International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Supercritical Steam Turbine Blade Design using Bezier Curves

Praveen Upadhyaya [Ȧ*], Srinivas Prasad.S [Ḃ], Bhavanarayana Murthy.Ch [Ċ] and A.S.Panwalkar [Ċ]

[Ȧ] Department of Mechanical Engineering, Anurag group of institutions, India
[Ḃ] Department of Aeronautical Engineering, MLR Institute of Technology, Hyderabad, India
[Ċ] Department of Mechanical Engineering, CVSR College of Engineering, India

Accepted 10 January 2014, Available online 01 February 2014, **Special Issue-2, (February 2014)**

Abstract

The design of ultra supercritical and Advanced Ultra Supercritical steam turbines is posing challenges to design Engineers. Also retrofitting old blades of steam turbine with new blades to get additional power from the existing thermal station needs meticulous design of blades for optimum performance. One such realistic design problem has been chosen for the design of supercritical steam turbine blades for a given pressure drop. TCL/TK code has been used for the given input data to obtain airfoil data with the help of Baziers curve technique. Bezier knots are moved to change the camber of the airfoil and airfoil has been generated with the modified data used for steam turbine blade. The effect of stagger angle has been studied by using a commercial software package. Analysis has been performed by changing stagger angle from 0 to 550. Six different cases are studied and best one was selected to give optimum performance.

Keywords: *Bezier Curve, Design of supercritical steam turbines, CFD*

1. Introduction

Modern steam turbines designs have seen a sea of change from conventional designs up to 500MW, which were of subcritical pressures (<221.5 bar) with the development of super critical steam turbines[1] (with pressure higher than 221.5 bar which is critical pressure of water above which water exists as a dry steam equivalent to a gas), ultra super critical steam turbines (280 bar/600 to 610°C) and advanced ultra super critical steam turbines (700 to 760°C with metal temperatures going to 815°C needing special super high temperature alloy materials) indicates that the design of steam turbines is changing by the day where pressures, temperatures and capacities are going up to 280 bar,1000MW/1000°C. As thermal power plants consume fossil fuels, which emit harmful pollutants like CO_2, the present day aim is to reduce CO_2 by using Advanced – Ultra Super Critical steam turbines[2]. It is told that CO_2 emissions for 800MW steam turbines will be reduced by 725,000 tons of CO_2 emissions per year. Reductions of 5% CO_2 emissions and efficiencies nearing 50% are promised by worlds leading steam turbine manufacturers like Hitachi, Alstom, BHEL, GE, Siemens, etc. World's seven largest fossil fuel units of 1300 MW were built by M/S Alstom. In India Gujarat has 5×660 MW super critical thermal power stations. Another major solution to the energy shortage is by running existing power plants under high availability and where ever possible up rate these stations by retrofitting existing steam turbines. M/S BHEL, and NTPC, two PSU majors have shown that old steam turbines can be renovated and retrofitted. For example, a 210MW steam turbine develops only about 202MW after about 10 years of service. By re-blading existing steam turbines, this can be increased to about 212 to 215MW, within the same space, with little alterations to existing auxiliary equipment. Aerofoil blade design technology has seen lot of developments, right from the days when the profiles used to be calculated, and numerically using singularities method. Then NACA profiles were used to be selected from design data books and the aerodynamic profiles used to be stacked from hub to tip to obtain a three dimensional profile[4]. With the advent of advanced and fast computers, this job has become less laborious by computer generation of NACA profiles. Using Bezier curves is one step further, which helps in modifying existing profiles meticulously for obtaining extra power. This paper presents a few test cases using NACA profiles and Bezier profiles and is applied to a given set of design data[5], which is case for design of 600 MW super critical steam turbines, for a given pressure drop.

2. Bezier Curve

Bezier developed the notation, consisting of nodes with attached control handles, with which the curves are represented in computer software. The control handles define the shape of the curve on either side of the common node, and can be manipulated by the user, via the software. Bézier curves were adopted as the standard curve of the PostScript language and subsequently were adopted by vector programs such as Adobe Illustrator,

*Corresponding author: **Praveen Upadhyaya**

DOI: http://dx.doi.org/10.14741/ijcet/spl.2.2014.115

CorelDraw and Inkscape. Most outline fonts, including TrueType and PostScript Type 1, are defined with Bézier curves. The scope of the present paper is curves aimed at designing an airfoil profile of super critical steam turbine blade using Bezier curves and fluent software. The design data of existing profile of supercritical steam turbine of 660 MW and its airfoil profile are taken and the profile is optimized to give better performance. Using CFD software the flow parameters are optimized for different stagger angles for 0˚ to 60˚. The Bezier curve with control points is shown in Fig 1.

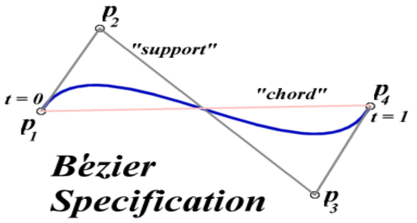

Fig.1 Bezier curve

2.1 Examination of Cases

A Bezier curve is defined by a set of control points P0 through P_n, where n is called its order (n = 1 for linear, 2 for quadratic, etc.). The first and last control points are always the end points of the curve, however, the intermediate control points (if any) generally do not lie on the curve.

2.1.1 Linear Bezier curves

Given points P0 and P1, a linear Bézier curve is simply a straight line between those two points. The curve is given by
B(t) = P0 + t(P1-P0) = (1-t) P0 + t P1 , t ϵ[0,1]
and is equivalent to linear interpolation.

2.1.2 Quadratic Bezier curves

A quadratic Bezier curve is the path traced by the function B(t), given points P0, P1, and P2
B (t) = (1-t) [(1-t) P0 + t P1] + t [(1-t) P1+tP2], t ϵ [0, 1]
which can be interpreted as the linear interpolant of corresponding points on the linear Bezier curves from P0 to P1 and from P1 to P2 respectively. Rearranging the preceding equation yields:
B(t) = (1-t)2 P0 + 2(1-t) t P1+ t2 P2 , t ϵ [0,1]
The derivative of the Bezier curve with respect to t is
B′ (t) = 2(1-t) (P1 – P0) + 2t(P2 –P1)

2.1.3 Cubic Bezier curves

Four points P0, P1, P2 and P3 in the plane or in higher-dimensional space define a cubic Bezier curve. The curve starts at P0 going toward P1 and arrives at P3 coming from the direction of P2. Usually, it will not pass through P1 or P2; these points are only there to provide directional information. The distance between P0 and P1 determines how long the curve moves into direction P2 before turning towards P3.Writing BPi, Pj, Pk(t) for the quadratic Bezier curve defined by points Pi, Pj, and Pk, the cubic Bezier curve can be defined as a linear combination of two quadratic Bezier curves:
B(t) = (1-t) B P0, P1, P2 (t) + t B P1, P2, P3 (t), t ϵ [0,1]
The explicit form of the curve is:
B(t) = (1-t)3 P0 + 3 (1-t2)t P1+3(1-t) t2 P2 + t3 P3, t ϵ [0,1]

2.2 Generation of Airfoil Profile through Bezier Curves

The airfoil profile is generated through Bezier curves by TCL/TK programming language as it is flexible to optimize the profile.

Tool Command Language (TCL)

TCL (Tool command language) is a string-based command language. The language has only a few fundamental constructs and relatively little syntax, which makes it easy to learn. The basic mechanisms are all related to strings and string substitutions, so it is fairly easy to visualize what is going on in the interpreter.TK (Tool kit) has a few ways of its own that it can be extended. You can implement new widgets, new canvas items, new image types, and new geometry managers. Fig 2 is the airfoil profile by using Bezier curves by TCL/ TK programming language. The points P1 to P8 indicates the Bezier knots on the pressure side of the airfoil and the points S1 to S8 are the Bezier knots on the suction side of the airfoil.

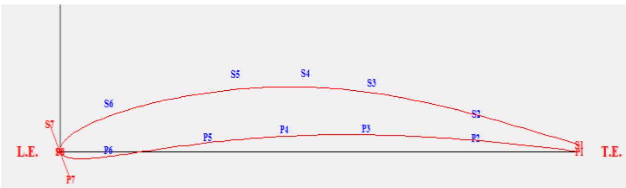

Fig.2 Airfoil profile through Bezier curves

The co-ordinates of the points on suction side and pressure side has been shown in Fig 3. The data appeared in blue colour can be movable to increase the Camber of the airfoil.

CURRENT BEZIER KNOTS

Pressure Surface		Suction Surface	
P1	100.0 , 0.0	S1	100.0 , 1.0
P2	80.0 , 2.0	S2	80.125 , 5.5
P3	58.875 , 3.375	S3	60.0 , 10.0
P4	43.125 , 3.25	S4	47.25 , 11.375
P5	28.375 , 2.125	S5	33.75 , 11.25
P6	9.25 , 0.25	S6	9.375 , 7.0
P7	2.0 , -4.0	S7	-2.0 , 4.0
P8	0.0 , 0.0	S8	0.0 , 0.0

NOTE: RED BEZIER KNOTS NOT MOVABLE
BLUE BEZIER KNOTS ARE MOVABLE
PICK THE KNOT WITH MOUSE AND DRAG

Fig.3 Current Bezier Knots

To optimize the airfoil profile the Bezier knots on the pressure surface and the suction surface are moved to get the orientation of the new profile. In this work the profile shapes are designed using Bezier curve techniques, for this purpose an interactive TCL/ TK code describes above is used. Bezier knots can be moved while Bezier curve shape (profile) changes which is displayed on computer screen. After satisfying visually the profile shapes.

3. Creation of Geometry in ICEMCFD

Fig.4 the coordinates of the curve are read by ICEM CFD software which enables further mesh generation. In the present study the airfoil profile is generated through Bezier curves and the data points of with respect to the pressure surface and suction surface are extracted to ICEMCFD (software) for the creation of the geometry. Then the created geometry is meshed with various mesh parameters and further the analysis is done in the FLUENT software.

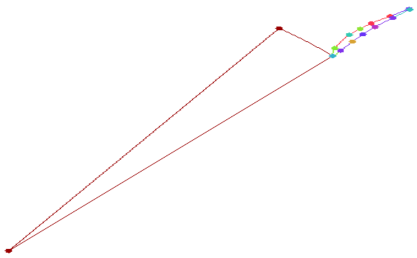

Fig 4 Airfoil geometry in ICEMCFD

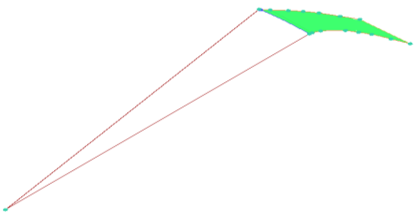

Fig.5 Airfoil profile with passage area in ICEM CFD

Fig 5 represents the airfoil geometry in which the data points from the Bezier curve are extracted and the geometry has been created and modified for further meshing process. Quad Mesh is used for analysis has been shown in Fig 6. The inlet, outlet, suction surface and pressure surface are indicated.

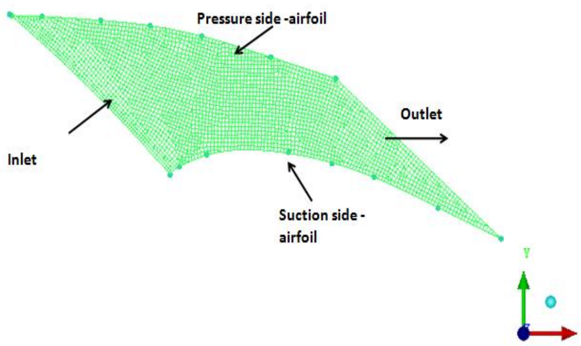

Fig 6 Mesh used for analysis

Boundary conditions

Far field boundary condition is used at inlet and pressure outlet condition is used at outlet and no slip condition for the walls has been used. Input data used for CFD simulation is shown in Table 1. The fluid domain with stagger angle = 0^0 has been shown in Fig 7. Velocity and pressure contours are shown in Fig 8 and 9.

Table 1 Input data for test case using Bezier curve

Type of boundary condition	**Pressure-far-field**
Static Pressure	246.46 (bar)
Mach number	<1.8
X-component of flow direction	0.939
Y-component of flow direction	0.342
Z-component of flow direction	0
Turbulence specification method	Intensity and viscosity ratio
Turbulence intensity (%)	5
Angular Velocity	194m/s
Total temperature	836˚C
Material Type	Steam
Type of flow	K-ε model
Pitch	30mm
Stagger angle	0˚
Analysis	2D

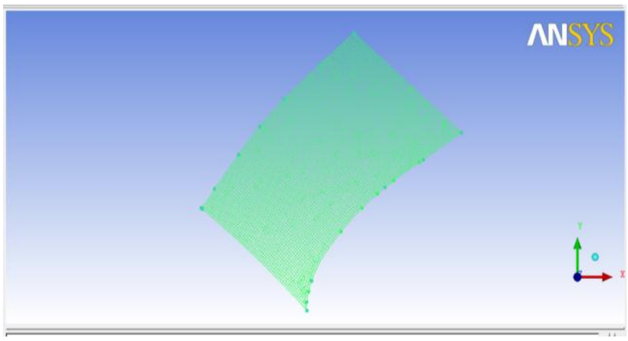

Fig.7 Profile in ICEM CFD with stagger angle = 0°

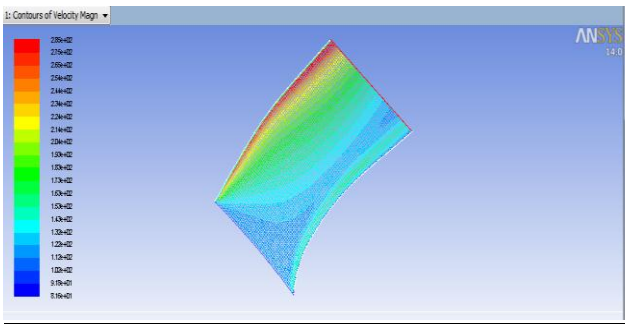

Fig.8 Contours of Velocity (m/s) stagger angle = 0°

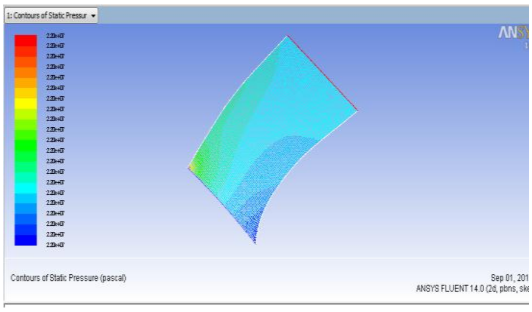

Fig.9 Contours of pressure stagger angle = 0˚

The flow from inlet to the outlet has been shown in Fig 10. The Maximum pressure drop = 217 bar. Maximum velocity = 169 m/s.

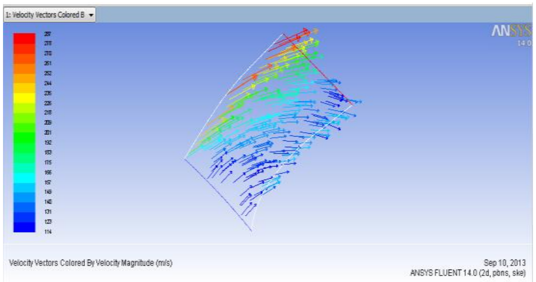

Fig.10 Vectors of velocity magnitude stagger angle = 0˚

The computations have been performed at stagger angle 0° to 55°. The velocity distributions on suction surface and pressure surface at various stagger angles have been shown in Fig 11.

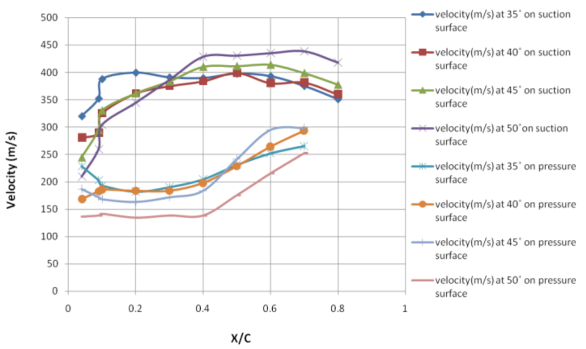

Fig.11 Superimposed velocity on suction and pressure surface

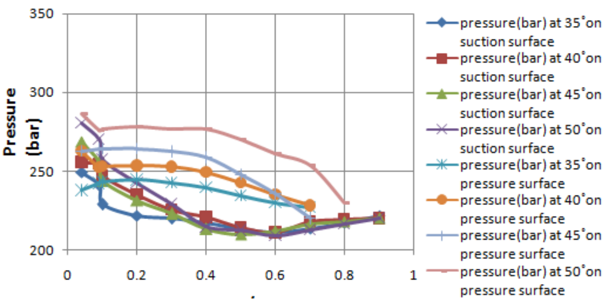

Fig.12 Superimposed pressure on suction and pressure surface

The pressure distribution from leading edge to trailing edge on suction side and pressure side at various stagger angles has been shown in Fig 12. These curves provide information to understand the flow from leading edge to trailing edge.

4. Results and Discussion

A practical problem arises in the retrofitting of existing steam turbine with new blades to obtain extra power and more efficiency (says from 500MW to 600MW and increase efficiency to say 32% from existing 27 %.) In such situations, the existing blade profile is to be modified. An existing blade profile with given design data, for pressure drop from 246 bar to 220 bar is taken. Inlet angle of 20° and chord length of 50 mm is used as input and Bezier curve technique is incorporated. Using TCL/TK software, Bezier knots for given chord length and inlet angle were obtained. Using these knots, new aerofoil profile is drawn. The two dimensional space between two adjacent profiles for given pitch and mean diameter was obtained and this area of space in 2D is imported into ICEM CFD software. In this software, using required input data the given area is meshed. This meshed area is given as input to CFD flow solver FLUENT with defined inlet and outlet domains. Various results where convergence criteria are satisfied like outlet flow velocity, velocity distribution on suction and pressure sides are obtained, for varying stagger angles of 0°, 10°, 20°, 25°,30°,35°,40°, 45°, 50°, 55° and 60°. At the stagger angles 0 and 10°, results were not converging. Hence these two sets are not considered for interpretation. The shift of maximum velocity with respect to chord for all these stagger angles was noted, which is shifting from leading edge to trailing edge with increasing stagger angle as shown in Fig 8.3 also pressure getting reduced from leading edge to trailing edge, as the fluid is transferred energy to blades causing it to move.

It was observed that for a stagger angle of 55°, maximum outlet velocity of 464m/s was obtained. It is seen that blade outlet velocity is increasing linearly with respect to increasing stagger angle. The change of maximum surface velocity and outlet velocity with stagger angle are plotted. Shift of maximum surface velocity with chord length for increasing stagger angle from 0° to 60° is plotted. Mach number is defined as the ratio between flow velocity and velocity of sound in fluid. The velocity of sound in fluid is assumed as 400m/s.

5. Results Conclusion

It has been observed that for optimized blade, compared to original blade, is thinner. The reduction of thickness (depends on structural requirements) has pushed optimization in thickness to chord ratio. This played important role in improving stage efficiency. The combinations of other two new features namely higher stagger angle and smaller radius of curvature of leading edge. This helps increase in stage leading. The velocity distribution curves for 35˚, 40˚, 45˚, 50˚ show an axial shift from leading edge to trailing edge for maximum velocity. This trend first indicates that the design is quite accurate. However study of 0˚, 10˚, 20˚, and 60˚ stagger angle shows that they are not compatible. 0˚ and 10˚ did not yield results. A stagger angle of 55.7° was used in the original profile. After optimization of profile blade stagger angle should be in the 35˚ to 40˚ range.

References

Jiaqi Luo, Juntao Xiong and Feng Liu, IvanMcBean,(2009), Three-dimensional aerodynamic design optimization of a turbine blade by using an ad joint method, *J. Turbomachinery,* Vol No 24.

Risto Peltonen (2006),Viscous-In viscid Method for Airfoil Analysis and Design for Aviation and Windmills, *Journal of aircraft* Vol No.4, pp. 43-52.

Mohammad Arabnia,(2012) Aerodynamic Shape Optimization of Axial Turbines in Three Dimensional Flows *Phd thesis Concordia University*, Montual, Canada.

Xin Yuan, Qian Pu, Xiaofeng Zhu,Zhirong Lin,Yoshiki Niizeki, Naoki Shibukawa and Tadashi Tanuma,m (2012), Fluid Dynamic Efficiency Optimization of Steam Turbine Stages Considering Leakage Influences and Inter-stage Reciprocal Interferences *International Journal of Gas Turbine, Propulsion and Power Systems*, Volume No 4

Ramakrishna, (2012) Airfoil profile design by reverse engineering bezier curve, *International Journal, Mechanical Engineering and Robotics Research* Vol No.1

Mahmood Ebrahimi and Mohammad Hossein Roozbahani, (2012), Comparative Investigation in a Turbine Blade Passage Flows with Several Different Turbulence Models *Journal of Mechanical Engineering*, Vol No.4.

Ralph.L.Carmichael, (2001) Algorithm for calculating coordinates of cambered NACA airfoils at specified chord locations, *Public Domain Aeronautical Software*, Santa Cruz CA 95061 USA. Published in AIAA

Samantha Acharya and Gazi Mahmood(1990) Turbine Blade Aerodynamics, Louisiana State University CEBA 1419B, and Mechanical Engineering Department Baton Rouge, LA 70803 published in *AGARD/NATO conference proceedings CP-469 Secondary flows in turbo machinery*

Myong H.Sohn and Kyu j.Lee, (2000) Bezier curve application in the shape optimization of transonic airfoils AIAA.

Peter J. Kunz, Ilan M. Kroo, (1992) Analysis, Design, and Testing of Airfoils for Use at Ultra-Low Reynolds Numbers.

Emre Alpman Airfoil shape optimization using evolutionary algorithmsGraduate Research Assistant Aerospace Engineering Department Penn state University Park, PA, 16802.