Effect of Different Aerodynamic Profile on Stresses for Steam Turbine Blade

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Abstract—*Blades are significant components of steam turbines which are failed due to stresses arising from centrifugal and bending forces. The turbine blade has a number of geometrical variables that need to be considered at the design stage. Hence, this paper investigated a three dimensional model of steam turbine blade with different aerodynamic profile using finite element method. A three-dimensional model of blade was developed using computer-aided design software. All materials were assumed linear, homogenous, elastic and isotropic. A 150 N widespread force was applied to the blade. The results of this study showed that thinner blades are experienced higher maximum Von Mises Stress and Maximum Principal Stress than thicker ones. The blade with the parameter of profile 2 experienced the lowest maximum Von Mises Stress at 4.998 MPa. Furthermore, blade with the parameter of profile 3 experienced the lowest Maximum Principal Stress at 4.419 MPa.*

Keywords—Blade Profile, Design, Steam Turbine Blade, Stresses in Blade

Nomenclature—

C	True chord (mm)
Cx	Axial chord (mm)
le	Leading edge radius (mm)
tr	Trailing edge radius (mm)
γ	Stagger angel (°)
H	Blade span (mm)
E	Young's modulus (N/mm)
ρ	Density (kg/m^3)
ν	Poisson ratio

I. Introduction

Blades are the heart of a steam turbine, as they are the elements that convert the thermal energy into kinematic energy. The efficiency and consistency of a turbine depends on the proper design of the blades. It is therefore necessary for engineers involved in the steam turbines field to have an overview of the importance and the basic design aspects of the steam turbine blades. The blade design is a multi-disciplinary task. It involves like thermodynamic, aero-dynamic, mechanical and material science restraints. The total development of a new blade is thus possible only when experts of all these fields come together as a panel. Efficiency of the turbine is depends on the parameters like, Inlet and outlet angle of blade, blade Materials, blade profile and Surface finishing of the blade and etc.

Blades are exposed to failure due to stresses arising primarily from centrifugal loads and bending forces related to the steam mass flow. In order to design a highly efficient steam turbine, it is essential to consider many design objective functions about the fluid dynamic performance (the smooth guidance of working steam, etc.) at the same time. Moreover, the steam turbine has a number of geometrical and topological variables (blade Shape, the number of blades number of stages, etc.) that also need to be considered at the design stage simultaneously.

Vijendra K and Viswanath T [1] the investigation on design of high pressure steam turbine blade addresses the problems of steam turbine efficiency. A precise focus on aerofoil profile for high pressure turbine blade and it gages the effectiveness of certain like Chromium and Nickel in resisting creep and fracture in the turbine blades. Zachary Stuck, Stanley Schurdak [2] this paper addresses the issue of steam turbine efficiency by discussing the overall design of steam turbine blades with a specific focus on blade aerodynamics, materials used in the production of steam turbine blades, and the factors that cause turbine blade failure and therefore the failure of the turbine itself. P. Vaishaly and B Ramarao [3] Low pressure turbine is very critical from strength point of view because of the high centrifugal and aerodynamic loading. The stress in these highly twisted blades is required to be evaluated accurately in order to avoid blade failures and cracking. The generated model is meshed in ANSYS package driven by customized software and the pressure distribution is mapped on the blade surface. Steady state stress analysis generated to understand the dynamic behavior of the blade.

II. Blade Material

With the wide range of services and the conditions of service that are encountered in the design of industrial turbines, one might expect an equally broad range of materials that could be specified for turbine blades. In fact, blades for modern industrial turbines and process drives, regardless of the original manufacturer, are almost all manufactured from a rather small set of widely used materials. An ideal turbine blade material has both high tensile strength and high fatigue strength. In addition an ideal blade material is corrosion-resistant and erosion-resistant, exhibits high ductility, is easily formed and machined, is widely available from multiple sources, and can be obtained at reasonable cost.

A. Stainless Steel

Type 403 and 410 stainless steels are among the most widely used materials for steam turbine blades. These alloys are very similar in chemical composition. Both are martensitic stainless steel alloys that can, through appropriate heat treatments, exhibit strength levels covering a wide range, depending on process variables such as the quenching and tempering temperatures, among others. Steam turbine blade material and their properties used for analysis are given below in the table 1.

Material	Stainless Steel

Elastic modulus	193 GPa
Yield stress	210 MPa
Poisson's ratio	0.31
Density	7750 kg/m3

Table 1: Mechanical Properties

III. Blade Design in CAD Software

A steam turbine blade was modelled using Catia V5. Catia is a multi-platform software suite for computer-aided design, computer-aided engineering, PLM and 3D, developed by the French company Dassault Systems. CAD model was prepared by taking dimensions of steam turbine blade from previous studies (Figure 1). In order to model, the first stage steam turbine blade was chosen. The modelling of blade profile is an important task due to its direct effect on the simulation results.

Standard parameter of steam turbine blade which consider

A. *Profile 1*

	Mean line	Near tip
Blade span (mm)		126 mm
True chord (mm)	65.08	64.16
Axial Chord (mm)	62.24	50.45
Leading edge radius (mm)	1.856	1.856
Trailing edge radius (mm)0.67	0.67	
Inlet angle (°)	43.3	50
Exit angle (°)	20.5	20
Stagger angle (°)		37.048

Blade parameter with different aerodynamic profile

B. *For Profile 2*

	Mean line	Near tip
Blade span (mm)		126 mm
True chord (mm)	64.88	63.97
Axial Chord (mm)	62.04	50.25
Leading edge radius (mm)	1.656	1.656
Trailing edge radius (mm)0.407	0.407	
Inlet angle (°)	43.3	50
Exit angle (°)	20.5	20
Stagger angle (°)		37.048

C. *For Profile 3*

	Mean line	Near tip
Blade span (mm)		126 mm
True chord (mm)	64.68	63.77
Axial Chord (mm)	61.84	50.05
Leading edge radius (mm)	1.456	1.456
Trailing edge radius (mm)0.207	0.207	
Inlet angle (°)	43.3	50
Exit angle (°)	20.5	20
Stagger angle (°)		37.048

D. *For Profile 4*

	Mean line	Near tip
Blade span (mm)		126 mm
True chord (mm)	65.28	64.36
Axial Chord (mm)	62.44	50.65
Leading edge radius (mm)	2.056	2.056
Trailing edge radius (mm)0.87	0.87	
Inlet angle (°)	43.3	50
Exit angle (°)	20.5	20
Stagger angle (°)		37.048

E. *For profile 5*

	Mean line	Near tip
Blade span (mm)		126 mm
True chord (mm)	65.48	64.56
Axial Chord (mm)	62.64	50.85
Leading edge radius (mm)	2.256	2.256
Trailing edge radius (mm)1.07	1.07	
Inlet angle (°)	43.3	50
Exit angle (°)	20.5	20
Stagger angle (°)		37.048

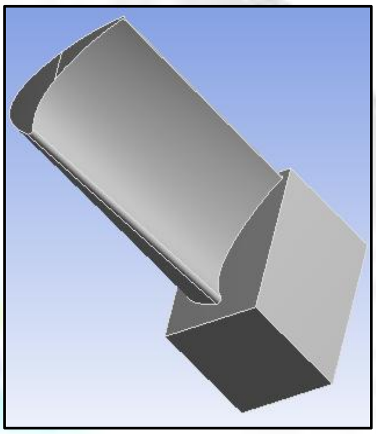


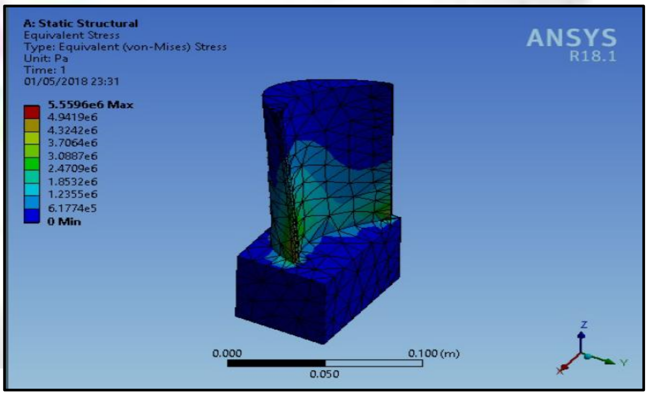
Fig.1: Modelled Blade

IV. Result of Stress Analysis

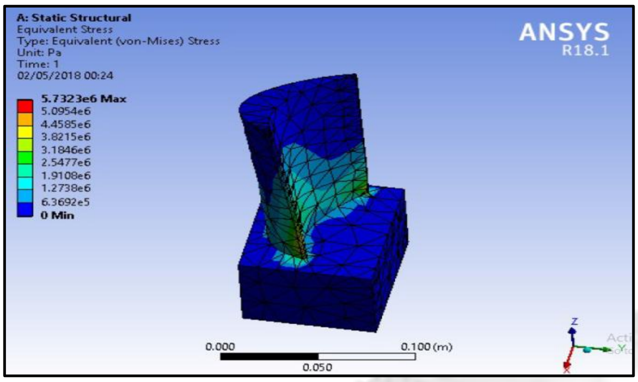
The following results are obtained from the above analysis:

A. *Von Mises Stress*

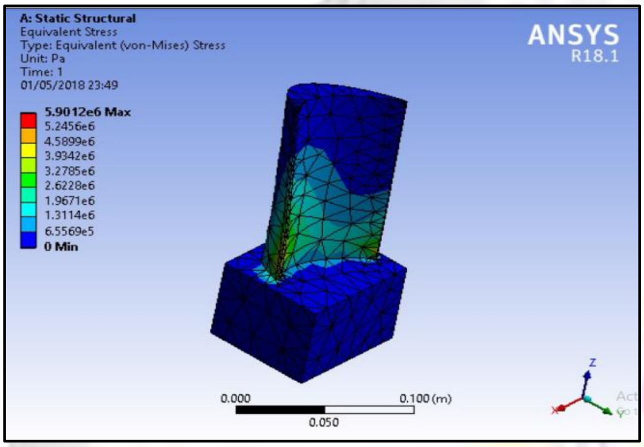
The Von Mises stress is used to predict yielding of material under complex loading from the result of uniaxial tensile tests. The Von Mises stress satisfies the property where two stress states with equal distortion energy have an equal Von Mises stress.



Profile 1



Profile 2



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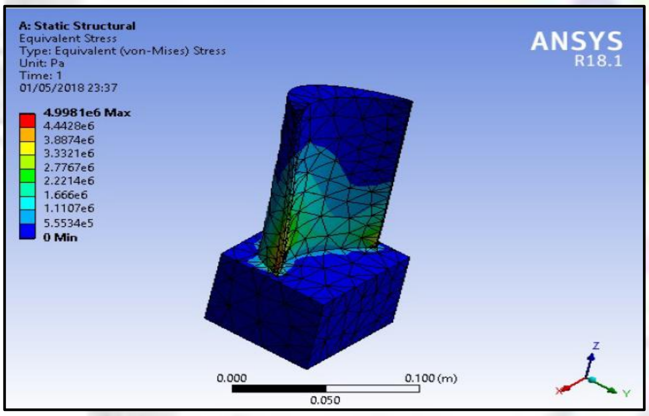
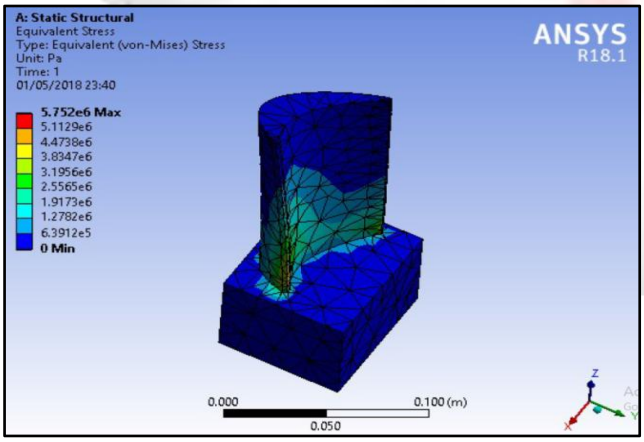


Profile 4

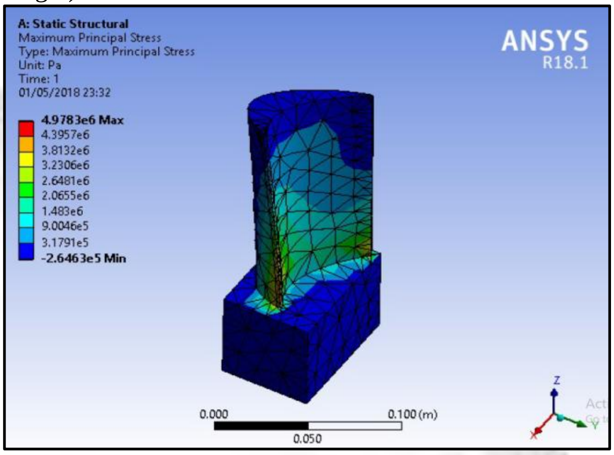


Profile 5

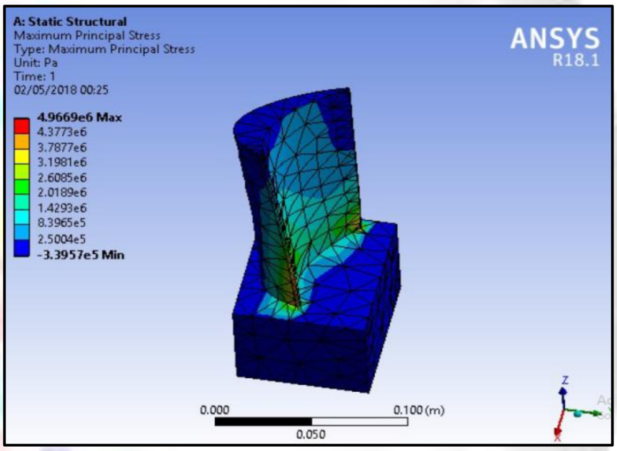
Fig.2: Von Mises Stress Distribution

B. Maximum Principal Stress

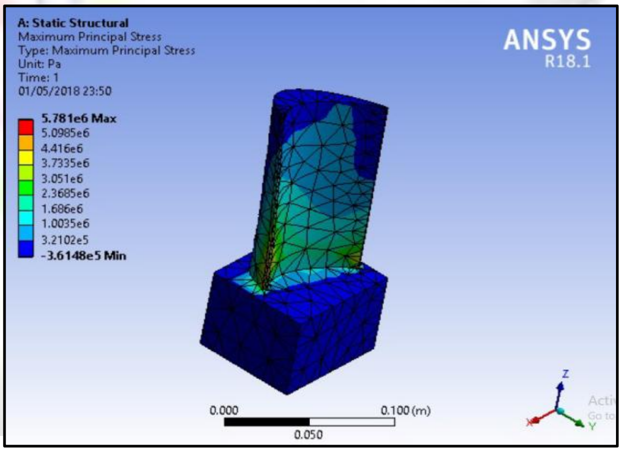
Maximum Principal Stress theory is useful for brittle materials. Maximum Principal Stress theory or Maximum Principal Stress criterion states that failure will occur when Maximum Principal Stress developed in a body exceeds uniaxial ultimate tension/compressive strength (or yield strength) of the material.



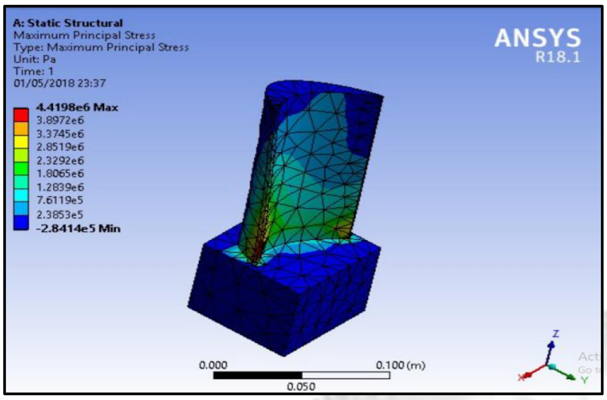
Profile 1



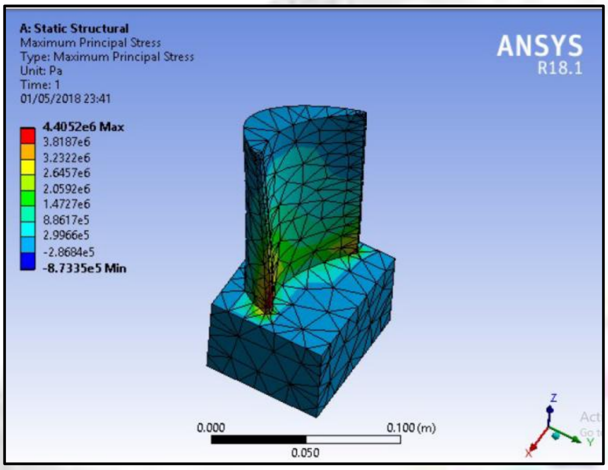
Profile 2



Profile 3



Profile 4



Profile 5

Fig. 3: Maximum Principal Stress Distribution

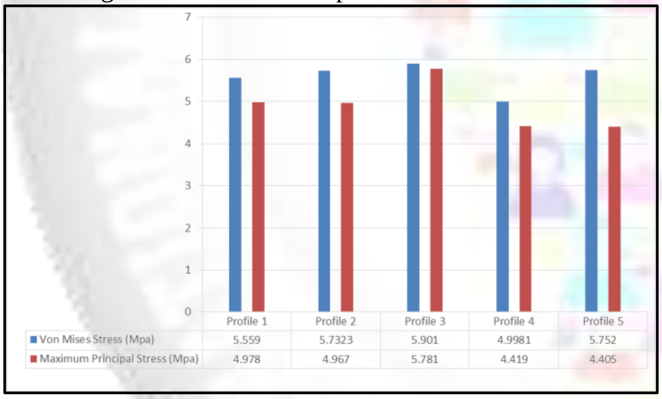


Fig. 4: Maximum Von Mises Stress &Maximum Principle Stress forBlade WithDifferent Aerodynamic Profile

V. Discussion

The different geometries affected the Von Mises Stress and Maximum Principal stress of blade. The variation of Von Mises stresses and Maximum Principal Stress for different aerodynamic profile of turbine blade is shown in figure 4. The highest Von Mises stress was observed at the base of all blades, but comparably with the highest stress was observed at less area of blade face (Profile 3). However, the lowest stress was seen in the tip of blades and comparatively was seen in the Profile 4.

Similarly, the highest Maximum Principal stress was seen in the Profile 3. However, the lowest Maximum Principal stress observed in Profile 5.

But overall observation is indicating the most suitable steam turbine blade is profile 4 amongst the all five profile.

VI. Conclusion

The objective of this study was to modify a steam turbine blade using FEM. It was found that changing the geometry of turbine blade including axial chord, true chord, leading edge radius and trailing edge radius can be useful in decreasing Von Mises stress and Maximum Principal Stress. Results showed higher stress at the base of blades rather than tips. It can be concluded that using thicker blades are better to reduce stress, which may provide more durability.

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