system. Some of them are given below:

- **Vortex bladeless**
- Saphonian
- Windbeam
- Wind belt
- Vaneless ion wind generator
- Piezoelectric
- Traffic-driven
- Blade Tip Power System (BTPS)
- Solar chimney
- Wind turbines on public display
- Rooftop wind-turbines

The one we chose for our wind turbine was the Vortex Bladeless sometimes called Vortex Induced Vibrations (VIV) turbines.

Bladeless Vortex/Vortex Induced Vibrations Wind Turbine:

Bladeless Vortex or VIV wind turbine is one of the unconventional wind turbines which have been developed by the Vortex Bladeless Ltd. powered by the European Union (EU) funded program called **Europe Horizon 2020.** The Bladeless Vortex turbine idea was thought by David Yáñez in 2002. The company was founded in 2014 and the concept of the vortex bladeless was praised in 2012.

The vortex bladeless turbine is characterized on the basis of the vortex shedding principle and Vorticity. The principle of resonance is utilized for more vibration generation.

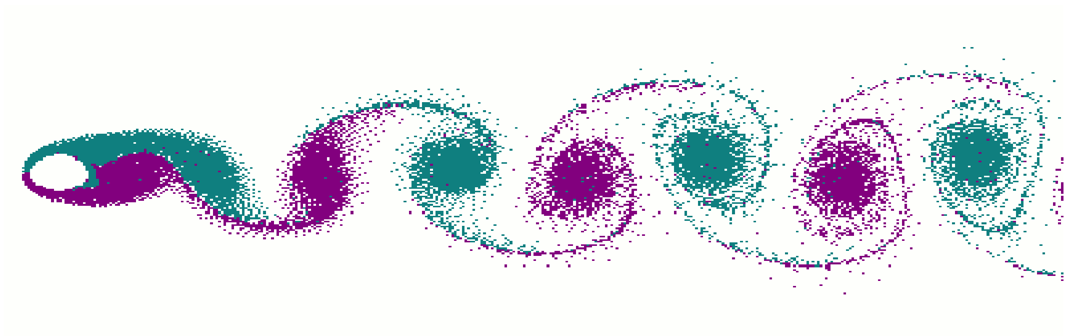


Figure 3 Vortex shedding

Working Principle:

The working principle of the VIV wind turbine is based on the frequency of the vortex shedding alternating as shown in Figure 3. The vortex shedding then oscillates the mast of the VIV wind turbine. The magnetic tuning system matches the frequency of the vortex shedding and causes resonance in order to increase the oscillations generated in the mast which in turn tends to increase the power generated. Then this process continues to generate electricity without much hindrance. Since it is omnidirectional it is beneficial in many cases.

Advantages:

- It is omnidirectional which reduces the wind direction tracking
- It is easy to maintain since less parts are present
- Takes less space as compared to others
- Has a higher usage efficiency
- Does not require more lubrication and oil as others
- Safe to birds and animals

- Can operate at even lower wind speeds
- Costs less as less parts are involved
- Easy maintenance and installation
- No complicated mechanisms involved

Disadvantages:

- Has lesser efficiency as compared to HAWT and VAWT
- Less power generation for a given wind speed
- Still in study so not much work is present at the moment
- Not many large scale VIV wind turbines are being used making it unsuitable

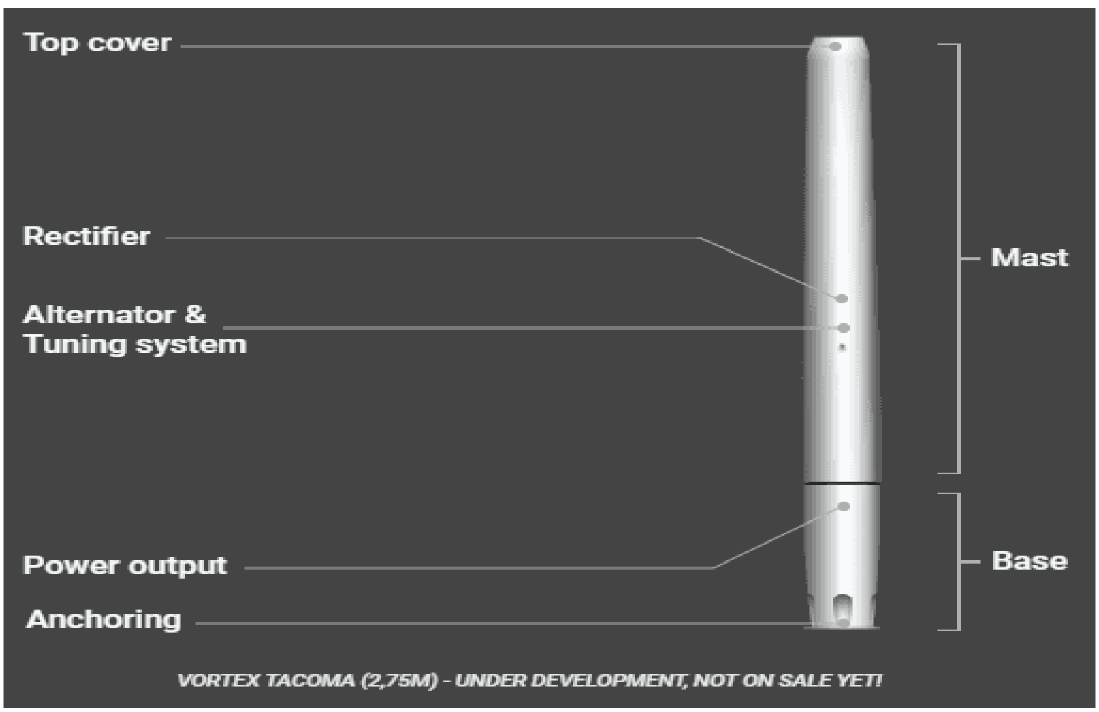


Figure 4 VIV Turbine Basic Model

CHAPTER 3: METHODOLOGY

Project overview

The idea of the project first came at the end of 6^{th} semester and the main theme of the project was to harvest vibrations due the wind to generate electricity. The main challenge of the project was how we can do it. We firstly thought that vibrational energy due to the wind can be converted into electricity by using a piezoelectric material. The piezoelectric material converts the pressure variations on it to electric signals and those electric signals can be converted into electric current. However, the magnitude of power that can be derived from these piezoelectric materials is 5mw which is very less as compare to the normal electric power that can generate from other methods. We then thought of various designs which are briefly discussed in the design development section and the finalized design that we are now working on it is the "vortex shedding bladeless wind turbine". The basic idea of vortex shedding is also discussed in the design section. The current update of the project is that we are entering the fabrication stage of our design. The main challenges ahead are the given below:

- The availability of the correct material
- The precise fabrication of the design

Steps involved in the calculations:

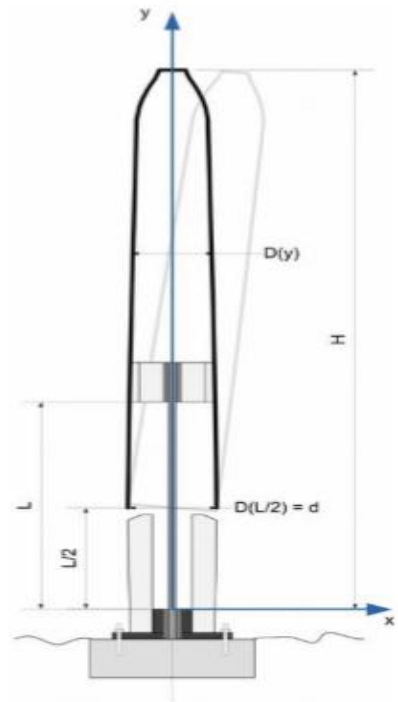


Figure 5 Model design parameters

- The first step in our calculations was to determine the natural frequency of vortex shedding across the Mast. The parameters on which the natural frequency depends are the
    1. Free stream velocity (V∞).
    2. Diameter of the Mast D(y)
    3. Amplitude of the Mast vibrations X(y)
    4. Factor depends in the geometry of the Mast (a)

In our design what we required was a uniform frequency of the vortex shedding throughout the length of the Mast. For that we assumed the f(y) to remain same throughout the length and then tried to find the D(y) assuming the X(y), the deflection profile is given.

$$f(y) = \frac{S_t . v_\infty(y)}{D(y) + a . X(y)} \qquad (3)$$

- Calculating the Diameter of the profile of the bladeless wind turbine D(y) by making sure the vortices generated have same frequency throughout the length. Here we have assumed that the deflection profile is given.

For the deflection profile we have assumed that the maximum deflection at the top of the Mast is 0.05m and it is zero at the bottom of the mast and it varies linearly with the length of the mast.

$$X(y) = \frac{y - L/2}{H - L/2} . \gamma . d \qquad (4)$$

Using the below given formula we were able to determine the diameter profile of the mast and to our surprise it turned out to be a tapered profile having tapered angle of 1.41 dgrees.

$$D(y) = d . \frac{v_\infty(y)}{v_\infty(L/2)} - a . X(y) \qquad (5)$$

- Calculating the wind shear coefficient and the wind profile

The below chart is taken from a research paper and we have done our calculations for Gharo.

To calculate the wind velocity at different sections of the mast we utilized wind power law formula as given below and where:

Reference velocity **V_{ref}**

Velocity at any section at a distance H from the reference point **V**

Reference height at which reference velocity is calculated **H_{ref}**

Given height at which velocity is to be measured **H**

Wind shear coefficient **α**

$$V = V_{ref}\left(\frac{H}{H_{ref}}\right)^{\alpha} \qquad (6)$$

The wind shear coefficient was taken from a research paper. The chart given below depicts that the shear coefficient varies throughout the year and specifically the Gharo (area in Punjab) has an average shear coefficient of 0.4.

For this value refer to **APPENDIX 1**

Table 1: FREQUENCIES RELATIVE TO VELOCITY

Y m	X(Y) m	L/2 m	V_{inf} (Y)m/s	V_{inf}(L/2 m/s)	D(Y) m	f(y) Hz	phi(y)	Re
0.9	0	0.9	3	3	0.1	6	0.1	19758.06
1	0.005555556	0.9	3.162278	3	0.102631	6	0.105409	21953.41
1.1	0.011111111	0.9	3.316625	3	0.104999	6	0.110554	24148.75
1.2	0.016666667	0.9	3.464102	3	0.107137	6	0.11547	26344.09
1.3	0.022222222	0.9	3.605551	3	0.109074	6	0.120185	28539.43
1.4	0.027777778	0.9	3.741657	3	0.110833	6	0.124722	30734.77
1.5	0.033333333	0.9	3.872983	3	0.112433	6	0.129099	32930.11
1.6	0.038888889	0.9	4	3	0.113889	6	0.133333	35125.45
1.7	0.044444444	0.9	4.123106	3	0.115215	6	0.137437	37320.79
1.8	0.05	0.9	4.242641	3	0.116421	6	0.141421	39516.13

Using this coefficient we were able to get the wind profile of Gharo and used that in our calculations

- Basic assumptions and the dimensions of the design
- Strouhal number as per the chart our value is 0.2

Maximum height of the bladeless wind turbine =1.8m (0.9m is a fixed base and 0.9m is an oscillating head).

Velocity profile V(y) and the Diameter of oscillating tube D(y) are given below in the table along with the maximum allowable deflections X(y).

Stress analysis of the Mast

In our assumption we assumed that the mast is a cantilever beam and a uniform force distribution exists at its surface due to the wind velocity as shown in the figure: These formulae assume that the cross-sectional area must be same throughout. However, our model has varying area and moment of inertia. Assuming the worst-case scenario we took the least area of our model and assuming it to be remain same throughout our model. Moreover, the model assumes a uniform force distribution, however our in our model the wind speed varies with the height as shown in the calculations chapter and thus again considering the worst-case scenario we assumed that our maximum value force intensity to be acting on the model uniformly throughout and we got the results given below.

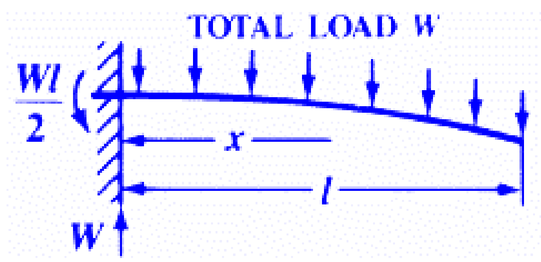


Figure 6 Beam parameters

Deflection at specified point

$$y = \frac{Wx^2}{24EIl}[2l^2 + (2l - x)^2]$$

Stress at specific point

$$s = \frac{W}{2Zl}(l - x)^2$$

Table 2: STRESS AND DIAMETER CALCULATIONS

E	Load intensity N/m	I	Xp m	L m	Deflection m	Stress Pa	Cross-sectional distance Z-m	D m
3000000000	70	2.8985E-06	0	0.9	0	**543385.4**	5.8E-05	0.1
3000000000	70	2.8985E-06	0.1	0.9	1.68E-05	**450180.5**	5.53E-05	0.104854
3000000000	70	2.8985E-06	0.2	0.9	6.23E-05	**359755.3**	5.3E-05	0.109443
3000000000	70	2.8985E-06	0.3	0.9	0.00013	**274840.5**	5.09E-05	0.113803
3000000000	70	2.8985E-06	0.4	0.9	0.000213	**197837.3**	4.91E-05	0.117963
3000000000	70	2.8985E-06	0.5	0.9	0.000308	**130889.2**	4.75E-05	0.121944
3000000000	70	2.8985E-06	0.6	0.9	0.000411	**75932.75**	4.61E-05	0.125766
3000000000	70	2.8985E-06	0.7	0.9	0.000517	**34734.93**	4.48E-05	0.129444
3000000000	70	2.8985E-06	0.8	0.9	0.000625	**8921.746**	4.36E-05	0.132992
3000000000	70	2.8985E-06	0.9	0.9	0.000734	**1.13E-26**	4.25E-05	0.136421

Notice that for the worst-case scenario we can see that the maximum stresses being generated are below the Tensile strength of the material (PVC rigid) of the Mast (**28 MPa**) which is as shown in the diagram:

Table 3:PROPERTIES OF THE PVC MATERIAL

Property	**Value**
Elongation at break	50-80 %
Short term creep rapture	44 MPa
Long term creep rapture	28 MPa
Elastic modulus	3.0-3.3 GPa

Natural frequency of the Mast calculations:

Some of the mathematical modeling was done by hand. The images are displayed below.

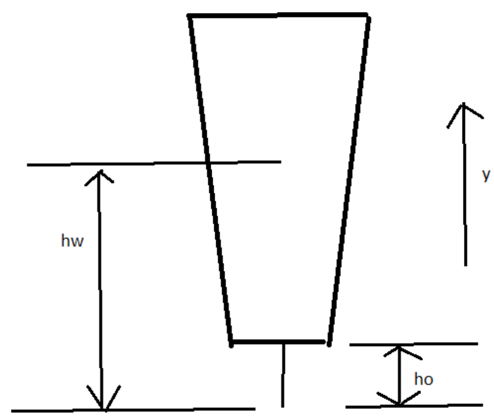


Figure 7 Mathematical model (a)

$$Fw = 0.5Cl.V\hat{}2\rho A \qquad (7)$$

Where,

Cl is the coefficient of Lift

V is the velocity

p is the density

A is the frontal area of the mast projecting in the direction of wind.

K is the spring stiffness

Consider the free body diagram of the spring deflection as shown in the diagram

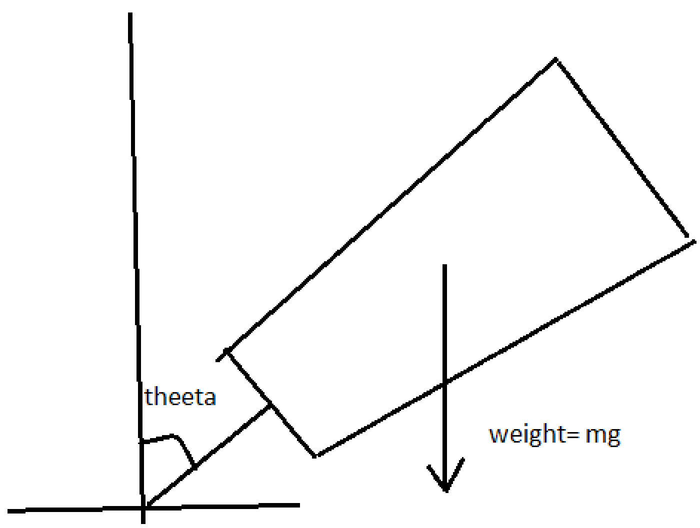


Figure 8 Mathematical model (b)

The equation of motion of the body is shown as following:

$$Ia = -Fh0\sin(t) - mghwsin(t) + FhoCos(t) \qquad (8)$$

Using small angle approximation, we have the following equation for the natural frequency of the mast

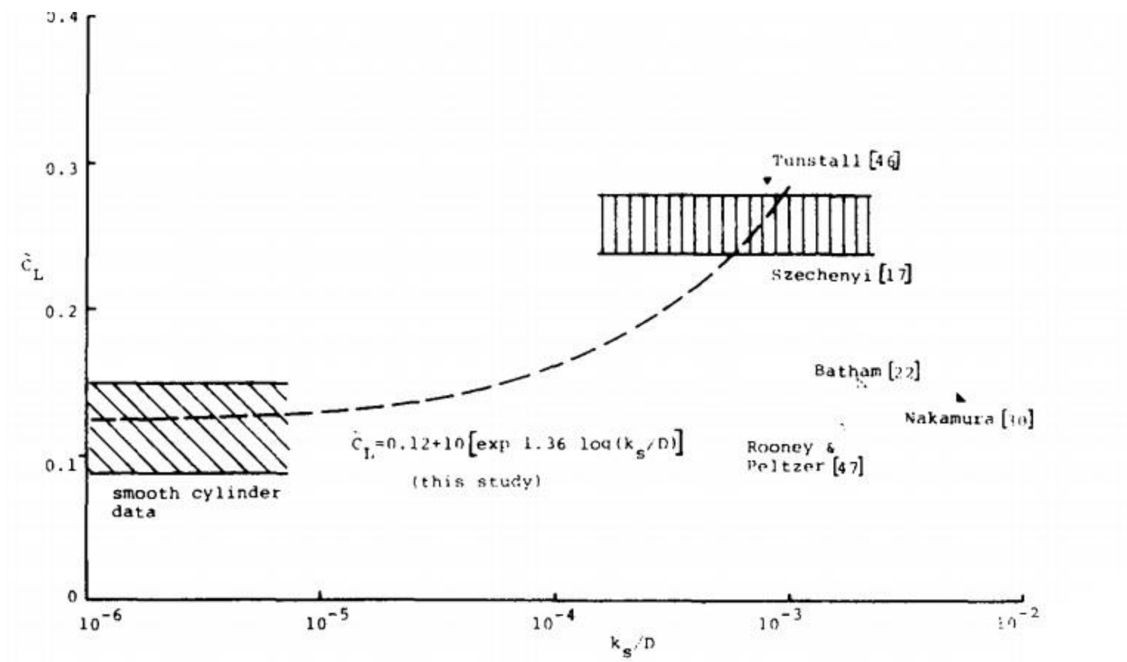
$$w = \sqrt{\frac{mghw}{I}} \quad (9)$$

Where,

F is the applied Force

Ho is height of the centre of mass

Hw is the length of the spring



RMS lift coefficient as a function of relative roughness in the postcritical Reynold number regime.

Figure 9 CL relation with wind velocity

The design overviews

The design phase took more than 3 months to be finalized and implemented. Several designs were modeled on Solid works and these designs were based on the following parameters decided:

- Design should use vibrational energy to convert into electrical energy

- Design should be simple and easily assembled
- Design should be less costly
- Design should be able efficient

These parameters were quintessential for deciding which design is better and which design needs to be implemented

The First design that was selected is shown in the figure

Figure 10 Initial design

This design’s subjective performance evaluation was as following:

- The design was easy to be manufactured
- Design was easy and no complex parts such as fan angles and other parameters were required.
- Design was less costly as compare to other designs in the market
- Design was vibrating(our primary prerequisite)

However, the drawbacks of the design were as following:

- The design would have been noisy

- The design would have frictional losses
- A gear system must be designed which would add in the intricacies

Based on these facts we were in position to decide whether we would go with design or change the design. We decided to change our design as this design was heavy as well as lots of parts were involved which would decrease the efficiency of the design. Moreover, applying the concepts of the Wind turbine it was seen that this design uses drag to convert wind kinetic energy to electric energy and we know that efficiency of a drag mechanism wind turbine is 0.5 times the efficiency of a wind turbine working on the principle of pressure difference.

We then decided for a next design which is shown in the figure

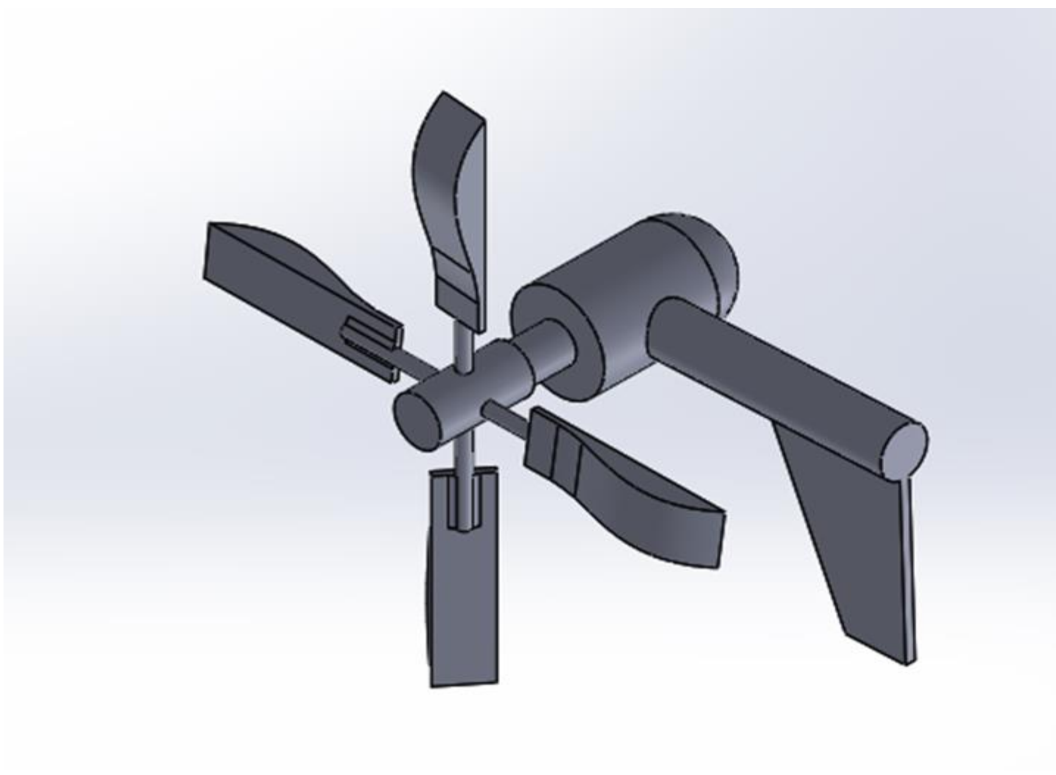


Figure 11 Altered Second Design

The design shown in the figure was based on the principle that a pressure difference causes lift on the turbine blade and combine this lift with changing effective area of the blade we were able to convert kinetic energy of the wind into the rotary motion of the blade effectively. The effective area of the blade was changed using motors attached to each blade and as the blade would rotate the blade angle would change accordingly using the motor to adjust for effective conversion of energy. There was also an automatic turbine yaw angle adjuster mechanism attached to the turbine as shown in the figure which would automatically align the turbine in the direction of coming wind. The automatic yaw angle adjuster is a fin shown in the above figure. The subjective evaluation of this turbine is as following:

- The design was not complex
- It was easy to manufacture
- Gearbox assembly was needed to be incorporated
- Vibrations were not utilized to generate electricity

Based on above conclusion we were needed to revise our design and our third design was designed as shown in the following figure:

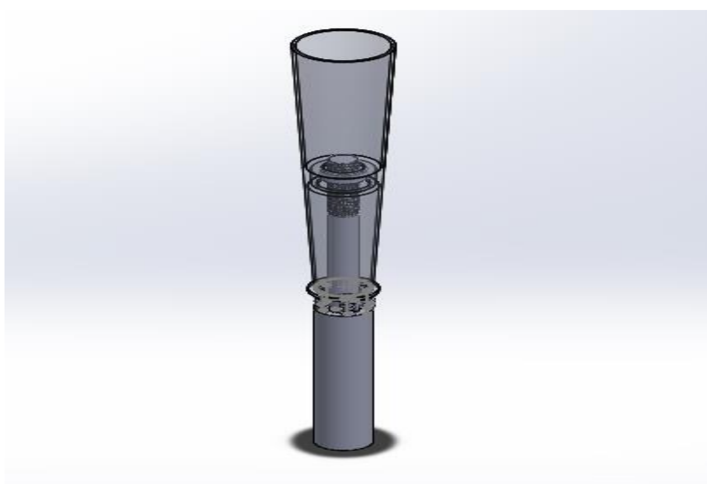


Figure 12 Modified Final Design

The above design is based on the principle of vortex shedding. Wind with a Reynolds number greater than 49 produce vortices as they pass across a circular beam. The wind as it passes across a circular beam; a less pressure zone is developed in the wake of the flow. This low-pressure zone sucks the flow in the free stream inwards generating the vortices. These vortices have energy associated with them and they are generated at a frequency. This frequency depends on the Strouhal number (St) and the wind speed. The idea is basically to use the energy of these vortices to generate electricity. The subjective evaluation of this project was as following:

- The design was light
- The design did not include the gearbox mechanism
- The design was utilizing vibrations to generate electricity
- The design was meant to be less costly and less complex

Finally, we were able to decide whether this design was acceptable or not and we decided to go with the design as it has fulfilled all the initial criteria we have put forward.

Design component and parameter

- **Mast**

The main part of our design is a tapper pipe which we called Mast. The Mast is shown in the figure below:

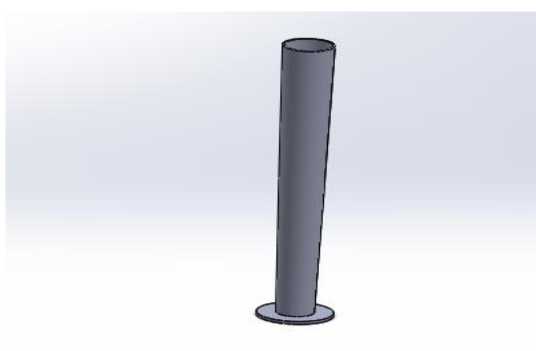


Figure 13 Mast external view

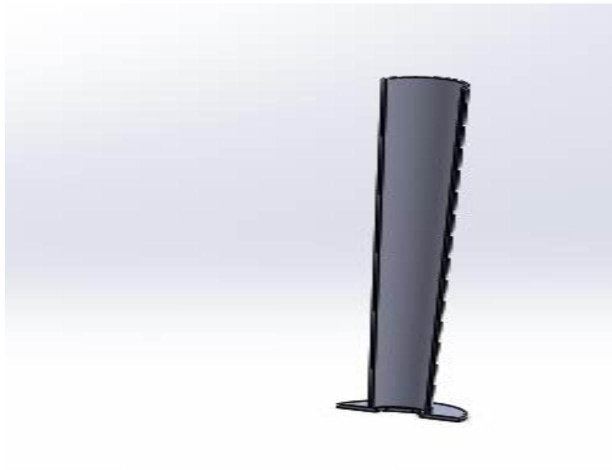


Figure 14 Mast cross-sectional view

The material for the Mast is chosen to be Rigid PVC pipe. A thorough analysis of the material and stress analysis is done to make sure our design can withstand the load due to the wind. The properties of the Mast are as following:

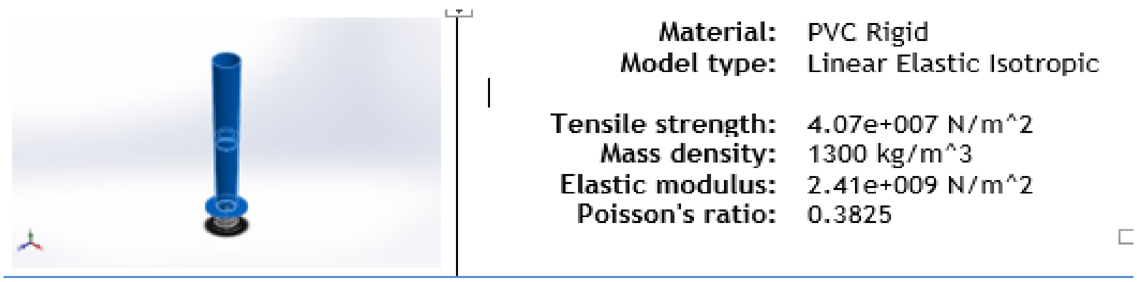


Figure 15 Mast properties

The Mast is 0.9m in height and is tapered in such a way that the tapper angle is 1.41 approximately. The length diameter values for the Mast cross-section is a shown in the **Table 1.**

The diameter was calculated on the basis the fact that the frequency of the Vortex shedding should remain constant throughout the length of the Mast. The steps involved in the design calculations of the diameter are given in the calculations chapter.

- **Springs**

We have a spring assembly below the Mast so that Mast would oscillate freely. The springs are made of stainless steel. Our design is based on two types of spring assemblies. The first one is as shown in the figure:

Figure 16 Spring view (a)

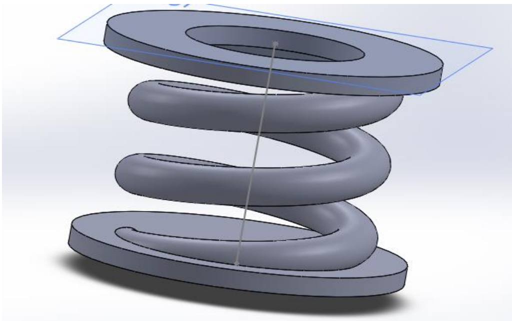


Figure 17 Spring view (b)

The above assembly of spring consists of a single spring whose

D (Outer diameter) is=10 cm

d (wire diameter) is= 2 cm

Spring constant is=5359.3142 N/mm

No. 0f turns equal to=3

Select your unit of measure:		English	Metric
A Wire Diameter, *wd*:	20.000	IN	MM
B Outer diameter, *OD*:	100.000	IN	MM
C Length Inside Hooks, L_{ih}:	120.000	IN	MM
Select a material:	Stainless 302 ASTM A313		

Rates & Loads	
Spring Rate (or Spring constant), *k* :	5,359.3142 N/mm
Maximum load possible, *Fmax* :	12,238.2896 N
Maximum load possible Considering Hook Stress, *FmaxHS* :	9,976.2297 N
Initial Tension, *Tensioninit* :	6,088.0139 N

The second spring assembly consists of several small springs arranged in parallel to form the whole assembly.

Select your unit of measure:		English	Metric
A Wire Diameter, *wd*:	4.000	IN	MM
B Outer diameter, *OD*:	20.000	IN	MM
C Free length, L_{free}:	60.000	IN	MM
D Number of active coils, n_a	8.000		
Select a material:	Stainless 302 ASTM A313		

Rates & Loads	
Spring Rate (or Spring constant), *k* :	66.991 N/mm
True Maximum Load, *True* F_{max} :	761.494 N
Maximum Load Considering Solid Height, *Solid Height* F_{max} :	761.494 N

Since 5 spring are attached in parallel configuration our spring stiffness is=66.991*5=335 N/mm.

- **3-Frequency tuning mechanism:**

The mechanism based on which our bladeless vortex shedding wind turbine will work is on the fact that the natural frequency of our structure should match the vortex shedding frequency of the vortices being generated. If the frequency does not match we have to device a mechanism which should match the frequency of the Mast and vortices being generated. The vortices being generated have frequency dependent upon the wind velocity and in our calculation chapter we have already covered it and for the natural frequency of the Mast we have used Solidworks simulations to calculate the frequency of the Mast. To match the frequency of the mast and the vortices we would try to vary the length of the spring assembly by a servo motor and using a Wind speed sensor we will be able to adjust the length of the spring accordingly so that its frequency matches the frequency of the vortices being generated.

- **4-Radial electric motor configuration:**

The main challenge of the vortex bladeless wind turbine was devising the mechanism through which we would be able to convert the vibrational energy of the mest to the electric energy. Our design criteria were such that a minimum of 5W should be generated by our turbine at the wind velocity of 3m/s. The criteria can be met by a radial arranged magnetic core and the disk like arrangement of the copper wires. The arrangement is shown in the diagram below: The diagram below is the magnetic core in which the cylindrical protrusions are the magnets arranged radially

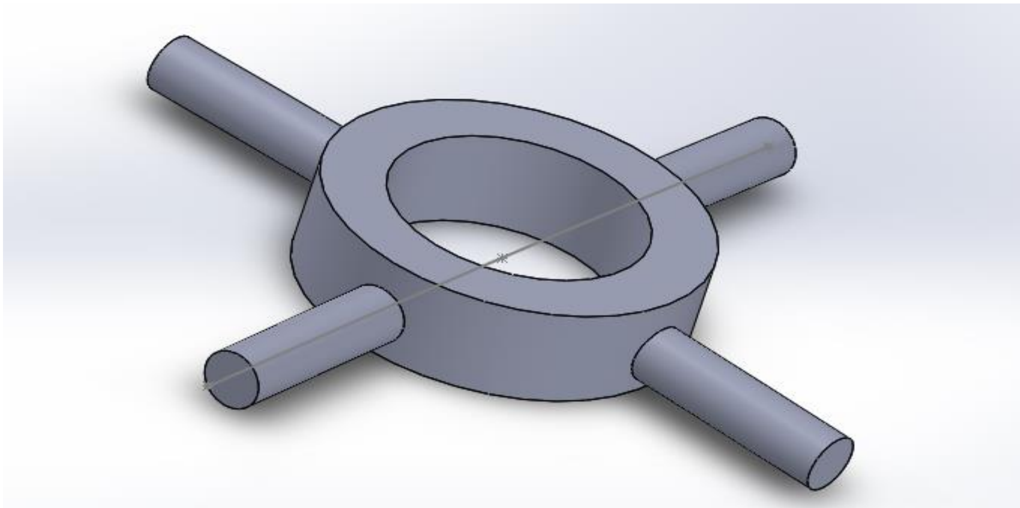


Figure 18 Magnetic core

The detailed calculations for amount of winding required to produce the required amount of the power e.g. 5V is given in the calculations section.

- **4-Base**

The base is made of the mild steel and the reason why a heavy base is used is the fact that a heavy base would make sure the stability of the whole system and avoid over turning. In addition to this, hooks will used to fix the base to the ground to make sure additional support is provided. The base model is shown in the figure below:

Figure 19 Base

CHAPTER 4: RESULTS AND DISCUSSIONS

Simulation:

We have done great deal of simulations to get a better understanding of the project and how to do it more efficiently. We optimized the parameters before going in the fabrication phase as we can't make our project cost efficient if we waste material and try random experiments. Simulation helped us a great deal in understanding the results and how we can go about countering a particular problem. Our entire simulation can be sub divided into 2 portions.

- CFD based simulations(Ansys)
- Structural vibration based simulation(Solidworks)

Simulation model:

At 1st as we didn't know what we are dealing with, we assumed our model to be a 2D one that gave us a vague idea what factors can affect our solution, how can we improve it and what type of domain will be suitable for our design. We did an extensive 2D simulation and noticed that to decrease our computation time significantly we need to make our fluid domain like a rectangular box instead of cube as there are significant changes occurring along the direction of progression of fluid flow.

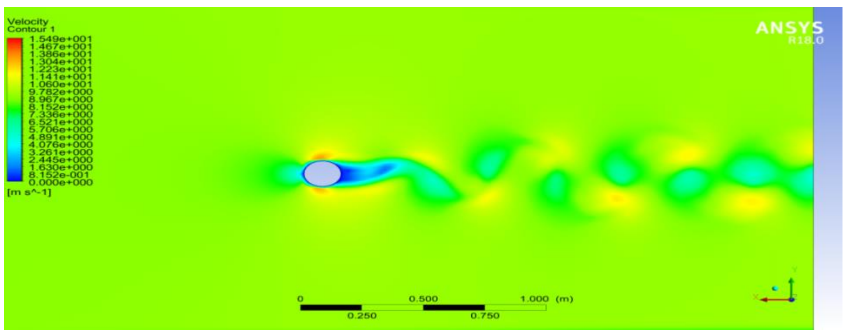


Figure 20 2D Fluid flow simulation

As one can easily that velocity gradient is considerable along the flow direction and there is a velocity trail so we have to make our domain rectangular to save computational time.

CFD simulation:

After our 2D analysis we were ready to use our 3D model in a CFD simulation in order to get the frequency of vortex which can then be compared with the natural frequency of the body and if they don't match then tuning can be applied to the system. Given below is our CFD model for entire 3D simulation.

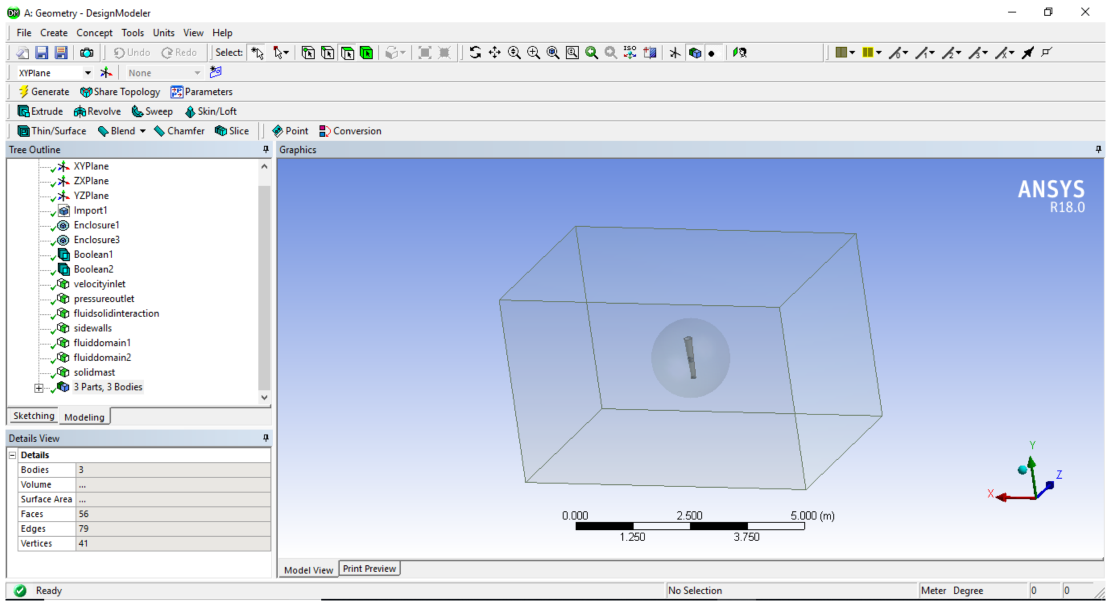


Figure 21 CFD 3D Model

In order to do CFD part of the project we separated the mast (top part) of our model from rest of the body and then took it into the fluid domain because this is the part that is going to be responsible for making **Vortex formation.** Our goal here is estimating the velocities and variation around mast and, frequency of the vortex formation. Frequency can be estimated by the total number of vortex formed in particular number of time steps corresponding to a particular time step size giving us a total time interval.

We can see multi region fluid domain which can be used to further refine the mesh without creating too many cells and thus saving us time in simulation thus increasing the time interval that we need for calculating frequency.

Solver Used:

We used a 2 equation K-omega model with low Re and shear flow corrections that involved less equation and had significantly low time per iteration and it results can be viewed by normal computers unlike LES as its results viewing and saving requires tremendous amount of ram and computational power.

The material used for fluid domain is Air and for solid is aluminum given below is the set of boundary condition we used.

Boundary Conditions:

- **Velocity Inlet:**

The inlet velocity is taken to be 9ms^-1 and the turbulence is specified by turbulence intensity and hydraulic diameter as 10 percent and 2.5m respectively.

- **Pressure Outlet:**

The outlet pressure is taken as 0 (gauge) and all walls are taken as stationary walls as our basic concern was to calculate the frequency of vortex.

We used a report file to save the time values that can be used later on the method for solving is default and hybrid initialization was used and the number of iteration was 500 with .001s of time step size and 1 iteration per time step size to give us a total interval of .5 sec.

- **Wall Conditions:**

No Slip condition was applied on walls.

Meshing:

We use a multi-region mesh. The purpose was to refined the entire domain in such a way as to achieve maximum accuracy in results with minimum number of elements thus increasing computational efficiency. We could have used fine meshing that would have created more number of elements and have obtained the same accuracy in results as our current model but that would have been problematic in later part of the simulation.

We had total number of 935854 number of elements and this the mesh we used for our calculation and this has very high convergence rate unlike other simple mesh though it take a little more time per iteration for coarse mesh.

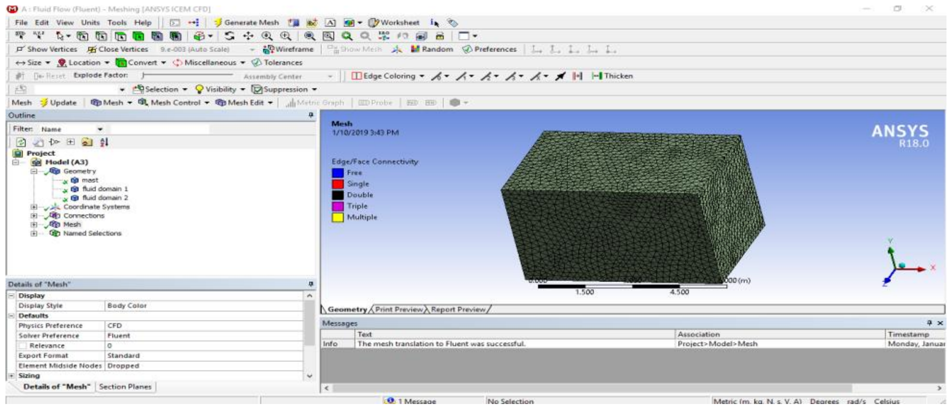


Figure 22 Meshing outer domain

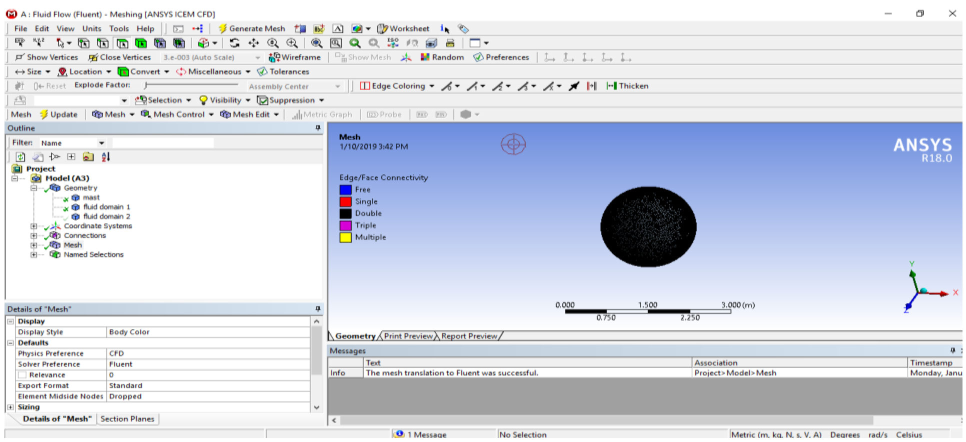


Figure 23 Meshing inner domain

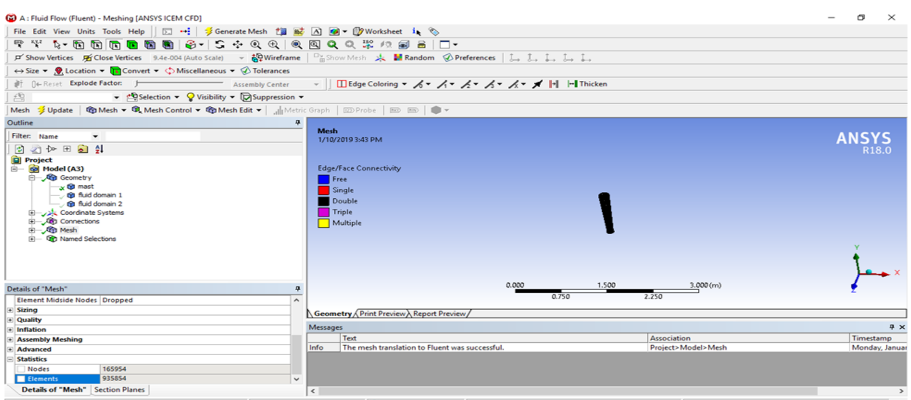


Figure 24 Meshing model

Results:

The results we got from our CFD model was quite promising and was almost in agreement to the calculation based results as the frequency we obtained from our model is 5Hz and the Frequency we obtained from calculation is 6Hz and that was under similar condition and geometrical model. Thanks to our multi regional mesh we managed a time step size of ½ Second and obtained the frequency by making a video of that time step size and counted the number of vortex formed in that time spam at a slower video speed. The convergence rate of our model was quite good and we performed a number of simulations to get accurate the results. The convergence plot for 300 iterations is given below:

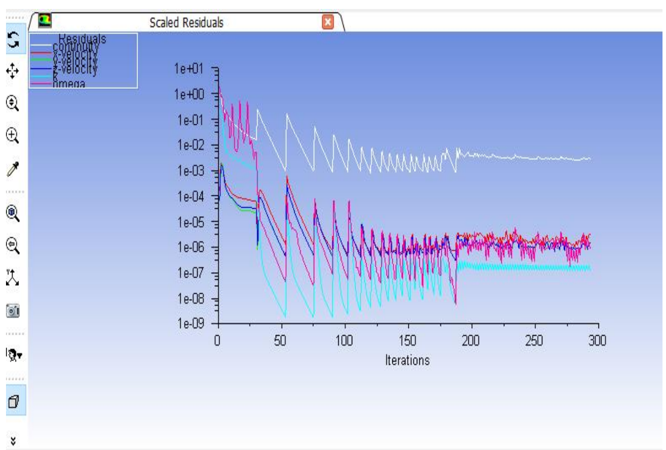


Figure 25 Convergence plot

We did 200 more iteration to get a time step size of ½ second as time step size for each iteration is 1/1000th of a second. We went up to residual of 1e-9 and the velocity of 14.34m not far from the 2D results. With each progression in iteration value was decreasing so for further iteration let's say about 2000 iteration it could have been brought close to 14.3.

I would like to add that decreasing mesh size is important but we need to optimized mesh size with regional refinement with compute time so that we can get good results with minimum compute power. The velocity contour of our 3D model is given below which has a maximum of **14.34 ms^-1.**

Note: this is a velocity contour at a particular interval of our total time step size.

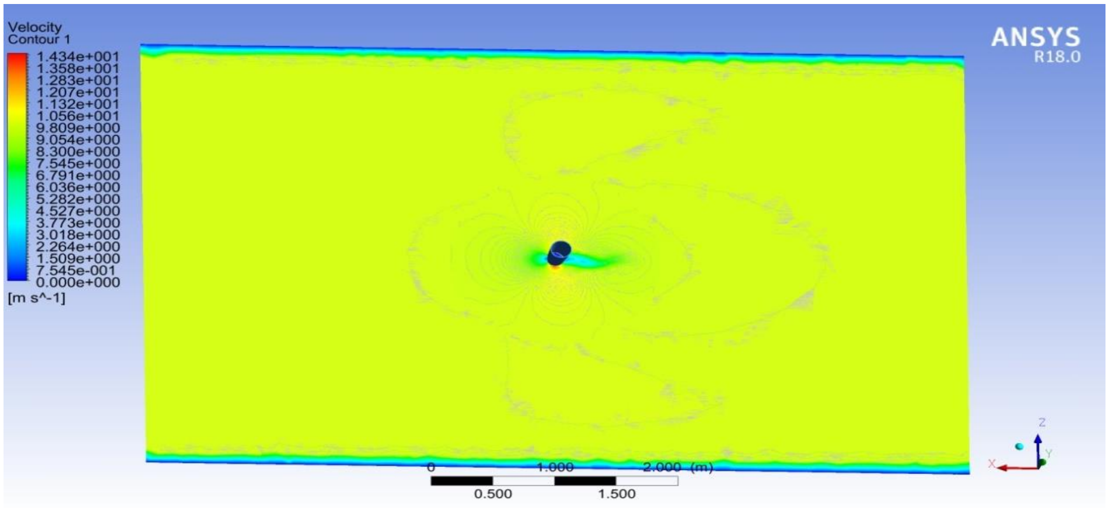


Figure 26 3D Contour velocity profile

Combining all these step size we created a video which has almost 2.5 vortex formations and that was in ½ of a second and that all gives us a **vortex frequency of 5Hz @ 9ms^-1** air velocity coming into the fluid domain as

$$vortex\ frequency = \frac{Number\ of\ Vortex}{time\ step\ size} \quad (3)$$

$$f = \frac{2.5}{.5s} = 5Hz \quad (4)$$

Problem Faced and countermeasure:

- The results in our CFD simulation weren't converging with moderate mesh we used multi regional mesh and used extra fine meshing in regions where it mattered.
- At 1st our iteration time was greater as I saved report file after each iteration but later on 1 chose to save file at the end of 5 iterations so that it decreases total iteration time.

- Time step size was the real issue as with increase in time step size we wouldn't be able to get good results and with increase in it we have to do more calculations so we refine the meshing a bit more and was able to get good results at time step size of .001s.
- The contour plot was using much ram and was unable to display so we reduced the number of contours to create a balance between the fineness and the amount of RAM it takes.

Solidworks Simulation:

To calculate natural frequency of our body we used Solidworks. We chose Solidworks for this part of simulation because Solidworks provide wide range of frequency modes and the deflection which can be used to determine the safe limit of displacement variation. We need natural frequency of the body because comparing this frequency with the frequency of the vortex we can determine the extent of circuit tuning required.

Material Assignment:

The material assigned to the entire body can be seen by a picture below

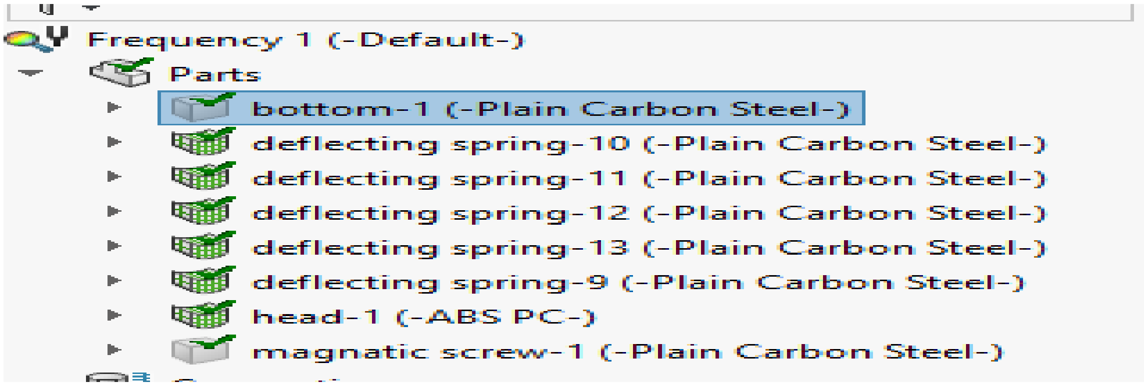


Figure 27 Material assignment

Entire body was assigned plain carbon steel except Head which is made of a light plastic like material ABS PC which is significantly light and study and have exceptional strength to weight ratio.

Part exclusion:

The parts of the body which were not required in the simulation were excluded so that the meshing can be done without any error. At initial stage our mesh failed and the reason is following

The mesh element size is not enough to define the profile of threading in the bottom and screw of our design. I tried decreasing the size to a certain level by using mesh control but this still wasn't enough to prevent the mesh failure and then I had to exclude these parts and then reevaluated the condition applied.

Condition applied:

As we need natural frequency of the body we didn't used any external force but as we excluded the bottom part and screw we have to apply fixed condition on something.

As the frequency depends on the stiffness of the spring applied we used bottom of the spring as the fixed support of our entire body so that spring should be included in the frequency evaluation.

Meshing:

The meshing in Solidworks is quite simple as it can be improved with mesh control and factors determining the mesh element size are its fineness scale and regional application which is either scaled or a mesh size can be defined as well, in our case we used both.

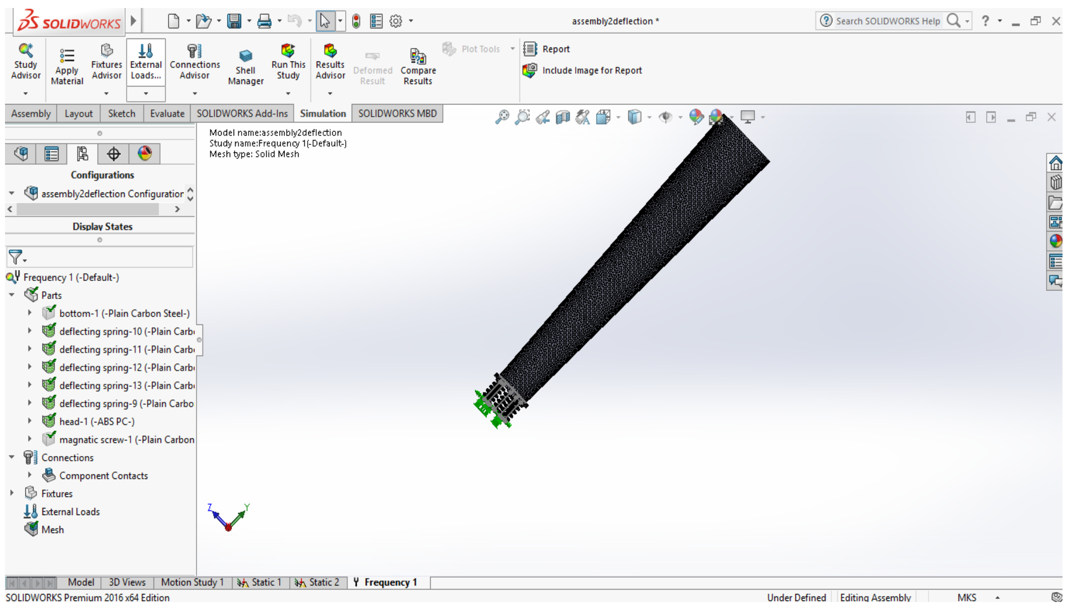


Figure 28 Final Mesh

Results:

The results of this simulation were in close agreement to the calculation as we obtained 4.5Hz as natural frequency of our body and with calculation we obtained 5Hz. Furthermore the deflection obtained was within the safe limits and it is between the tolerances allowed so that the internal shaft doesn’t hit the mast. The vortex frequency we obtained from the CFD model is 5Hz and the natural frequency of the body is 4.5Hz we in order to obtain resonance in our system we need to tune the system so that these two frequency matches. The tuning applied to the system is through electromagnets whose current supply determines the magnetic resistance provided to the solenoid which is then connected to the mast.

There are many modes of frequency but the one indicating the oscillation of mast that induces the current in the solenoid coil is first mode frequency and its results can be seen in the picture given below.

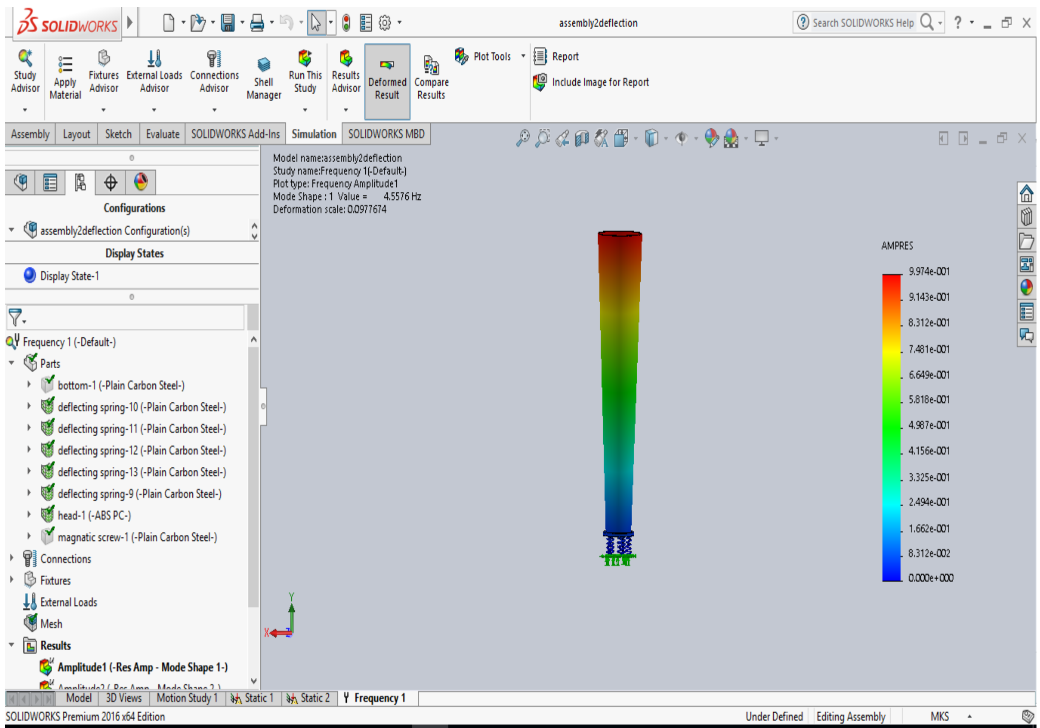


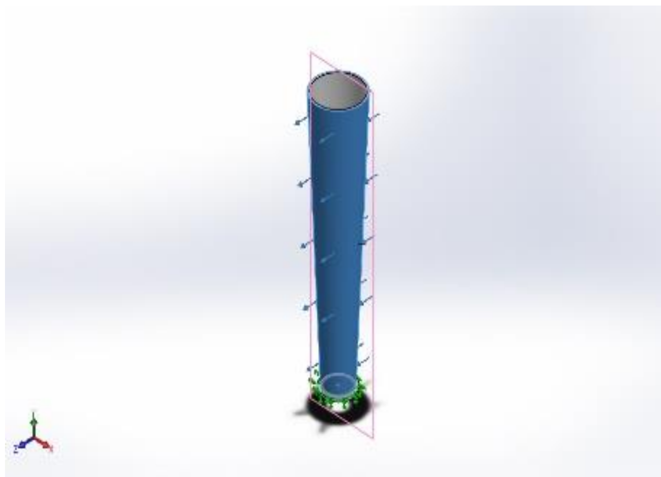
Figure 29 Structural frequency results

Problems faced and countermeasure:

- The meshing failed a couple of time as the meshing was not enough to define the threading profile so we excluded these parts as they weren't involved in frequency determination as fixing the springs at bottom is same as fixing the body connected to the springs.
- The solving at 1st was taking much time with smaller mesh size so I upsized the mesh to get a balance between the computational time and its fineness

Stress simulations

- In our design we were able to do stress simulations as well. We used solid works software to do stress simulations. For our simulation we assumed the beam as cantilever and applied uniform load of 70 N as shown in the diagram:

Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s), 1 plane(s) **Reference:** Front Plane **Type:** Apply force **Values:** ---, ---, 70 N

We were then able to determine the von mess's stress as shown below

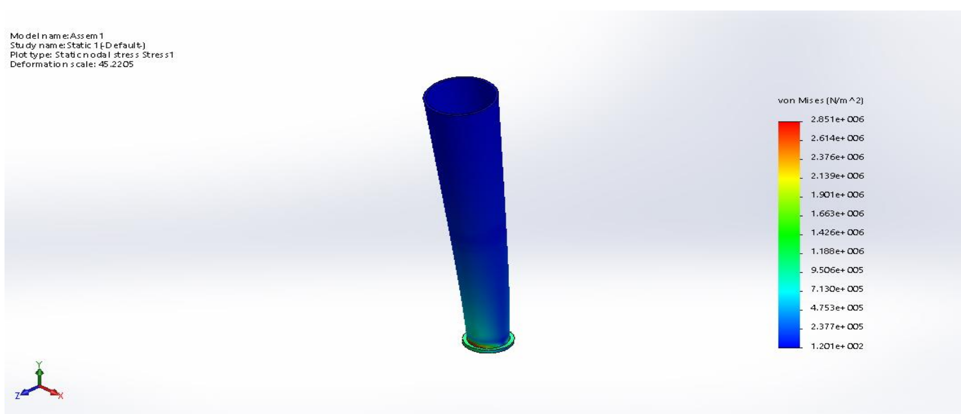


Figure 30 Stress Analysis

The displacement results are as following:

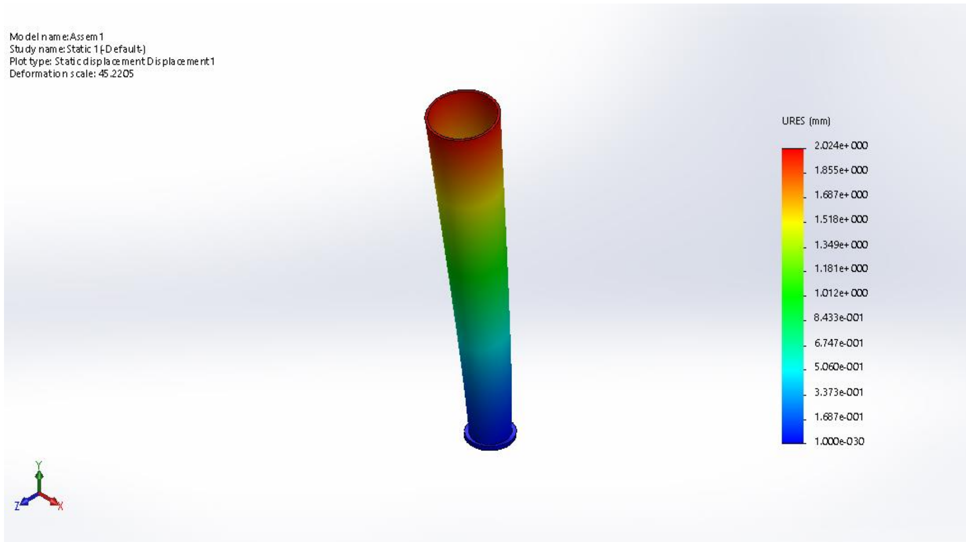


Figure 31 Displacement results

Conclusion:

In our stress simulation part we were able to find that the maximum stress developed at 70 N uniform Force is less than the yield strength of the material which is **28 MPa and the maximum stress developed is 3 MPa.** So our design is safe.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

Conclusion

In our project we devised two domains. These domains are as following:

- Simulation domain
- Calculation domain

The simulation domain comprises of the simulation of the concept design on Ansys and solid works to calculate the natural frequency of the mast and the vortex shedding frequency of the vortices. Following results were drawn from the simulation software

The natural frequency of the mast turns out to be **4.5 HZ**

The frequency of the vortex shedding turns out to be **5 Hz**

The stresses developed for a force of 70 N were not exceeding the safety limits of the design stresses, so our design was safe

The calculations part consists of developing the mathematical model for the design and calculating the natural frequency through it. Moreover, it also comprises developing the mathematical models for the mast to calculate the stresses developed under the wind loads. Furthermore, the calculations domain also includes the calculation of the stiffnesses of the spring assembly used in our design. Furthermore, it also includes the vortex shedding frequency

Following conclusions were drawn from our calculation part

The frequency of the vortex shedding turns out to be **6 HZ** which is in close agreement with the frequency calculated from the simulation software.

The natural frequency of the mast turns out to be **8 rad/s, 2 HZ** which is the almost half the frequency which have got from the simulation software. The mast has several modes of frequencies and each higher order frequencies are the multiples of the lowest

frequency, so we can say our calculations and simulation part are in close agreement to each other.
The stress analysis part of the calculation domain consists if assuming the mast as the cantilever beam and then calculating the total bending stress developed. We concluded that our design was safe as the stresses developed were less than the tensile stresses of the mast.

Recommendations

In recommendation, utilizing the vibrations rather than cursing is one of the most attractive fields of research and needs a proper attention. Vibrations are usually very common in nature as they are random and cause of disorderliness. Since they are much prevailing in nature, so we can easily utilize these vibrations to generate electricity. Specifically, in our project the vortex shedding plays a vital role in producing vibrations however there might be other mechanism that we can utilize to generate the vibrations. For instance, the vibrations of leaves due to the wind can give us a clue that how we can generate vibrations in a system.

Moreover, in cooperating a piezoelectric material with our design can have a better effect our efficiency and we can generate much more power than without using a piezoelectric material.
Moreover, the use of carbon fiber as the material for our project might have increase the strength and reduced the weight of our design and if the material of the mast was itself a piezoelectric material our efficiency might have increased.

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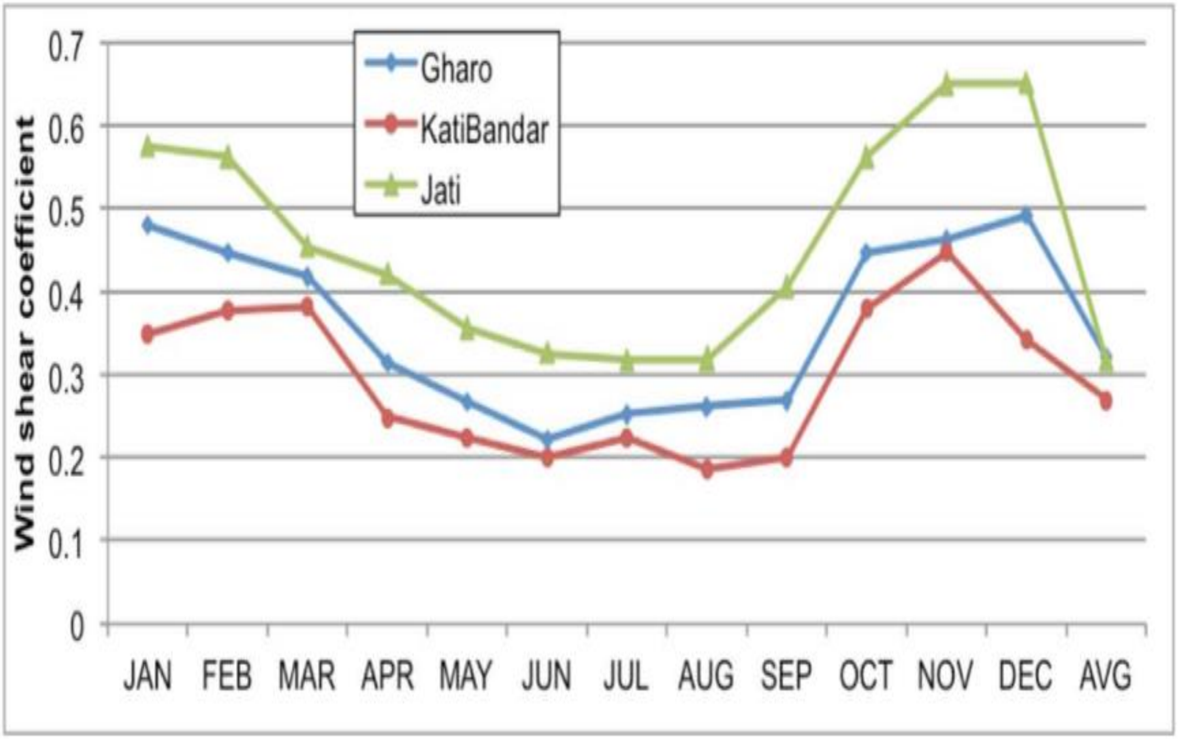
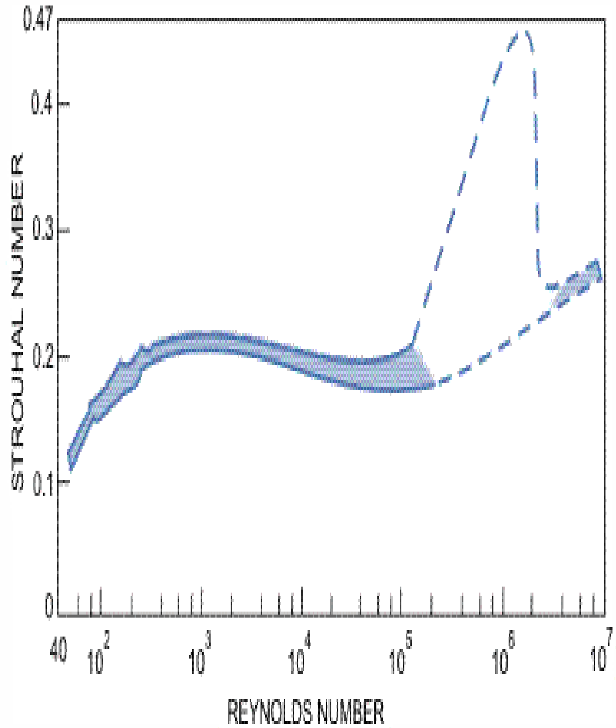
APPENDIX I: WIND SHEAR COEFFICIENT GRAPH



2: Monthly variation of (10 to 30 m) WSC measured by the three monitoring stations (2002 to 2005).

APPENDIX II: STROUHAL NUMBER



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