iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** VIII **Month of publication:** August 2021

DOI: https://doi.org/10.22214/ijraset.2021.37806

Design and Analysis of Steam Turbine Rotor Blade

Sanket Sangode[1], Vaibhav Bankar[2]
[1]Researcher, Master of Technology in CAD/CAM, Vidarbh Institute of Technology, Nagpur, Maharashtra.
[2]Asst. Prof., Department of Mechanical Engineering, Vidarbh Institute of Technology, Nagpur, Maharashtra.

Abstract: A steam turbine is a tool that extracts thermal electricity from pressurized steam and makes use of it to do mechanical work on a rotating output shaft. The steam turbine offers the better thermodynamic performance with the aid of the usage of a couple of levels inside the growth of steam. The levels are characterized by using the manner of strength extraction from them is considered as impulse or reaction mills. On this work the parameters of steam turbine blade various and evaluation is carried out for electricity, existence and warmth switch fees. The varied parameters are the ratio of x-axis distance of blade profile with the aid of chord length and ratio of maximum peak of blade profile in y-path to the chord period. The three-D modeling is executed by way of using Catia software program. The Ansys software is used for static, thermal analysis, subsequently concluded the best design and material (haste alloy, chrome steel, inconel 600) for steam turbine blade, after steam turbine blade imported the stl record 1:2 ratio in to 3-d printing we carried out fast prototyping technique.
Keywords: Steam Turbine, Thermal Energy, Impulse Turbine, Reaction Turbine, Static Analysis, Thermal Analysis.

I. INTRODUCTION

Steam turbine converts the heat strength of steam into useful paintings. Steam jets strike the transferring rows of blades installed on rotor causes trade within the course of steam which imparts momentum. Hence, blades convert the kinetic electricity of steam into the rotational strength of shaft. Shifting blades in a turbine are loaded by means of centrifugal forces and steam forces. Depending upon the design and working conditions, centrifugal force may additionally expand tensile, compressive or torsional stresses in shifting blade. Steam turbines are subjected to wide variety of begin-united states and shut-downs at some point of its life span. Meaning it's far subjected to repetitive cyclic loading situations which causes a fatigue failure of transferring blades.

This challenge summarizes structural overall performance of the blade because of centrifugal loading that acts at the blade because of excessive angular speeds. Additionally fatigue or provider lifestyles of blade are expected. The blades are designed in one of these way to supply maximum rotational power via directing the drift of the steam alongside its surface. The blades are made at particular angles with a view to comprise the internet drift of steam over it in its want. The blades can be of stationary or fixed and rotary or moving types, and shaft is designed to paintings in extreme conditions, hear it has to bear the temperature that's coming from the steam and hundreds (weight and centrifugal pressure) of the blade's assembly and different assembly components.

II. PROBLEM DEFINITION

All cutting-edge steam strength plants use impulse-response turbines as their blading performance is better than that of impulse turbines. Ultimate level of steam turbine impulse-response blades are very lots immediately have an effect on performance of plant. With the facts that an information of the forces and stresses acting at the turbine blades is important significance; in this work we will compute this kind of pressure performing on a ultimate level low pressure (lp) blade of a massive steam turbine rotating at 3000 rpm so that you can estimate the material stresses at the blade root. One such lp steam turbine blade is show in figure 1. We studied structural and thermal analysis of blade the usage of fea for this paintings and with the aid of use of the operational facts have finished via the use of fea (ansys) and this examine work involved the examine blade and take a look at fea records of std. Blade with diverse fabric.

III. OBJECTIVE

The objective of this work is to make a Steam turbine blade with 3D model, to examine the static - thermal conduct of the steam turbine blade with one of a kind substances through performing the finite detail analysis. Three-D modeling software (catia v5) become used for designing and analysis software (ansys) changed into used for analysis.

IV. LITERATURE SURVEY

Many investigators have cautioned diverse methods to give an explanation for the effect of strain and loading on turbine blade, rotor and evaluation the diverse parameters. A paper on layout and analysis of gas turbine blade [1] makes use of to get the natural frequencies and mode form of the turbine blade. In this paper we have analyzed previous designs and generals of turbine blade to do in addition optimization, finite detail outcomes for free status blades deliver a entire image of structural characteristics, which can utilize for the development inside the layout and optimization of the working situations.

Dr. Murari P. Singh, Dr. George M. Lucas, PE Are concise reference for practicing engineers worried within the layout, specification, and evaluation of commercial steam generators, mainly critical system compressor drivers. A unified view of blade layout standards and techniques is supplied. The book covers advances in modal analysis, fatigue and creep analysis, and aerodynamic theories, alongside an outline of usually used materials and manufacturing tactics. This authoritative manual wills useful resource within the layout of effective, efficient, and reliable generators.

This paper discusses *the design points of the compressor, drive turbine and auxiliary Pelton wheel drive, as well as the design requirements for the bearings and seal system*. A preferred outline of the ssthc improvement program finished at gulf widespread atomic is given. The subsequent regions are covered in the improvement software: aerodynamics, compressor noise, number one coolant shutoff valve, water bearings and rotor dynamics, seals, blade vibration, and disk catcher. Similarly, a comprehensive series of transient assessments on a circulator had been accomplished.

In this paper, *Tulsidas. D, Dr. Shantharaja. M,& Dr. Kumar*. Are addresses the huge type of faster-equipment blade root geometries utilized in enterprise brought on the query if an most beneficial geometry might be discovered. An premiere blade root turned into defined, as a root with sensible geometry which, while loaded returns the minimal fillet stress concentration component. The existing paper outlines the layout change for fillet stresses and a unique interest is made on scf of the blade root (t-root) which fails and to assure for safe and dependable operation underneath all possible service conditions. Finite element analysis is used to decide the fillet stresses and peterson's pressure attention component chart is correctly applied to alter the blade root. The root is modified because of the difficulty in production the butting surface of the tang which grips the blade to the disk crowns having small contact place.

V. METHODOLOGY

The methodology followed in the work is as follows:

A. Create a 3D model of the different Steam turbine blades using parametric software Catia v5.
B. Convert the surface model into IGS and import the model into ANSYS to do analysis.
C. Perform static and thermal analysis on the steam turbine blade.
D. Finally it was concluded which material is the suitable for steam turbine blade on these three materials.

The scopes of this proposed project are,

1) To generate 3-dimensional geometry model in catia workbench of the steam turbine blade.
2) To perform structural analysis on the model to determine the stress, shear stress, deformation, of the component under the static- thermal load conditions.
3) To compare analysis between three different materials of steam turbine blade.

VI. CALCULATIONS & ANALYSIS OF STEAM TURBINE BLADE

A. Material Selection

As we discussed in literature survey under subtitle "Required material properties for steam turbine blades" blade material should have a Creep Strength, Creep-fatigue Resistance, Notch sensitivity and damping property. X22CrMoV121 is one such a material which has all these properties. And it is the one most commonly used material for HP blades in steam turbine.

B. Centrifugal Force Calculation

Centrifugal force is directed outwards, away from centre of curvature of the path. A simplified 2D figure of the blades under discussion is shown in figure 6. The general equation for centrifugal force is

$$F=mr\omega^2 \quad (1)$$

Where m is the mass of the moving object, r is the distance of the object from the centre of rotation (the radius of curvature) and ω is the angular velocity of the object.

Consider a small segment of mass δm, of having width δr at a distance r from the centre. Then the equation for the centripetal force δF on this small segment is given by:

$$\delta_F=\delta mr\omega^2 \quad (2)$$

The blades have a cross sectional area A (mm2) and material density ρ (kg/mm3). Then we can write the mass of the element

$\delta_m = \rho_A \delta_r$

Equation (2) can be write as

$\delta_F = (\rho_A \delta_r) r\omega^2$

Or formally it can be writing as

$d_F = \rho_A \omega^2 r dr$ (3)

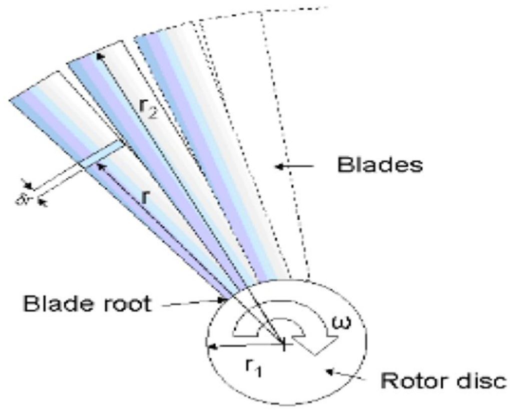


Fig.1. Simplified blade dimensions.

Then, integrating equation (3) along the total length of the blade, the total centrifugal force acting on the blade is given by

$$F = \rho A \omega^2 \int_{r1}^{r2} r dr$$

$$F = \rho A \omega^2 \int_{r1}^{r2} r dr \quad (4)$$

The following data is considered for design and centrifugal force estimation,

Blade speed N = 8000 rpm

Blade cross-sectional area

A = 165.161 mm2

Material density ρ = 7850x10-6 kg/mm3

Blade tip radius r2 = 267.5 mm

Blade root radius r1 = 220.5 mm

Blade length r2-r1 = 47mm

Substituting the all above values in equation (4)

Centrifugal Force F = 10,436.2N

C. Fatigue life calculation

There are many methods to calculate the Fatigue life. Based on the available data, accuracy and ease Smith, Watson and Topper (SWT) Mean Stress Correction for Strain Life method used for the present work. SWT equation for Fatigue Analysis is given below,

$$\sigma'_{Maximum}\frac{\Delta\varepsilon}{2} = \frac{(\sigma'_{failure})^2}{E}(2N_{failure})^{2b} + \sigma'_{failure}\varepsilon'_{failure}(2N_{failure})^{b+c}$$

Where, ζmax = Maximum stress

Δε/2 = Total strain applitude

ζ'failure= Fatigue Strength Coefficient or Effective strength

ε'failure = Fatigue ductility coefficient

E = Modulus of Elasticity

Nfailure= Number of reversals

B = Fatigue strength exponent

c = Fatigue ductility exponent

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

D. FE Analysis of Steam Turbine Blade

The intention of the FE analysis was to determine the stress and Fatigue life of the components at the critical location of the blade. It has been found out that the critical location of the blade is situated at the T root of the blade.

More precisely, at the convex side of the neck. However, it is required to assess the fatigue life of the whole blade-disc connection. For the purpose of simple solving and solution time in ANSYS the 3D model of blade is simplified by removing the tenon on the blade.

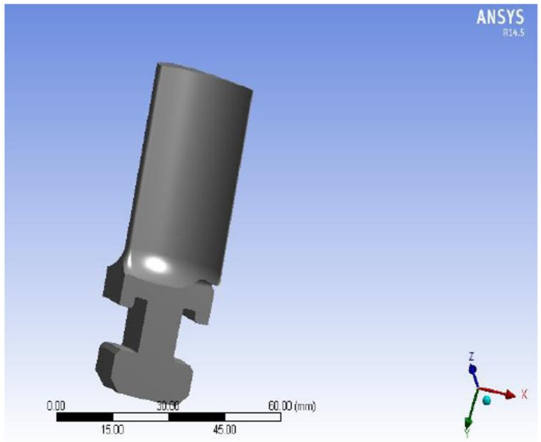


Fig.2. Imported Blade model.

As discussed in literature survey centrifugal force is the major force acting on blades. When compared magnitudes of all other forces acting on blade with centrifugal force magnitude they can be negligible. So in this analysis centrifugal force only considered as load of application.

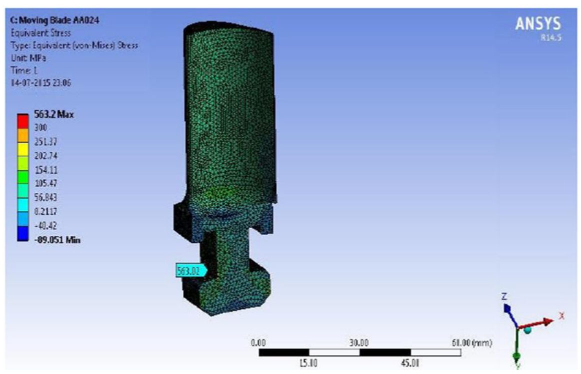


Fig.3. Equivalent stress of the steam turbine blade.

Equivalent von mises stresses observed (563 MPa) on the fillet region of the blade as depicted in the figure 8.

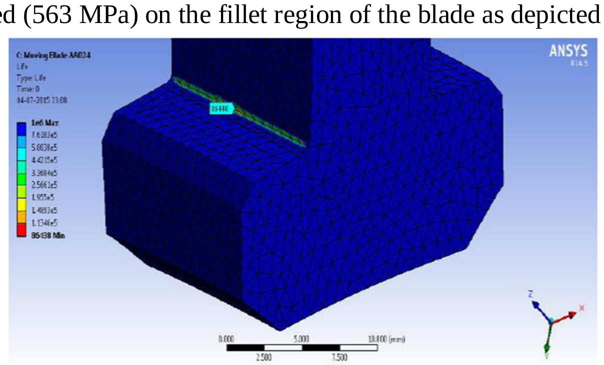


Fig.4. Fatigue life of the steam turbine blade

Minimum Fatigue life observed at the fillet region is 86438 as depicted in the figure 4.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

VII. DYNAMIC STRUCTURAL ANALYSIS

Dynamic behavior of blades is usually responsible for their safety and calm operation, therefore high attention was paid to tuning LSB48" well from view of its natural frequencies.

A. *Modal Analysis Of Turbine Blade*

Rotating flexible structures like turbine blades are often idealized as rotating cantilever beams. The procedure followed in ANSYS to perform modal and harmonic analysis for rotating cantilever beam.

The same computational procedure is leveraged for the analysis of turbine blade structure for its operational speed i.e., 0 Hz to 50 Hz. To this end, the following steps were performed:

1) Geometric 3D modeling of the turbine blade in CATIA V5 from the drawings.
2) The solid model generated above is used to develop the FE model in ANSYS.
3) Modal analysis is performed and Campbell diagram is plotted for operational speed i.e., 0 Hz to 50 Hz.
4) Critical speeds for synchronous and asynchronous excitation is determined from the Campbell diagram.
5) Considering only self-weight in the rotating frame, harmonic analysis is performed.
6) A stress analysis is performed to evaluate the reliability of the component.

B. *Non-rotating Turbine Blade*

Solid 3D model of the turbine blade was developed in CATIA V5. Figure 7 shows the modeled turbine blade. The above model was imported in ANSYS to develop FE model as shown Figure 8. Using SOLID186 element, hexahedral mesh was generated. All degrees of freedom present in the bottom surfaces are constrained as they are attached to rigid rotor disk. The FE model was used to obtain the mode shapes and natural frequencies for the turbine blade in a stationary reference frame. The natural frequencies obtained are listed in Table 5. The mode shapes observed for of stationary turbine blades are flexural (F), axial or edge bending (EB) and torsional modes (T). Figure 9 shows the first four modes of the turbine blade in stationary frame.

Fig. 5. Geometric model of turbine blade

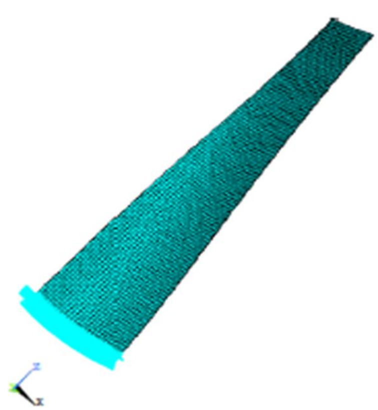


Fig. 6. FE model of turbine blade

Table 1 Natural frequencies for stationary turbine blade.

Mode	Natural Frequency(Hz)		
	9020 Elements	13332 Elements	55913 Elements
1F	71.307	71.319	71.331
2F	173.35	173.37	173.39
1T	295.84	295.84	295.82
1EB	398.08	398.11	398.12

C. Modal Analysis of Rotating Turbine Blade

A rotating turbine blade has larger bending stiffness than a stationary blade because rotation leads to stiffening effect due to the centrifugal force. The stiffening effect further depends on the rotational speed. Thus, in such structures natural frequency is a function of rotational speed and they are presented in the form of Campbell diagram.

All the modal analyses were done with the QR Damped method because it works best with big models and damping can be included. The same computational procedure in ANSYS is performed for different rotational speeds. The obtained natural frequencies for different rotational speeds are listed in Table 6 and Campbell diagram is plotted as shown Figure 10. Mode shapes obtained through the FEM analysis is presented in Figure 11. These mode shapes are computed for a rotational speed of 50Hz (maximum speed in the operating range). The mode shape contour plots are presented in the form of sum of deformations in the three orthogonal directions in Figure 11. It has been observed that the nature of these mode shapes remain largely unaffected by the rotational speed.

Table 2 Natural frequencies for different rotational speeds

Mode	Rotational Speed (Hz)					
	0	10	20	30	40	50
1F	71.319	72.77	76.833	82.816	89.966	97.697
2F	173.37	174.78	178.93	185.59	194.41	204.95
1T	295.84	296.43	298.18	301.01	304.82	309.53
1EB	398.11	399.38	403.16	409.32	417.66	427.89

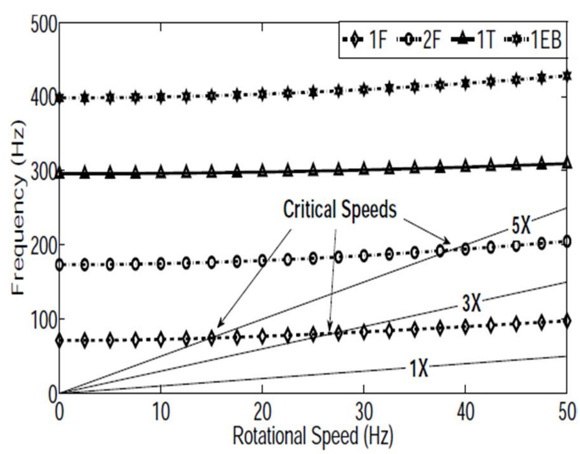


Fig. **Error! No text of specified style in document.** Campbell diagram of the steam turbine blade

1) The torsion mode frequency is almost constant over the rotational speed. This is because the torsional mode is unaffected by the centrifugal load acting in the axial direction For the first harmonic no critical speed is observed in the operating speed range.
2) Critical speeds occur if the excitation frequencies coincide with the natural frequency of the rotating structure. The excitation frequency itself may be synchronous to the rotational speed (1X) or multiples of it (2X, 3X, : : :). These excitation frequencies are represented as straight lines in the Campbell diagram.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue VIII Aug 2021- Available at www.ijraset.com

VIII. RESULTS & DISCUSSION

Existing blade design is good enough for fatigue life in theoretical calculation. But there is a problem in finite element analysis. In theoretical calculation blade model is getting infinite life (2.438e6). By running ANSYS software existing blade design is getting only 86436 is number of cycles as fatigue life.

A. Modifications Suggested In Design Of Steam Turbine Blade

Here failure of blade mostly occurs in T root. So it requires some modifications to get the infinite life (1e6). By doing some trial and error methods in changing the dimensions of T root. Finial a modification is suggested to turbine designer as below.

1) Neck width of the blade is increased by 1mm. i.e. Neck width is modified to 11mm from 10mm
2) Fillet radius of the root is modified to 0.8 mm from 0.5mm
3) Chamfer dimensions of the tang (bottom part of the root) is changed to1x45o and 2.77x45o from 1.25x45o and 3x45o respectively,

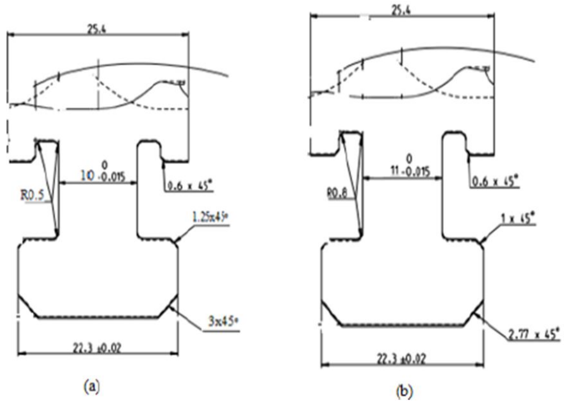


Fig.8. (a) Existing design (b) Modified design.

After making modifications in blade root design. Same loads and constrains are applied to check the strength of the blade. Then the results are as follows,

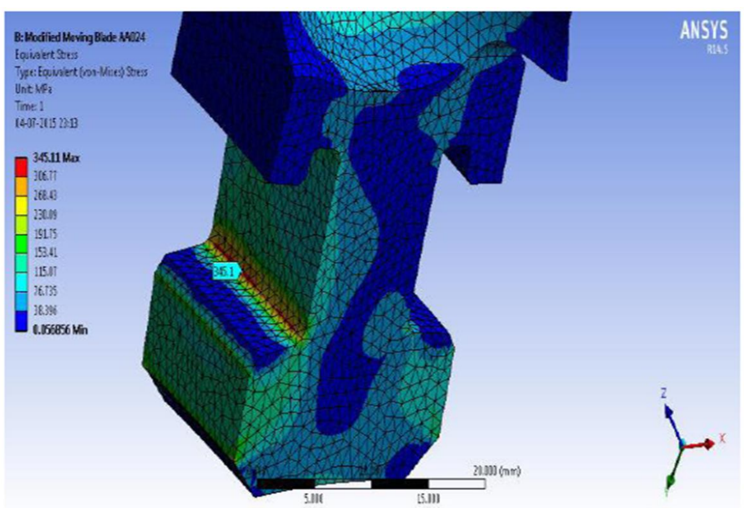


Fig.9. Equivalent stress of modified steam turbine blade

With the implementation of design modification, the Equivalent von mises stresses observed (345 MPa) on the fillet region of the blade as depicted in the fig above. The stress levels reduced from 563MPa to 345 MPa which will helps in improving the fatigue life.

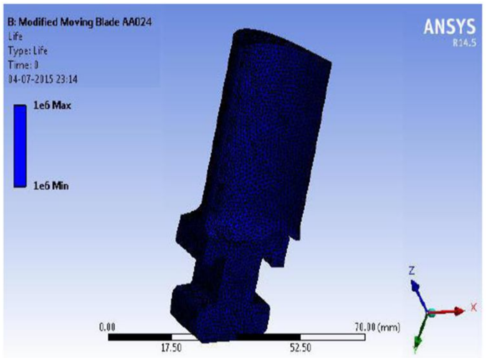


Fig.10. Fatigue life of modified steam turbine blade.

Table3. Comparison of results

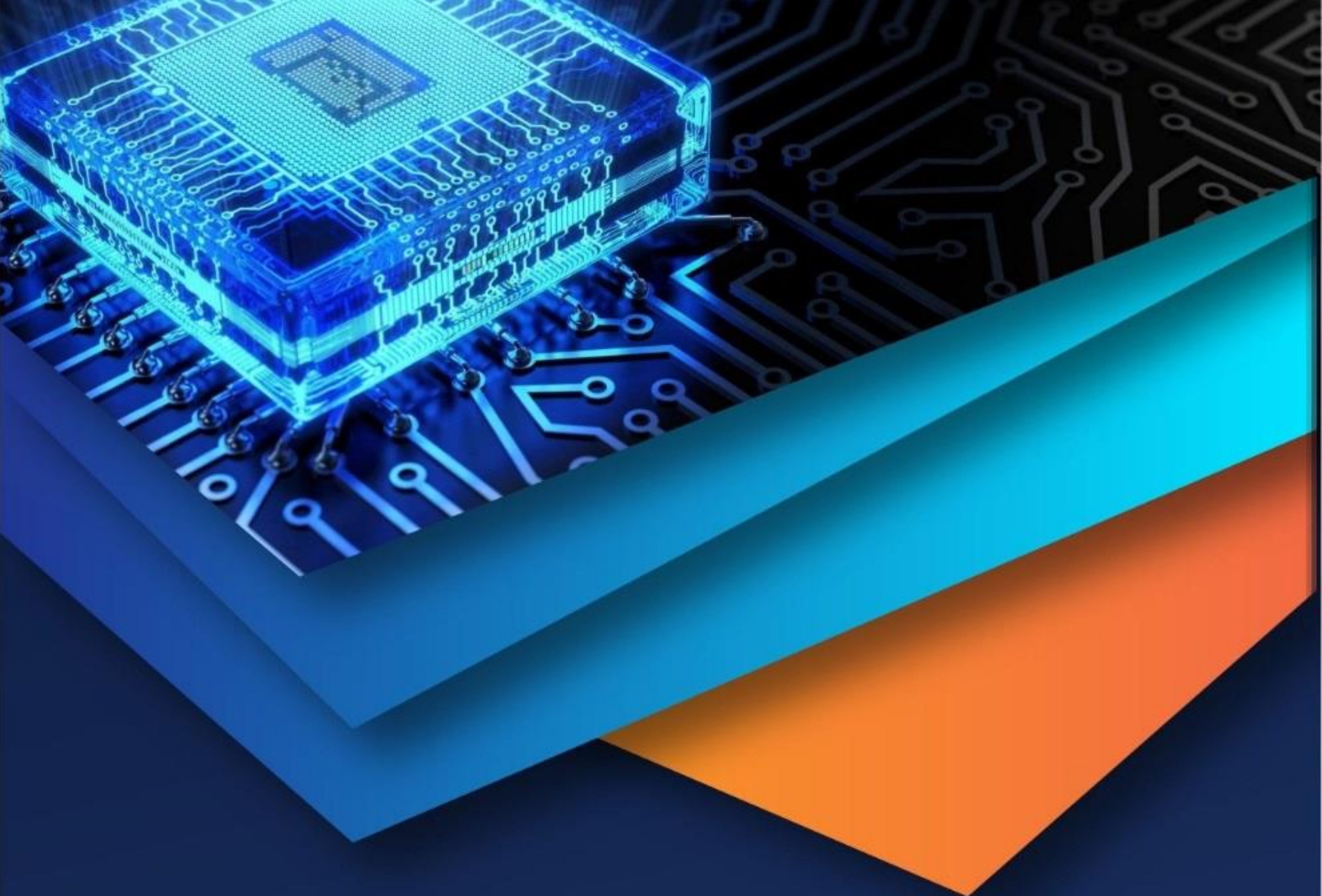
S.No.	Parameter	Existing Blade	Modified Blade
1	Equivalent stress (Mpa)	560	345.1
2	Fatigue life "N"	86438	1000000

IX. CONCLUSION

This project has attempted to investigate the fatigue response of the steam turbine blade in terms of high cycle fatigue. Existing blade design is good enough for fatigue life in theoretical calculation. But there is a problem in finite element analysis. In theoretical calculation blade version is getting endless life (2.438e6). However at some point of run of Ansys software program present blade design is getting most effective 86436 is number of cycles as fatigue lifestyles. Some changes are suggested to steam turbine blade fashion designer that's able to gain the existence of 1e6 cycles as fatigue lifestyles.

REFERENCES

[1] Heinz P. Bloch, Murari P Singh, "Steam Turbines Design, Application, and Re-Rating" Mc Graw Hill publisher, PP 109-124, 188-218.
[2] Tulsidas.D, Shantharaja.M & Bharath.V.G "Life estimation of a steam turbine blade usinglow cycle fatigue analysis", ELSEVIER, 2014, PP 2392-2399.
[3] Mestanek "Low Cycle Fatigue Analysis of last stage blade", University of Bohemia, 2008, PP 71-81.
[4] Norman E Dowling, "Mean Stress Effects in Stress-Life and Strain-Life Fatigue" 2004, PP 495-498. [5]Gallagher, J. P., et al." Improved High Cycle Fatigue (HCF) Life Predictions", Wright-Patterson, 200
[5] HE Ming-xing. Based on the ZigBee and GPRS technologies of wireless sensor network gateways design [J]. Indust ry and Mine Automation. 2009•C8•F106-108.
[6] Shlyakhin "Steam Turbines Theory & Design" Foreigne Languages publishing house, PP 7-30,209-220.



10.22214/IJRASET

45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY