DESIGN AND STRESS ANALYSIS OF TURBINE BLADE PROFILE USING NURBS

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ABSTRACT

CAD provides the opportunities to explore design options and development. Most of the existing design systems rely upon Non Uniform Rational B-Splines for geometric definition and representation. Curve fitting is the process of constructing a curve, or mathematical function that has the best fit to a series of data points, possibly subject to constraints. A curve may be represented as collection of data points. Provided the points are properly spaced, connection of points by short straight line segments yields an adequate visual representation of curve. In the proposed paper NURBS are used to generate 2D turbine blade profile using the designer's imaginative input coordinates. The stress analysis is done on various profiles generated to check the effectiveness of proposed model from manufacturing point of view.

Keywords: **CAD, Curve fitting, interpolation, NURBS, ANYSY14.5**

I. INTRODUCTION

Curve fitting can involve either interpolation, where an exact fits to the data required, or smoothing process in which a smooth function is constructed that approximately fits the given data. Fitted curves can be used as a means for data visualization, to infer values of a function where no data are available and to summarize the relationships among two or more variables.

Development of NURBS began in the 1950s by engineers for mathematically precise representation of freeform surfaces like ship hulls, aerospace exterior surfaces, and car bodies, which could be exactly reproduced whenever technically needed. In statistics and image processing, to smooth a data set is to create an approximating function that attempts to capture important patterns in the data, while leaving out noise. It may be used in two important ways that can aid in data analysis (1) By being able to extract more information from the data as long as the assumption of smoothing is reasonable and (2) By being able to provide analyses that are both flexible and robust.

II. LITERATURE SURVEY

In 1993, the first interactive NURBS modeler for Personal Computers was developed by CAS Berlin, a company cooperating with the Technical University of Berlin. Today most professional computer graphics applications available for desktop use offer NURBS technology, which is most often realized by integrating a NURBS engine from a specialized company.

The use of 4^{th} order splines results in continuous slope of curvature [1]. The blade shapes were specified by a few points and other geometric parameters on blade surfaces, and an optimization routine was used to minimize change in the slope of curvature. It was found that the blade performance is very sensitive to changes in the curvature distribution and to small geometry changes of blade design. The analytic and synthetic method of obtaining and researching of the curve lines, using different means and procedures, can be mutually intertwined, complemented and overlapping while striving towards the common goal. [2]

When designing a wind turbine, the goal is to attain the highest possible power output under specified atmospheric conditions. From the technical point of view, this depends on the shape of the blade. The change of the shape of blade is one of the methods to modify stiffness and stability, but it may influence aerodynamic efficiency of wind turbine. Other method to change dynamic and mechanical properties of wind turbine is modifying the composite material, which the blade is made of. [3]A program that implements a modified genetic algorithm which enables optimization of various objective functions subjective to various constraints can be used for the purpose.

For generating a solid model and drawing parts with free form surfaces (PFFS) using profile replacement technique can also be used [4]. Thus, maintaining the associativity between 3D model and drawing. Firstly, generation of new profiles from input data points was done. Then, the profile information was extracted from existing model. Lastly, old models were replaced with new profiles. This helped in preserving information of existing model and automatic generation of drawings including views, dimensions etc.

Modeling of turbine blade can also be done by constructing a series of section curves along blade height and then skinning the blade surface. In this geometric parameters are classified as blade modeling parameters and blade adjusting parameters which can be edited making the design process flexible [5] or by a generic model to generate and analyze the structural behavior of large composite wind turbine blades [6].The aerodynamic contour design and performance analysis of wind turbine blade are important parts of design and wind application. [7]

The parametric representation of curves and surfaces especially in polynomial form is most suitable for designer, as the planar curves cannot deal with infinite slopes and are axis dependent. The Bezier curves which are considered as ideal geometric standard for representation of piecewise polynomial curves can be used for various profile designs [8]. Quadratic Trigonometric Bezier curves presented with single shape parameter can be used to represent the arc of an ellipse or circle under certain conditions. Its applications can be extended to CAD/CAM systems.

In this paper, parametric modeling of various profiles is done using Non Uniform Rational B-Spline curves. The method uses geometric parameters as initial data allowing the designer with additional feature to refine the section curve by moving its control points. Thus, the profiles can be edited keeping geometric parameters same, helping the design the construct the desired profiles effectively and efficiently. The continuous slope of curvature should be used wherever the aerodynamic, heat transfer, hydrodynamic and aesthetic performances are critical.

III. DESIGN PROCESS

Non-uniform rational basis spline (NURBS) is used for generating and representing curves and surfaces in computer graphics and is capable of handling analytic and modeled shapes. Control points are used to determine the shape of the curve which may be connected directly to the modeled body or may appear as if rubber band is used to hold them together.

NURBS is a piecewise polynomial function and can be expressed mathematically (1)

$$\boldsymbol{R}(\boldsymbol{t}) = \sum_{i=1}^{n+1} \boldsymbol{P}_i \boldsymbol{N}_{i.k}(\mathbf{t}) \quad (1)$$

$$t_{min} \leq t < t_{max} \quad (2)$$

$$2 \leq k \leq n+1$$

where,

$R(t)$ is the position vector along the curve as a function of parameter t

P_i are position vectors of n+1 defining polygon vertices

$N_{i.k}$ are normalized B-spline basis function

The Cox – de Boor formula used to calculate the B spline basis function:

$$N_{i,K}(t) = \frac{(t-T_i)N_{i,K-1}(t)}{T_{i+K-1}-T_i} + \frac{(T_{i+K}-t)N_{i+1,K-1}(t)}{T_{i+K}-T_{i+1}} \quad (3)$$

$$N_{i,1}(t) = \begin{cases} 1 \; if T_i \leq t \leq T_{i+1} \\ 0 \; otherwise \end{cases}$$

Using the algorithm of Nurbs'C' program is formulated which can be used to design variety of 2D objects such as cup model, plate model, turbine blade, car body, aircraft winglets etc. which can be modified to meet the customer's demand.

Further,finite element analysis is applied to reduce the equations to efficient numerical algorithms computable at interactive rates on common graphics workstation.

In this paper a turbine blade profile (1) is designed without using any pre-defined standard parameters. A free hand sketch made on the graph paper, without use of any geometrical parameter such as length, angle etc. provides the input for the design process. The coordinates measured from graph are used as input (control points) in the program .The splines for each set of control points are defined independently on the basis of weight functions. The values of weights are adjusted for each control point such that they form the desired shape of any profile. The mathematical value of weight for each coordinate can be changed at any point to generate various set of profiles using the same control polygon.

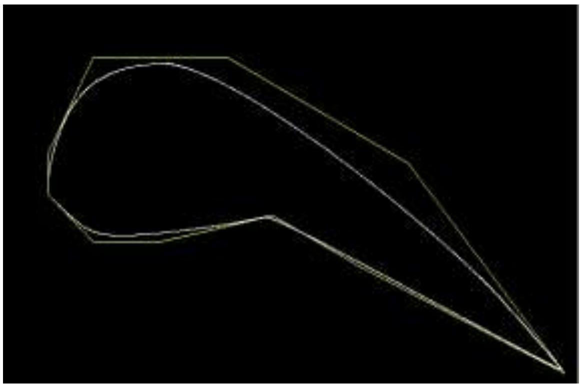


Fig. 3.1: Blade Profile (1) Generated Without Using Any Standard Data. Graph Plotted On Graph Paper Is Used As The Source Of Input Coordinates. Weights Are Adjusted Using Hit And Trial Method. Yellow Lines Specify The Control Polygon Enclosing The Blade Profile And White Shows The Blade Profile.

Similarly, various profiles can be generated using the same process. For the analysis three profiles are generated by varying few control points or their weights (Figure 3.1, 3.2, 3.3).

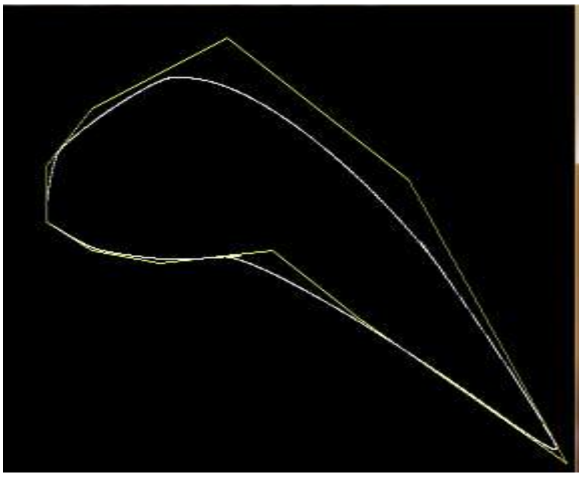


Fig. 3.2: Blade Profile (2) Generated Without Using Any Standard Data

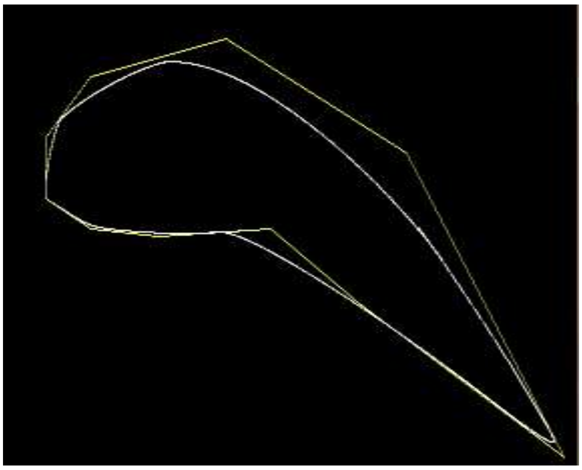
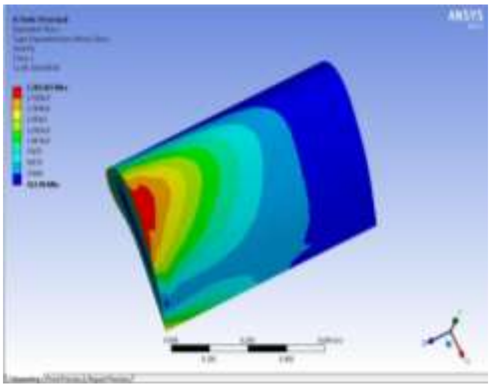


Fig. 3.3: Blade Profile (3) Generated Without Using Any Standard Data.

IV. ANALYSIS OF BLADE PROFILE

The three profiles generated are extruded to length of 1 meter for further analysis. Load is applied along the span of profile, keeping one end fixed. The load is increased preferably to study the stress distribution in the various profiles (Figure 4.1, 4.2, 4.3).



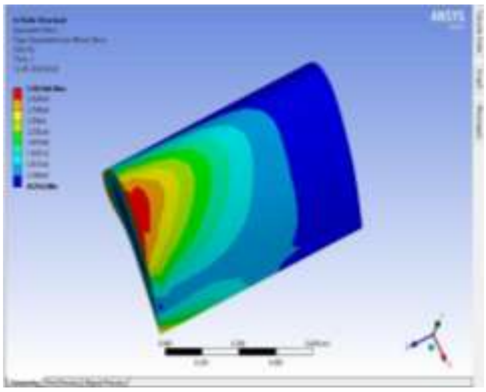


Fig. 4.1: Stress Analysis of Profile 1 For 1000 pafig. 4.2: Stress Analysis of Profile 1 For 10000Pa

Profiles 2 and 3 are also subjected to various loads and the results are compiled for comparative study. (Table 4.1)

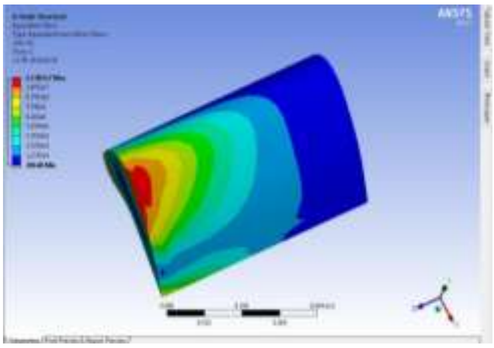


Fig. 4.3: Stress Analysis of Profile 1 for 50000Pa

Load applied / Profile	1000Pa	10000Pa	50000Pa
Profile 1	2.2614e5	2.2614e6	1.1307e7
Profile 2	3.1553e5	3.1553e6	1.5777e7
Profile 3	3.9477e5	3.9477e6	1.9738e7

Load applied / Profile	1000Pa	10000Pa	50000Pa
Profile 1	412.96	4129.6	20648
Profile 2	451.35	4513.5	22568
Profile 3	228.35	2283.5	11418

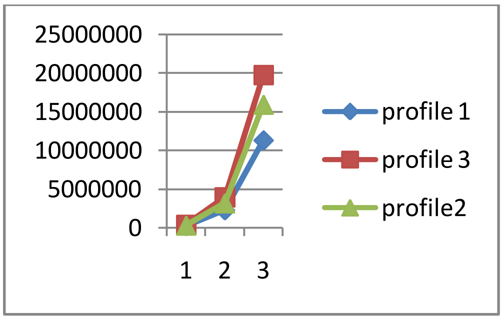
Table 4.1: Maximum Stresses Induced In Various Table 4.2: Minimum Stresses Induced In Various profiles on application of loadprofiles on application of load

As the load increases, maximum and minimum value of stress also increases. This can be observed in Figures 4.1, 4.2 and 4.3.

V. RESULTS AND DISCUSSIONS

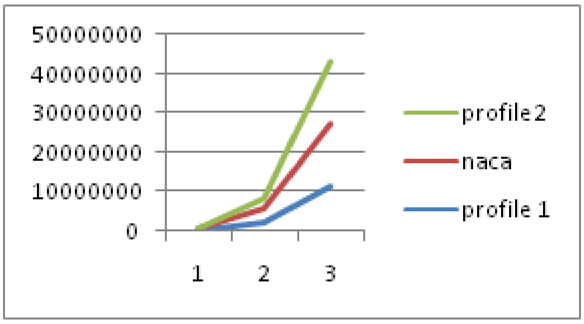
The maximum value of stress for varying loads is considered for comparative study, as the maximum stress bearing capacity of profile is to be tested.

The data observed from Table 4.1 is used to plot graph 5.1 to study the effect of load on various profiles. It is seen that the maximum stress induced is considerably less in profiles 1 and 2 in comparison to profile 3.



GRAPH 5.1: Comparison of maximum stresses induced for profile 1, profile 2 and profile 3 for loads of 1000Pa (1), 10000Pa (2) and 50000Pa (3) shown on x-axis.

Therefore, profiles 1 and 2 are further compared with the maximum stress values of NACA 42 profile for three different loads (GRAPH 5.2).



Graph 5.2: Comparison of stresses induced in generated profiles (1 & 2) and standard profile (NACA42)

VI. CONCLUSION

The stress analysis of profile 1, 2 and standard NACA profile (Graph 5.2) suggests that the results of profile 1 and 2 are comparable with standard data. Also, the maximum value of stress induced in profile 1 is 18% less than the NACA 42 used for reference purpose.

Thus, this profile can be used for further study. At any step if any discrepancy is found in the curvature, it can be easily altered by changing the weights associated with that particular coordinate without affecting the whole profile. This extra feature of weights provides the designer with extra degree of freedom which can be used to alter or modify the profile easily.

The conventional shape modification process is clumsy and laborious. With the help of NURBS a modeler can interactively sculpt complex shapes to satisfy required specifications by adjusting control points and setting weights but also through direct physical manipulation by adding simulated forces and local and global shape constraints.

VII.F UTURE SCOPE

NURBS have become a de facto standard in commercial modeling system because of their power to represent both free form shapes and common analytic shapes.

The process can be further extended for strain, deformation and other testing of the various profiles designed to ensure the feasibility of blade profile designed from manufacturing point of view. The aerodynamic properties and effect of heat and temperature can also be studied further.

REFERENCES

[1] T KORAKIANITIS AND G I PANTAZAPOULOS(1993), Improved turbine – blade design techniques using 4th order parametric spline segments.

[2] SONG YUWANG, XI PING 2004.Parametric design of turbine blades on feature modeling. Journal of Beijing University of Aeronautics and Astronautics. 30(4): 321-324

[3] KIM YEOUNG-IL,KIM LI-RA, JUN CHA-SOO 2006.Parametric design of a part with free- form surfaces. Journal of Zhejiang University SCIENCE A. 1530-1534

[4] PAUL A. BONNET and GEOFF DUTTON 2007.Parametric Modeling of Large Wind Turbine Blades. Energy Research Unit.

[5] BISERKA MARKOVIÆ 2001. Comparison of the analytic and synthetic Methods for transformation of the nth order curves into the 2^{nth} order curves, Architecture and Civil Engineering Vol. 2, No 3, 2001, pp. 219 – 230.

[6] THOMAS W. SEDERBERG,G. THOMAS FINNIGANZ, XIN LIY. HONGWEI LINX, HEATHER IPSON, Watertight Trimmed NURBS.

[7] FANGFANGSONGA, YIHUANIA, ZHIQIANGTANB (2011), Optimization Design, Modeling and Dynamic Analysis for Composite Wind Turbine Blade,International Workshop of Automobile, Power and Energy Engineering 369 – 375.

[8] UZMA BASHIR, MOHAMMAD ABBAS, MOHD NAIN HJAWANG, JAMALUDINMD ALI (2012),The Quadratic Trigonometric Bezier Curve with Single Shape Parameter ,Journal of Basic and Applied Scientific Research.2090-4304.

[9] JIN CHEN , QUAN WANG , WEN ZHONGSHEN , XIAOPING PANG , SONGLIN LI , XIAOFENGGUO,(2013) Structural optimization study of composite wind turbine blade, Materials and Design 46 247–255.