

Development of A Cubic Blade Profile Horizontal Axis Wind Turbine

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Abstract – A wind turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy in a process known as wind power. Wind energy is one of the most widely used renewable energy resources. In the present scenario, there is a need of generating power for various sectors, in order to accomplish this situation there are different sources but the cheapest sources is wind energy. But for many decades the design of wind turbine blade has no changes, hence in this paper a new model of the wind turbine. A new blade model of wind turbine blade is designed by using hermit curve. A cubic profile wind turbine is designed with the help of Pro-E software and analyzed through Computerized Fluid Dynamics (CFD).

Index Terms – Wind turbine blade, Hermit curve, Cubic profile, CFD analysis, Turbine blade design and analysis.

1. INTRODUCTION

The use of wind turbines for electrical power generation has been around for over one hundred years. A greater understanding of aerodynamics and advances in materials, particularly polymers, has led to the return of wind energy extraction in the latter half of the 20th century. Wind power devices are now used to produce electricity, and commonly termed wind turbines. Today there is a wide variety of commercial wind power systems commercially available. Even the lower power rated turbines, however, are generally designed for relatively high wind speeds, typically around 10 to 15 m/s. At lower wind speeds typical of many inland sites in South East Asia the commercially available wind power systems do not produce a significant amount of power. This either excludes them from use, or results in very inefficient power extraction in lower wind speed regions. With careful design of the turbine and generator, power production greatly in excess of commercial turbines is possible at lower wind speeds.

The wind potential of India is very high. The wind turbines have been installed and wind energy is being harvested, predominantly in the high wind velocity areas. However, due to the restriction of space, the comparatively lower wind areas are beginning to populate with similar wind turbines. In order to ensure the extraction of maximum wind potential even at lower wind speeds, these turbine blades have to be designed and analyzed to suit the low wind areas. At present India stands fifth in the world of wind power generation. Taking into consideration that a large portion of the Indian land will not be viable for the use of traditional windmills due to low wind speeds, a generator which would produce the energy even at low wind speed is required. Also the transmission losses in India are very high. Hence, to reduce the losses due to transmission the turbine could be placed near the place of consumption. Most of the leading wind turbine manufacturers consider blades as their key components of wind turbine system and have concentrated their efforts on developing their own blade design and increasing the supply through in-house production facility. This paper elaborates the design and development of such a wind turbine blade profile for domestic application by comparison with various profiles. This research work is for generating electricity at low wind speeds and that can be used to power the lighting requirements of a house.

With progress of economics and socialism, there is an expanding demand on renewable energy to secure the supply of energy such as solar, wind power. Wind energy is a plentiful resource in comparison with other renewable resources. In wind energy wind power is converted to electrical energy and this machine is called the wind generator. Power in the wind comes from the transformation of the air that is driven by the heat of the sun, which is abundant, clean and renewable. As the end of 2011 the installed capacity for wind power worldwide (cumulative total) was 238 GW. Of this, India's installed

capacity (16.1 GW) placed in fifth in the world and second in Asia after China (India's Potential Installed Capacity for Wind Power (Cumulative Total as the End of 2011)).

The discontinued mainstream development of the Vertical Axis Wind Turbine (VAWT) can be attributed to a low tip speed ratio and difficulty in controlling rotor speed. Difficulties in the starting of vertical turbines have also hampered development, believed until recently to be incapable of self-starting. However, the VAWT requires no additional mechanism to face the wind and heavy generator equipment can be mounted on the ground, thus reducing tower loads. Therefore, the VAWT is not completely disregarded for future development. A novel V-shaped VAWT rotor design is currently under investigation which exploits these favorable attributes. This design is currently unproven on a megawatt scale, requiring several years of development before it can be considered competitive. In addition to the problems associated with alternative designs, the popularity of the Horizontal Axis Wind Turbine (HAWT) can be attributed to increased rotor control through pitch and yaw control. The HAWT has therefore emerged as the dominant design configuration, capitalized by all of today's leading large scale turbine manufacturers.

2. PROBLEM IDENTIFICATION

Now days in the power generation field wind energy is the cheapest power source and a leading growing technology the use of wind turbines for electrical power generation has been around for over one hundred years. Recent concerns over the price and environmental impacts of fossil fuels have spurred the proliferation of wind turbines in a wide range of powers. The lack of electricity is a worldwide problem that affects over 1.6 billion people. This problem especially affects rural areas in developing countries. Here in generation of power source in wind energy the main influence depends upon the TURBINE BLADE design and engineering is one of the most complicated and important aspects of current wind turbine technology. Today engineers strive to design blades that extract as much energy from the wind as possible throughout a range of wind speeds and gust yet be durable, quiet and cheap. There is also no involvement of project considering both blade geometrical design and structural design.

3. INTRODUCTION TO HERMITE CURVE

Airfoil and wing design methodologies have made large steps forward through the availability of rapid computational tools which allow for specification of goals in aerodynamic performance. These goals are mainly to increase a measure of efficiency, like the ratio of lift over drag, or, in the higher speed regimes, its product with flight Mach number. The need for increased lift at higher flight speed, with drag kept low, has led to the development of knowledge bases for aerodynamic design: The art of shaping lift generating devices like aircraft wings is based on geometric, mechanical and fluid dynamic

modelling, carried out with the help of mathematical tools on rapid computers. Given a designer's refined knowledge about the occurring flow phenomena, his goal may be to obtain certain pressure distributions on wing surfaces: This may be reached by inverse approaches with a shape resulting from the effort, or by applying optimization strategies to drive results toward ideal values.

With such methods we have refined tools available for extending our practical knowledge how the geometries of airfoils and wings are related to pressure distributions and aerodynamic performance. Certain details of desirable pressure distributions require a modelling of details in the boundary condition, usually a special feature of the curvature distribution. This is true especially in the transonic flow regime, where favorable as well as undesirable aerodynamic phenomena are correctly modelled by certain weak or strong singularities in the local mathematical flow structure including the flow boundary. Numerical optimization methods iteratively adjusting the resulting 2D or 3D shapes usually employ smoothing algorithms based on polynomials, splines and similar algebraic functions. These functions may be ignoring local properties of the shape being compatible to the inverse input, while they should accommodate the results from analytical inverse methodology using hodograph formulations of the governing equations. Hodograph- type methods, though not practical tools, have led to a deeper understanding about the relations between surface geometry and the structure of recompression shocks. These methods are most usefully applied to designing nearly shock-free airfoils and wings with favorable design behavior. Understanding the resulting refined shapes and modelling them in a direct approach with a suitable geometry generator is a continuing challenge for more complex 3D configurations like complete aircraft, turbo machinery components and models for interdisciplinary design. The present contribution is aimed at using explicit mathematical functions with a set of free parameters to define wing surfaces of practical interest for realistic aircraft applications, with a potential to arrive at optimum values of objective functions like aerodynamic efficiency, with a minimum of parameters having to be varied, because these parameters are defined from application of the fluid mechanic and gas dynamic knowledge base or prescribed by modelling kinematic models of a mechanical adaptation device.

With airfoil theory and airfoil data bases being well established components of applied aerodynamics on the ground of lifting wing theory, it is necessary to allow for using such data as a direct input in any wing geometry definition program. This fact was the motivation to provide spline interpolation for such given airfoil data in a first version of our geometry code, which has been described in various papers and publications. Recently these developments have been summarized in, here we focus on continuing this activity in the area of describing

airfoils with more a sophisticated method than providing a set of spline supports.

4. MATHEMATICAL & GEOMETRICAL MODELLING OF CURVE PATTERN FOR BLADE DESIGN

Here for modelling of curve we have chosen the HERMITE CUBIC CURVE pattern generation. In numerical analysis, a cubic Hermite spline or cubic Hermite interpolator is a spline where each piece is a third-degree polynomial specified in Hermit form that is, by its values and first derivatives at the end points of the corresponding domain interval. Cubic Hermite splines are typically used for interpolation of numeric data specified at given argument values, to obtain a smooth continuous function. The data should consist of the desired function value and derivative at each. Cubic polynomial splines can be specified in other ways, the Bezier form being the most common. However, these two methods provide the same set of splines, and data can be easily converted between the Bezier and Hermit forms; so the names are often used as if they were synonymous. Cubic polynomial splines are extensively used in computer graphics and geometric modeling to obtain curves or motion trajectories that pass through specified points of the plane or three-dimensional space. In these applications, each coordinate of the plane or space is separately interpolated by a cubic spline function of a separate parameter t. Cubic splines can be extended to functions of two or more parameters, in several ways. Bicubic splines (Bicubic interpolation) are often used to interpolate data on a regular rectangular grid, such as pixel values in a digital image or altitude data on a terrain. Bicubic surface patches, defined by three bicubic splines, are an essential tool in computer graphics.

Hermite cubic curve is also known as parametric cubic curve, and cubic spline. This curve is used to interpolate given data points that result in a synthetic curve, but not a free form, unlike the Bezier and B-spline curves. The most commonly used cubic spline is a three-dimensional planar curve (not twisted). The curve is defined by two data points that lie at the beginning and at the end of the curve, along with the slopes at these points. It is represented by a cubic polynomial. When two end points and their slopes define a curve, the curve is called a Hermite cubic curve. Several cubic splines can be joined together by imposing the slope continuity at the common points. Parametric spline curves are defined as piecewise polynomial curves with certain order of continuity. The parametric cubic spline curve connects two data (end) points and utilizes a cubic equation.

General condition required:

1. Two end points
2. Two end slopes

The parametric equation of a cubic spline segment is given by:

$$P(u) = \sum_{i=0}^3 C_i u^i \quad 0 \leq u \leq 1$$

Where, u – Parameter, Ci . Polynomial coefficients, the scalar form of equation:

$$X(u) = C_{3x} u^3 + C_{2x} u^2 + C_{1x} u + C_{0x}, y(u) = C_{3y} u^3 + C_{2y} u^2 + C_{1y} u + C_{0y}$$

$$z(u) = C_{3z} u^3 + C_{2z} u^2 + C_{1z} u + C_{0z}$$

The vector form of equation:

$$P(u) = C_3 u^3 + C_2 u^2 + C_1 u + C_0$$

P ₀ X	P ₁ X	P' ₀ X	P' ₁ X
1	1	2	2
P ₀ Y	P ₁ Y	P' ₀ Y	P' ₁ Y
1	1	2	2

Table 4.1. Hermite cubic curve pattern

P₀ – Starting point, P₁ – End point, P'₀ – Starting slope, P'₁ – Starting slope

To find the coefficients Ci, Apply the known boundary conditions,

P₀, P'₀ at u = 0, P₁, P'₁ at u = 1, Position and slope equation are:

$$P(u) = C_3 u^3 + C_2 u^2 + C_1 u + C_0$$

$$P'(u) = 3C_3 u^2 + 2C_2 u + C_1$$

When applying u = 0 and u = 1 on the position and slope equations:

$$P_0 = C_0, P'_0 = C_1, P_1 = C_3 + C_2 + C_1 + C_0, P'_1 = 3C_3 + 2C_2 + C_1$$

After solving the above four equations by simultaneous solution method the coefficients are:

$$C_0 = P_0, C_1 = P'_0, C_2 = 3(P_1 - P_0) - 2(P'_0 - P'_1)$$

After substituting all four coefficient, the final blending functions are:

$$P(u) = (2u^3 - 3u^2 + 1)P_0 + (-2u^3 + 3u^2) P_1 + (u^3 - 2u^2 + u)P'_0 + (u^3 - u^2) P'_1$$

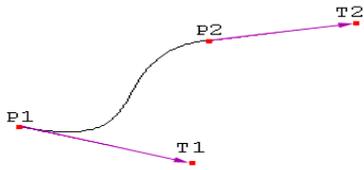
$$P'(u) = (6u^3 - 6u)P_0 + (-6u^2 + 6u) P_1 + (3u^2 - 4u + 1)P'_0 + (3u^2 - 2u) P'_1$$

$$B_1 = (2u^3 - 3u^2 + 1), B_2 = (-2u^3 + 3u^2), B_3 = (u^3 - 2u^2 + u), B_4 = (u^3 - u^2)$$

Now with this blending formula we have derived the various curve pattern by feeding this formula calculator in the MS-EXCEL shows the Table 4.1 and we have obtained this graph. This excel backup file is created so that various curve pattern

for starting points and for slope you can analysis and obtain a required graph.

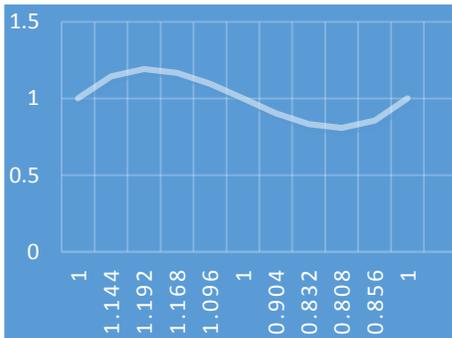
Table 4.1. Hermite Curve Blending Function



X-Y GRAPH INTERPOLATION

XY graph represent the main axis graph derived from the required points we have fixed.

P_0 – Starting point, P_1 – End point, P'_0 Starting slope, P'_1 Starting slope are shown in the table 3.2



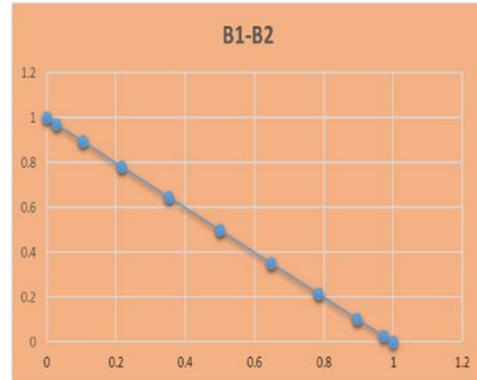
Graph generated for X & Y by using Hermite curve.

B1&B2, B3&B4 INTERPOLATION.

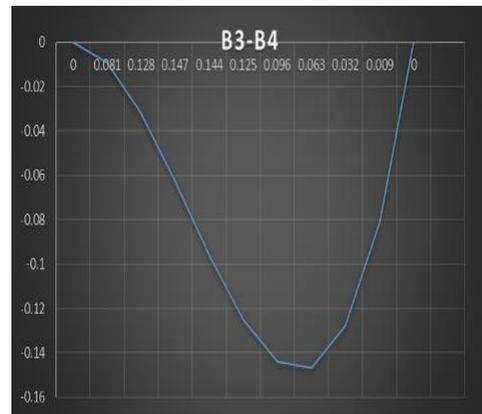
Table 4.2. Hermite Curve Blending Function

B1	B2	B3	B4	X	Y
1	0	0	0	1	1
0.972	0.028	0.081	-0.009	1.144	1.144
0.896	0.104	0.128	-0.032	1.192	1.192
0.784	0.216	0.147	-0.063	1.168	1.168
0.648	0.352	0.144	-0.096	1.096	1.096
0.5	0.5	0.125	-0.125	1	1
0.352	0.648	0.096	-0.144	0.904	0.904
0.216	0.784	0.063	-0.147	0.832	0.832
0.104	0.896	0.032	-0.128	0.808	0.808
0.028	0.972	0.009	-0.081	0.856	0.856
0	1	0	0	1	1

These curve pattern studies about the various curve pattern with respect to the x-y curve. Now we can also study the various curve pattern for the changes in the obtained, for more complicated curve we can address this type of interaction are required. Also the verification and validation of the curve pattern can be done by using these interpolation standard curves is shown in Figure 7.1 and 7.2

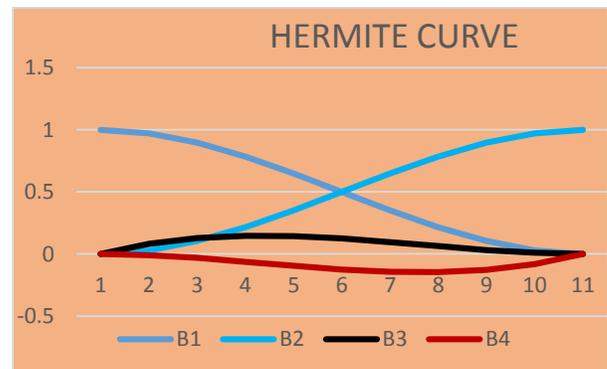


Graph generated for B1&B2 interpolation



Graph generated for B3&B4 interpolation.

HERMITE BLENDING CURVE INTERPOLATION



The interpolation of each subinterval in a linear combination of these four blending functions

- B1 starts at 1 and goes slowly to 0.
- B2 starts at 0 and goes slowly to 1

5. MODELLING OF HERMITE CUBIC SPLINE CURVE PROFILE USING PRO-E SOFTWARE

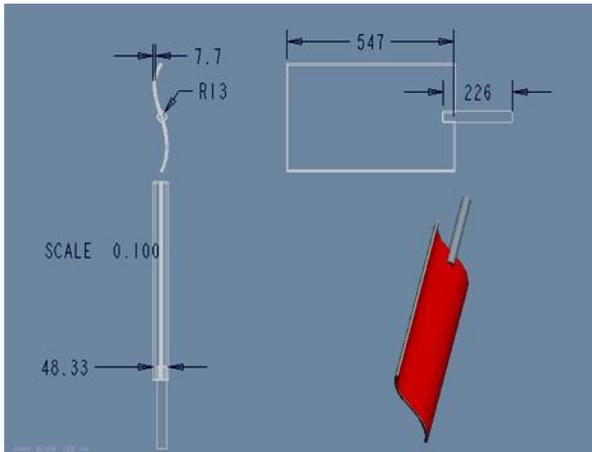


Figure 5.1 The 3D Modelling of the blade profile using the Hermite cubic curve by PRO-E software

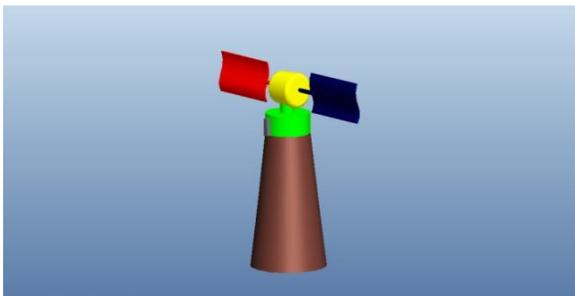
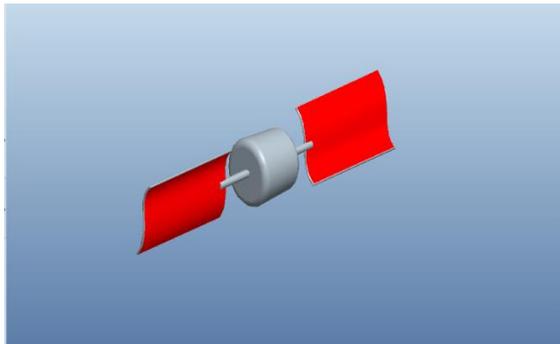


Figure 5.2 The 3D Modelling of the assembly of the wind turbine blade

6. ANALYSIS OF HERMITE CUBIC SPLINE CURVE PROFILE BLADE HORIZONTAL WIND TURBINE

COMPUTATIONAL FLUID DYNAMIC ANALYSIS

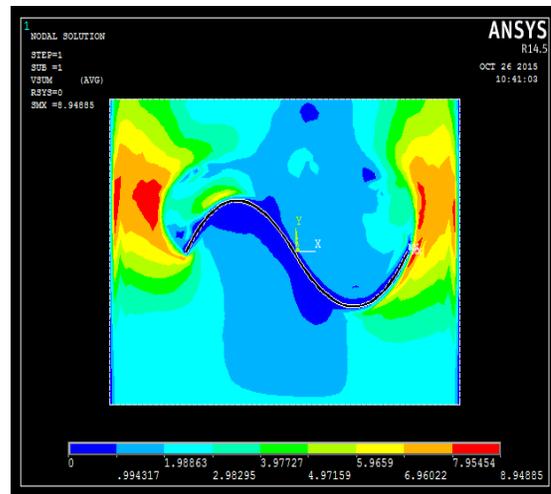
Computational fluid dynamics, usually abbreviated as CFD, is a branch of fluid mechanics that uses numerical

analysis and algorithms to solve and analyze problems that involve fluid flows.

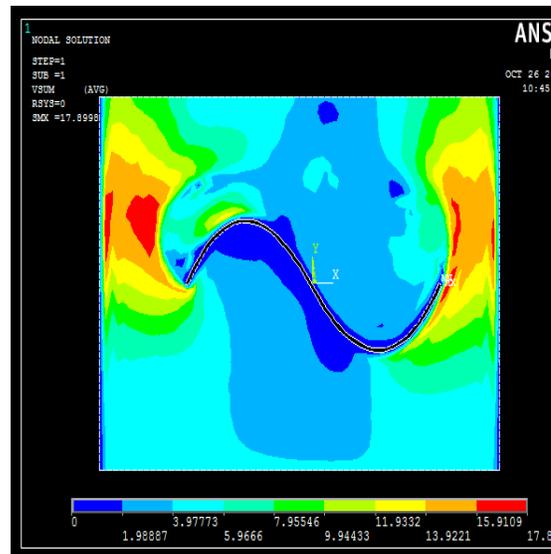
FLOTRAN analysis that ANSYS is able to perform include:

- Laminar or Turbulent Flows
- Thermal Fluid Analysis
- Adiabatic Conditions
- Free surface Flow
- Compressible or incompressible Flows
- Newtonian or Non-Newtonian Fluids
- Multiple species transport
- Contour Plots for Pressure And Velocity For Various Inlet Speed

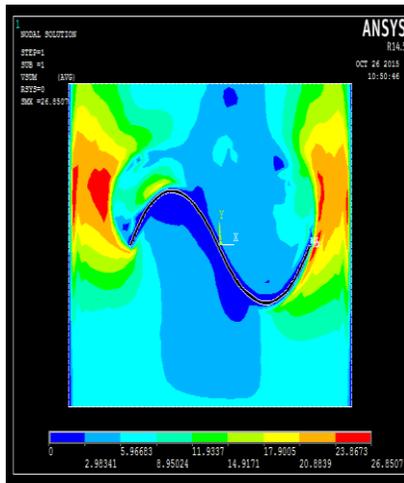
Velocity for 2m/s



Velocity for 4m/s



Velocity for 6m/s



Three dimensional analysis of single turbine blade:

Here now for more interpolation of result the three dimensional analysis is been done, where the air movement across the three dimensional view for the movement of the blade is done, this implies the clear movement of air which strikes the blade where one half of the rotation is actuated by air other half is actuated the design of the blade curvature design and makes the free movement of the blade. Hence this type of turbine infers more power generation than the normal three blade.

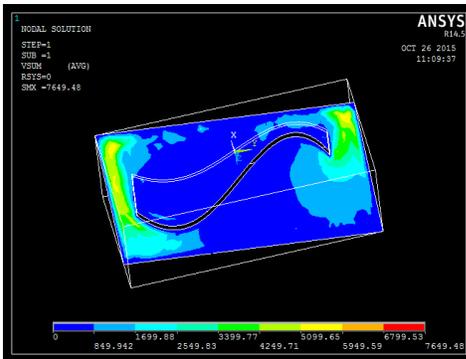


Figure 6.1 three dimensional contour plots for pressure and velocity

TORQUE CALCULATION

The kinematic energy K for an air mass M and wind velocity V

$$K = 1/2 MV^2$$

Air mass M can be expressed as

$$M = \rho AtV$$

ρ - Density of air

A-Sectional area

t- Time

HENCE KINETIC ENERGY

$$K = 1/2 \rho AtV^3$$

Now power is work done for unit mass and for one sec, hence power is

$$P = 1/2 \rho V^3$$

Now our derivation for pressure, Here the wind power density at temperature T and at pressure P can be written as

$$\text{Power} = 0.61125 * (P/101325) * (288.15/T) * V^3$$

For ideal gas at a standard temp of 15degree and sea level pressure of 101325Pa at a mass of 1.225Kg per cubic meter

NOMENCLATURE

K - Kinematic energy

M - Air mass A -Sectional area

t - Time

P - Pressure

Now for the temperature of 22 degree when we calculate final derivation we obtained is

$$\text{Power} = P * V^3$$

$$\text{Speed (rpm)} = 60,000 \times \text{speed (m/s)}$$

$$\pi \times \text{diameter (mm)}$$

$$\text{Angular velocity (Rad/sec)} = v / r$$

$$\text{Torque (Nm)} = 9.55 \times \text{Power (watts)} / \text{speed (Rpm)}$$

Now for the value of the pressure and velocity obtained in the CFD for various velocities we can evaluate the power and evaluate our model can be validated is been tabulated in Table 5.1.

Figure 6.2 Torque vs. Power

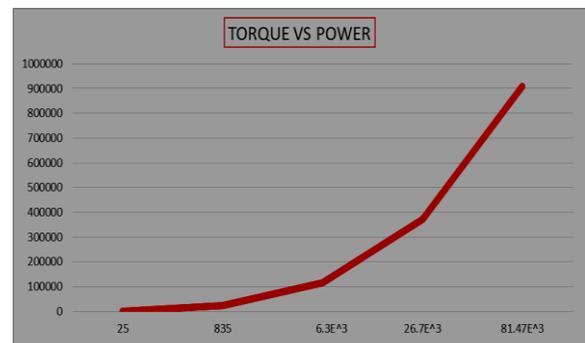


Table 6.1 Mathematical calculation for the input velocity and the power output

Results required for analysis

Stresses, strains and displacements as a function of time.

The procedure for a static analysis consists of three main steps:

- 1. Build the model
- 2. Apply loads and obtain the solution
- 3. Review the results

The overall equilibrium equations for linear structural static analysis are

$$[K] \{u\} = \{F\} \text{ OR } [k]_N$$

Where: $[K]$ = total stiffness matrix = $\sum [K_e]$

$\{u\}$ = nodal displacement vector

N = number of elements

$\{F_q\}$ = total applied load vector

$\{F_r\}$ = reaction load vector

Table 6.2 Geometrical properties of the model

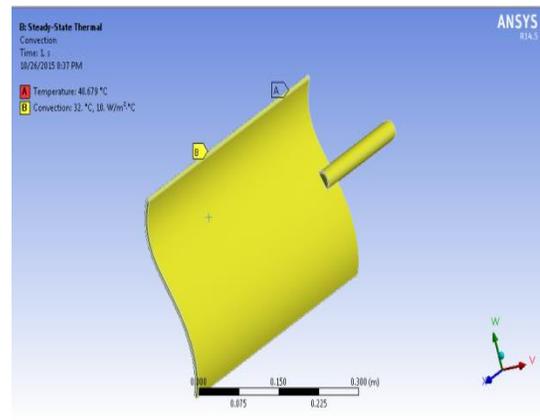
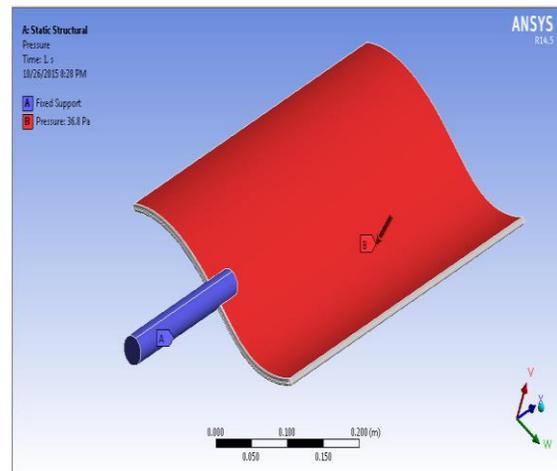
Length X	4.8327e-002 m
Length Y	0.30159 m
Length Z	0.738 m
Volume	1.4745e-003 m ³
Mass	11.575 kg
Centroid X	2.7647e-003 m
Centroid Y	-1.2572e-003 m
Centroid Z	0.23817 m
Moment of Inertia	0.47796 kg·m ²

Table 6.3 Material properties of the model

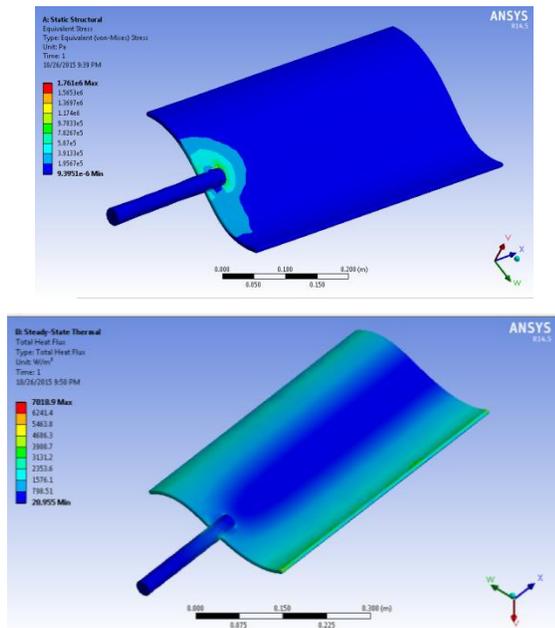
Density	7850 kg m ⁻³
Coefficient of Thermal Expansion	1.2e-005 C ⁻¹
Specific Heat	434 J kg ⁻¹ C ⁻¹
Thermal Conductivity	60.5 W m ⁻¹ C ⁻¹
Resistivity	1.7e-007 ohm m
Young's Modulus (Pa)	2.00E+11
Poisson's Ratio	0.3
Bulk Modulus (Pa)	1.67E+11
Shear Modulus (Pa)	1.67E+11

INPUT VELOCITY (m/s)	MAX PRESSURE (Pa)	MAX VELOCITY (m/s)	SP EED (R P M)	ANG ULAR VELOCITY (Rad /s)	POWER (Kw)	TOR QUE (NM)
2	36.48	8.94	168	4.47	25	1421.13
4	145.62	17.89	342	8.9	835	23316.52
6	327.56	26.85	513	13.85	6.3×10 ³	116666.67
8	582.18	35.8	684	17.9	26.7×10 ³	372924.71
10	909.61	44.75	855	22.38	81.47×10 ³	909986.55

STRUCTURAL AND THERMAL BOUNDARY CONDITION



DEFORMATION AND STRESS PATTERN FOR STEEL MATERIAL



Thermal Gradient and Heat Flux Pattern for Steel Material

7. CONCLUSION

Geometrical modelling of the curve pattern is derived using Hermite cubic curve and its blending function. Derived curve is patterned in PRO-E software.

Solid modelling of the blade structure is modelled using 3D modeling software PRO-E. Computational fluid dynamic analysis for curve pattern is obtained where the pressure and velocity contours for different input velocities is been achieved. Mathematical derivation for the Power output for our blade design is derived, where the output of the CFD result, pressure

and velocity is given as input data to verify the power output and torque.

The output of power and torque value infers that our new model of blade profile is under excellent performance condition. Structural and thermal analysis for the blade is been done to verify under various working condition, where the stress, deformation and thermal gradient result induces a positive result of implementation under real working condition.

CFD analysis of two blade and three blade profile to be done and their power output to be verified. Structural and thermal analysis for various materials yet to be done. Vibrational and fatigue analysis also to be done and verified for their performance and real time working condition.

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