The Design and Analysis of Steam Turbine Blades Effect with Hp and IP

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Abstract: - Steam turbine converts the heat energy of steam into useful work. The nozzles or fixed blades in turbine are designed to direct the steam flow into well formed, high speed jets as steam expands from inlet to exhaust pressure. These jets strike the moving rows of blades mounted on rotor causes change in the direction of steam which imparts momentum. Thus blades convert the kinetic energy of steam into the rotational energy of shaft. (i.e. Mechanical energy). Steam turbines are subjected to number of start-ups and shut-downs during its life span. That means it is subjected to repetitive cyclic loading conditions which causes a fatigue failure of moving blades. So we can say modern turbines are fatigue critical machines. Hence the prediction of service life time is becoming an essential part of the design process. This project summarizes structural performance of the blade due to centrifugal loading that acts on the blade due to high angular speeds. The design and analysis of turbine blade involves creation of turbine blade solid model using Creo-1.0 & ANSYS 14.5 software is used for F.E. model generation & post processing.

Keywords: Steam turbine, heat energy, jets, High Pressure (HP) and Intermediate Pressure (IP) rotating blades, centrifugal force.

I. INTRODUCTION

A steam turbine converts the heat energy of steam into useful work. The nozzles and diaphragms in a turbine are designed to direct the steam flow into well-formed, high-speed jets as the steam expands from inlet to exhaust pressure. These jets strike moving rows of blades mounted on the rotor. The blades convert the kinetic energy of the steam into rotation energy of the shaft.

There are two principal turbine types: reaction and impulse (Fig No 1). In a reaction turbine, the steam expands in both the stationary and moving blades. The moving blades are designed to utilize the steam jet energy of the stationary blades and to act as nozzles them-selves. Because they are moving nozzles, a reaction force produced by the pressure drop across them supplements the steam jet force of the stationary blades. These combined forces cause rotation.

To operate efficiently the reaction turbine must be designed to minimize leakage around the moving blades. This is done by making most internal clearances relatively small. The reaction turbine also usually requires a balance piston (similar to those used in large centrifugal compressors) because of the large thrust loads generated. Because of these considerations, the reaction turbine is seldom used for mechanical drive in the United States, despite its occasionally higher initial efficiency. Reaction turbines are, nevertheless, in widespread use in Europe and the rest of the world. They deserve to be discussed and will be dealt with later.

The impulse turbine has little or no pressure drop across its moving blades. Steam energy is transferred to the rotor entirely by the steam jets striking the moving blades. Since there is theoretically no pressure drop across the moving blades (and thus no reaction), internal clearances are large, and no balance piston is needed. These features make the impulse turbine a rugged and durable machine that can withstand the heavy-duty service of today's mechanical drive applications.

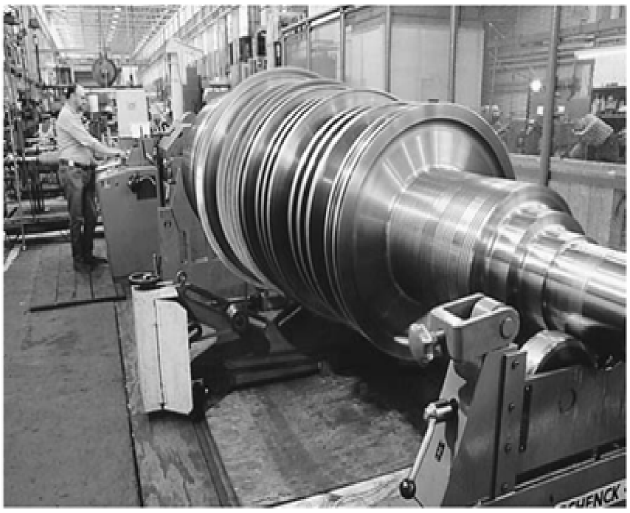

Fig No 1.1 Solid turbine rotor wheels and shaft

HP and IP Rotating Blades

The rotating blades convert the kinetic energy into impulse and reaction forces, caused by pressure drop, which together result in the rotation of the turbine shaft or rotor. The blades in the high-pressure (HP) and Intermediate pressure (IP) turbine are small and medium because of the low volumetric steam flow. Basic features of the short blades typical of HP turbines are identified in Figure

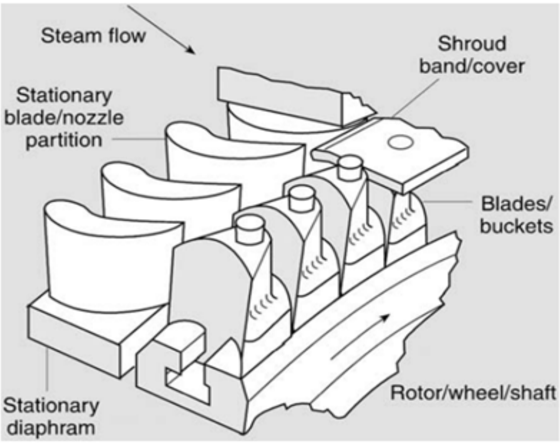

Fig No.1.2 Arrangement of stationary and rotating blades

Rotating HP blades are usually straight; however, the use of leaned and bowed blades has recently introduced a three-dimensional aspect to designs. Shrouds (also called covers or connecting bands) provide a sealing surface for radial steam seals and are used to minimize losses due to leakage. Shrouds also tie the blades together structurally and allow for some control over the damping and natural frequencies of the blades. The shrouds are typically attached either by peened tenons or are integral with the blade airfoil.

Various methods of attaching both HP and LP blades to the rotor are used, depending on the manufacturer. Figure 32 shows the most common types of root attachments. The choice of type of attachment will depend on a number of factors. For example, for one manufacturer, a side-entry fir-tree root design is used in the HP control stage for ease of replacement if required because of solid particle erosion. For longer blades in the control stage, however, a triple-pin construction is sometimes used as the side-entry design has too many modes close to the nozzle wake frequency [8].

A particular challenge in HP blading design is the first (control) stage where operation with partial-arc admission leads to high dynamic stresses. Design factors such as choice of leading-edge configuration and blade groupings are chosen to reduce the vibratory stresses produced. Blades in IP turbines are very similar in design to those in the HP, with somewhat more twist (and most recently bowing and leaning) to account for greater radial variation in the flow. Design of HP turbine blades in nuclear unit manifest similar features as those in fossil units; for example, use of the same root attachment designs. HP blades in nuclear units are longer in order to handle the higher volumetric flows.

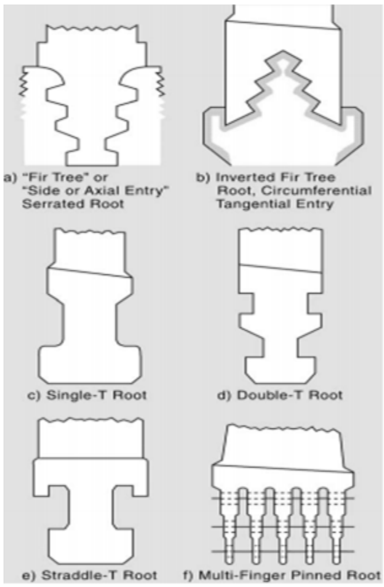

Fig No.1.3 Steam turbine blade roots

Blades are connected at the root to the rotor or disk by several configurations as shown in Fig. The blade roots may be of the ‘‘serrated’’ or ‘‘fir-tree’’ configuration, inserted into individual axial slots in the disk or a similar serrated or T-shape, inserted into a continuous circumferential slot in the disk (this requires a special insertion gap), or may comprise one or several flat ‘‘fingers’’ fitting into circumferential slots in the disk and secured by axially inserted pins. Serrated or T-roots, furthermore, may be of male or female type.

II. DESIGN OF TURBINE BLADE

There are complicated methods to properly harness steam power that give rise to the two primary turbine designs:

(i) Impulse

(ii) Reaction turbines.

These different designs engage the steam in a different method so as to turn the rotor. As water converts into steam, the molecules grow further apart. While steam can exert pressure, it cannot exert the correct pressure needed to spin the rotor quickly enough to generate electricity. Thus, a special design of rotor is required to properly harness the steam and spin. In an impulse turbine, nozzles direct the steam towards the rotors, which are equipped with concave panels called buckets. The nozzles are able to project a jet of steam that spins the rotor at a loss of roughly 10 percent energy. As the jets change their position, they can increase or decrease the rate of rotor spin.

A reaction turbine works opposite the impulse turbine. The steam nozzles are attached to the rotor blades on opposite sides. The nozzles are so positioned that when they release jets of stream, they propel the rotor in a spinning motion that keeps it rotating as long as steam is being expelled. It can reach high speeds because the nozzle designs focus the steam into a thin stream, although the initial warm up period may take several moments.

Turbine Blade Stresses

There is a myriad of static and dynamic stresses and loads on turbine blades, particularly the longer blades of the steam turbine. Blades in nuclear and fossil turbines are mostly affected by the same types of stresses; further, the magnitude of the stresses tends to be about the same. Blades in nuclear units are longer, but the machines typically rotate at 1,500 or 1,800 rpm instead of 3,000 or 3,600 rpm, and thus the magnitude of the centrifugal stress (the highest magnitude blade stress), by design, is about the same.

Centrifugal Stresses

Centrifugal loads, caused by rotation, are the primary source of stress on blades. The centrifugal loads on HP and IP blades are relatively small as the blades are short and the diameter small because of the relatively low volumetric flows. In contrast, as a rule of thumb, in typical last-row LP turbine blades (unshrouded), the steady stresses will be roughly 0.5Syover about half the blade airfoil length, and in excess of 0.25Syover about 80% of that length, whereSyistheyieldstrengthofthematerial.Figure38shows a typical distribution of centrifugal stresses and the benefits associated with the use of titanium (because of its lower material density). Centrifugal stresses are generally proportional to the square of the speed, i.e., a 120% overspeed will produce a 1.44 times increase in the centrifugal load. As a result, during over speed tests, the centrifugal stresses on a blade can increase to as high as 75%of the material's yield strength [38, 39]. See Figure.

Centrifugal stresses can also have a dramatic effect in those locations where there are stress concentrations such as in the root attachment and at the wire holes. For example, in the blade root, where stress concentrations are high, design steady stresses are lower than the aforementioned maximum, perhaps in the range of 0.2 to 0.4Sy.

However, during start-up, dynamic centrifugal stresses near to these stress concentrations can exceed the yield strength. Also, actual stresses are strongly influenced by the local geometry. For example, in those designs where multiple hooks share the load, variations in the gap between blade and disk in the root attachment can lead to a wide variation in actual stresses. High mean stresses, such as those induced by centrifugal loads, have a pronounced detrimental effect on the fatigue strength of high-strength materials such as blading alloys.

Blade Root Geometry and Load Transfer

The most common types of blade fastenings in steam turbines were shown in Figure 1 under columns A and B. Blades, fastened in this manner, have to conform in their root design with the cylindrical geometry of the rotor.

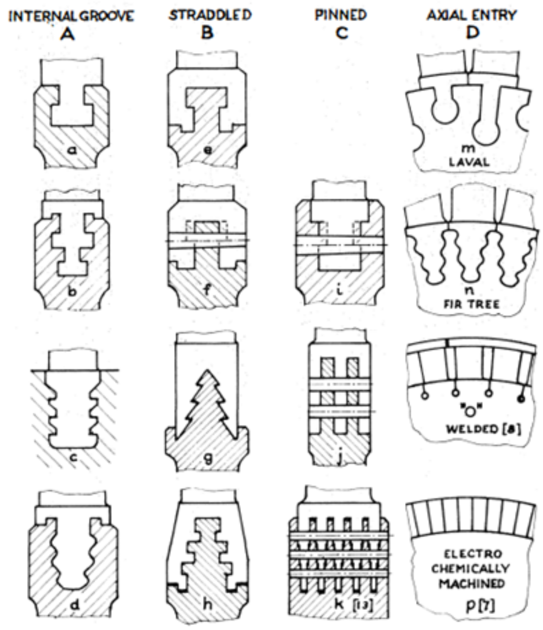

Fig No.2.1 Blade fastenings

For clarity of discussion the following planes are defined in Figure 2. Axial planes are formed by the centerline of the rotor and a radial line (these planes are perpendicular to the paper), radial planes coincide with the plane of the paper and circumferential planes are cylindrical surfaces as shown. The two features, which a blade root should possess to conform with the cylindrical geometry , are a wedge shape, formed by the two axial planes and arc shapes for all circumfer-ential surfaces, as shown in Figure 2. Any nonconformity will generate looseness associated with increased alternating stress amplitudes and high concentrated contact loads, see Figure 3.Less expensive blades do not have curved root lands. As difficult a task as it may be to achieve conformity with the cylindrical geometry, high reliability requires extremely high precision (± .0004") .This poses substantial demands on the accuracy of machining and quality control .

As a method of identifying surface loading and stresses within a body in a qualitative manner, two types of cross-hatching symbols are used. As shown in Figure 10, a diagonal hatching shall represent tensile stresses, while parallel cross-hatching identifies compressive loading. The density or dark-ness of the hatching shall be a measure for the relative magnitude of either loading or stresses. The darker the area, the higher the stress value. As a first example, a root cross section of an impulse blade with a T-root, as shown in Figure , shall be considered. The cross section is taken just above the top plane of the root lands as indicated. Figure shows the load and stress distribution for a centrifugal load only. Due to flexing of the root lands the load increases slightly toward the shank. Stress concentrations exist in the shank cross section on both sides near the root lands. This is in agreement with Figure , where the highest tensile stress occurs on both sides of the blade shank in the fillet region.

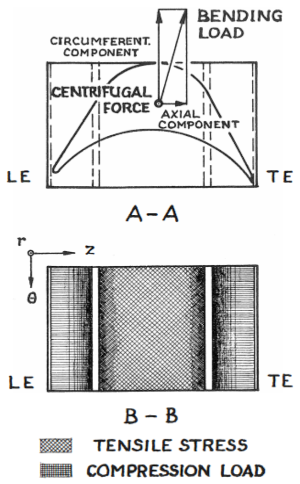

Fig No.2.2 Load and stress distribution due to centrifugal force

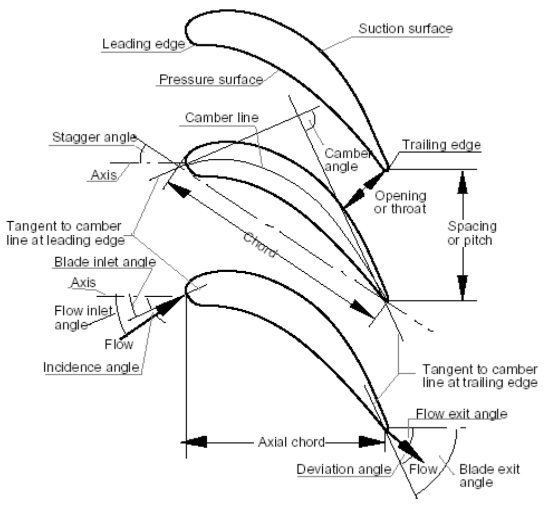

Fig No.2.3 Moving blade cross section nomenclature

Operating conditions

Speed of the blade N = 8000rpm

No. of blades in one disk = 87

Moving Blade height = 47 mm

Material of Rotor = 21CrMoV57

$\sigma_{0.2}$ min for Rotor Material= 468Mpa

Material of Blade = X22CrMoV121

$\sigma_{0.2}$ min for Blade Material = 488.6 Mpa

Bending stress = 0.486 T/sq.in = 7.39692 Mpa

Blade design is very difficult and confidential to every turbine designer. So here only outlining the design by just some important dimensions only.

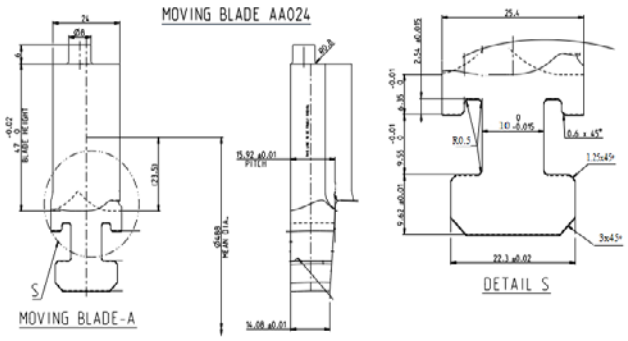

Fig No. 2.4 Blade design

Centrifugal force

Centrifugal force is directed outwards, away from centre of curvature of the path.

The general equation for centrifugal force is

$$F= mr\omega^2 \text{ ----- } (1)$$

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.

In the case under consideration, we need to account for the fact that the mass of the blade is distributed over its length and the radius of curvature also changes along the length of the blade. Consider a small segment of mass δm , of length 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: $\delta F = \delta m r\omega^2$----(2)

The blades have a cross sectional area A (mm^2) and material density ρ (kg/mm^3). 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 write as $dF = \rho A\omega^2 r dr$

Let be the radius of the rotor disc and be the distance between the centre of the rotor disc and tip of the blade. Then, integrating equation (3) along the total length of the blade, the total centrifugal force acting on the blade is given

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

$$F = \rho A\omega^2 \left(\frac{r_2^2 - r_1^2}{2} \right) \ldots (4)$$

We can convert the angular velocity from revolutions per minute (rpm) to radians per second using the following relationship:

$$\omega = \frac{N \times 2\pi}{60} \quad \dots (5)$$

CALCULATION:

The following details considered for design and centrifugal force estimation:

Blade speed	N	= 8000 rpm
Blade cross-sectional area	A	= 165.161 mm^2
Material density	ρ	= 7850×10^{-6} kg/mm^3
Blade tip radius	r_2	= 267.5 mm
Blade root radius	r_1	= 220.5 mm
Blade length	r_2-r_1	=47mm

So we can calculate the angular velocity in radians per second as $\omega = 8000 \times 2\pi/60$

ω= 837.75 rad/sec

Substituting the all above values in equation (4)

$F=7850 \times 10^{-6} \times 165.161 \times 837.75^2 \times (267.5^2-220.5^2)/2 \times 1000$

F=10,436.2 N

Hence the magnitude if the centrifugal force acting on the blade due to high angular velocity is 10,436 N.

III. PREVIOUS WORK

In this paper, Subramanyam Pavuluri and Anup Magdum addresses the issue of steam turbine efficiency by discussing the overhaul design of high pressure steam turbine blades. A specific focus on blade profile, material used in the production of steam turbine blades, and the factors that cause turbine blade failure and therefore the failure of the turbine itself. This project enumerates and describes the currently available technologies that enhance the overall efficiency of the generator and prevent turbine failure due to blade erosion and blade cracking. In particular, this project evaluates the effectiveness of certain titanium alloys and steels in resisting creep and fracture in turbine blades. The effectiveness of chemical and thermal coatings in protecting the blade substrate from corrosion when exposed the wet steam will also be addressed.

In this paper, Dr. A. Siva Kumar & Subramanyam Pavuluri are addresses the Experimental investigation on design of high pressure steam turbine blade addresses the issue of steam turbine efficiency. A specific focus on aerofoil profile for high pressure turbine blade, and it evaluates the effectiveness of certain Chromium and Nickel in resisting creep and fracture in turbine blades. The capable of thermal and chemical conditions in blade substrate from to prevent the corrosion when exposed to wet steam. The efficiency of the steam turbine is a key factor in both the environmental and economical impact of any coal-fired power station. To increasing the efficiency of a typical 500MW turbine by 1% reduces emissions of CO2 from the turbine station, with corresponding reductions in NOx and SOx. In this connection an attempt is made on steam turbine blade performance is important criterion for retrofit coal fired power plant. Based on the research presented modifications to high pressure high pressure steam turbine blades can be made to increase turbine efficiency of the turbine. The results and conclusions are presented for a study concerning the durability problems experienced with steam turbine blades.

In this paper, Tulsidas. D, Dr. Shantharaja. M,& Dr. Kumar. are addresses the large variety of turbo-machinery blade root geometries used in industry prompted the question if an optimum geometry could be found. An optimum blade root was defined, as a root with practical geometry which, when loaded returns the minimum fillet stress concentration factor. The present paper outlines the design modification for fillet stresses and a special attention is made on SCF of the blade root (T-root) which fails and to guarantee for safe and reliable operation under all possible service conditions. Finite Element Analysis is used to determine the fillet stresses and Peterson's Stress Concentration Factor chart is effectively utilized to modify the blade root. The root is modified due to the difficulty in manufacturing the butting surface of the tang which grips the blade to the disk crowns having small contact area.

Dr. Murari P. Singh, Dr. George M. Lucas, PE are concise reference for practicing engineers involved in the design, specification, and evaluation of industrial steam turbines, particularly critical process compressor drivers. A unified view of blade design concepts and techniques is presented. The book covers advances in modal analysis, fatigue and creep analysis, and aerodynamic theories, along with an overview of commonly used materials and manufacturing processes. This authoritative guide will aid in the design of powerful, efficient, and reliable turbines.

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 general outline of the SSTHC development program carried out at Gulf General Atomic is given. The following areas are included in the development program: aerodynamics, compressor noise, primary coolant shutoff valve, water bearings and rotor dynamics, seals, blade vibration, and disk catcher. Further, a comprehensive series of transient tests on a circulator have been carried out.

IV. CALCULATIONS& ANALYSIS OF STEAM TURBINE BLADE

IV.PROBLEM STATEMENT

With the knowledge that an understanding of the forces and stresses acting on the turbine blades is of vital importance, in this project we calculated such a force acting on a High Pressure (HP) blade and root of a steam turbine rotating at 8000 rpm. This project focuses on structural performance of the steam turbine blade due to centrifugal loading that acts on the blade due to high angular speeds.

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 one such a material which have all these properties. And it is the one most commonly used material for HP blades in steam turbine.

Element	**C**	**Si**	**Mn**	**P**	**S**	**Cr**	**Mo**	**Ni**
Min %	0.18	0.10	0.30	---	---	11.0	0.80	0.30
Max %	0.24	0.50	0.80	0.03	0.02	12.5	1.20	0.80

Table 1: Chemical Composition of X22CrMoV121

Tensile strength N/m^2	0.2% Proof stress N/mm2 (Min)	Elongation (%) $l=5.65\sqrt{S_o}$ (Min)	Impact Strength Joules (Min.)	%Reduction in Area Min
900-1050	700	11	20	14

Table 2: Mechanical properties of X22CrMoV121

Other properties of X22CrMoV121 are listed below.

Young's Modulus or Modulus of elasticity E = $2.10e^5$ MPa

Fatigue Strength Coefficient (Effective strength) σ_f'=1945MPa

Fatigue ductility coefficient ϵ_f' = 2.58

Fatigue strength b = -0.106

Fatigue ductility exponent c = -0.777

V. FE ANALYSIS OF STEAM TURBINE BLADE OR RESULTS

The FE analysis was performed using the finiteelement computational software ANSYS 14.5.The intention of the FE analysis was to determinethe stress of the components at the criticallocation of the blade. It has been found out that the critical location of the blade is situated atthe T root of the blade. More precisely, at the convex side of the neck. Bladed turbine disc is a cyclic symmetrical structure. Modelling only one blade and the belonging disc section is representative for the whole structure. Nevertheless, the effects of the surplus disc section that is not modelled must be compensated by the boundary condition of cyclic symmetry. The effect of the rotor is replaced by the axial displacement boundary condition. The situation is depicted in figure. 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. No.5.1 HP turbine blade

Pre-prosser for blade analysis:

Step1: Geometry creation

First step of Ansys is creating the geometry. This can be directly done in design module or else we can import the geometry from other location also. But it should in the format which can be read by ANSYS. Some of those types of formats are IGES, STEP. Here for this analysis geometry file is imported in "STEP" which is exported from the Creo 1.0 (it is modelling software also known as PROE).

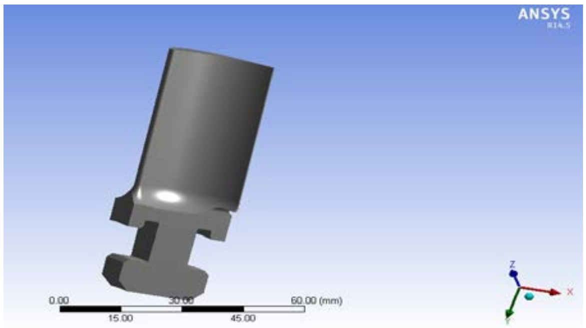

Fig No. 5.2 Creating Geometry model

Step 2: Material assignment is the second step for analysis. Because based on the type of material same geometry will give different results even for same working conditions. So after importing the model, it should be assigned the material properties.

Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7850	kg m^-3		
3	Isotropic Secant Coefficient of Thermal Expansion				
6	Isotropic Elasticity				
12	Alternating Stress Mean Stress	Tabular			
16	Strain-Life Parameters				
17	Display Curve Type	Strain-Life			
18	Strength Coefficient	1945	MPa		
19	Strength Exponent	-0.106			
20	Ductility Coefficient	2.58			
21	Ductility Exponent	-0.777			
22	Cyclic Strength Coefficient	1E+09	Pa		
23	Cyclic Strain Hardening Exponent	0.2			
24	Tensile Yield Strength	2.5E+08	Pa		
25	Compressive Yield Strength	2.5E+08	Pa		
26	Tensile Ultimate Strength	4.6E+08	Pa		
27	Compressive Ultimate Strength	0	Pa		

Fig No. 5.3 Material properties of blade

Processor for blade analysis:

Step 1: Mesh Generation or Ansys model generation

Mesh generation means discritising the model into small element. Finite element itself expling that dividing a complex element into small well known shape. Once model is assigned with material then meshing of the geometry will be done. Then onwards geometry can be named as Ansys model. Here tetrahedron mesh is used to generate the meshed model with element size 1mm.

Step 2: Constraining the element

The main aim of any analysis is to get some results by applying some forces on it. So geometry should not be allowed to free moment due to the force application. Hence it need some constrains. Constrain means arresting the motion at some location. That may be fixed, displaced constrain. Here blade is constrained by fixed supports at side of the blade tang. This is due to locking of blade in rotor disk.

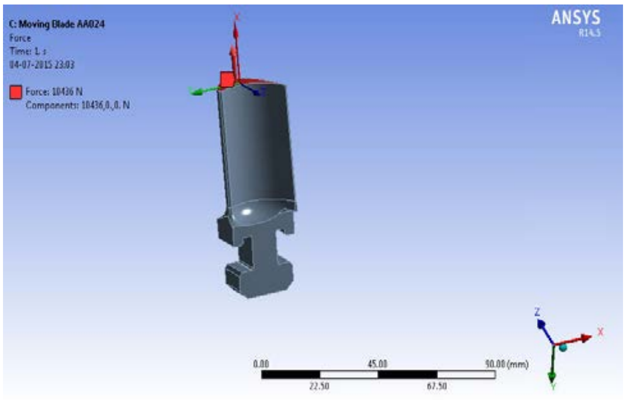

Fig No. 5.4 Centrifugal force acting on blade

Step 3: Application of loads

As discussed in literature survey under chapter 2 centrifugal forces 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.

Post processor:

Step1: Solving the model, it means allowing the system to run all given conditions like application of constrains and loads.

Step 2: Generating the results

After proper solving Analyst can able to get the required results. Here Stress developed within the blade and fatigue life estimation is major criteria of project. So get the results by selecting the required options like equivalent stress and Fatigue tool.

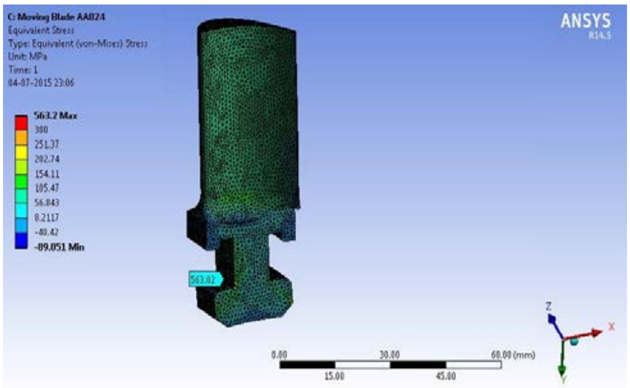

Fig No. 5.5 Design of Meshed blade

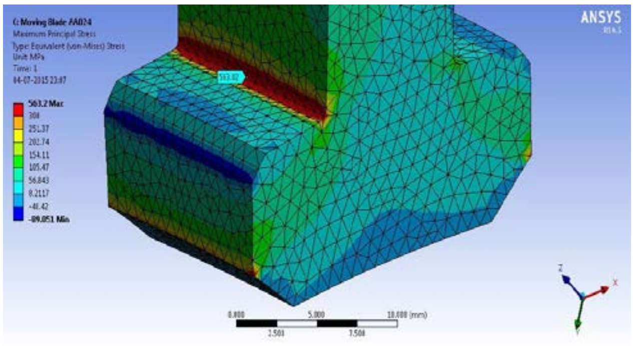

Fig No.5.6 Stress observed in blade

Equivalent von-meshes stress observed (563 MPa) on the fillet region of the blade as depicted in the fig above.

From the ANSYS results of the turbine blade design, the equivalent von-Meshes stress are found at the root and is equal to 560MPa.

V. CONCLUSION

This project has attempted to investigate the stress region and maximum stress of the steam turbine blade. The goal of the research was to find out the maximum stresses in the HP turbine blade equipped with the T root and to determine the weak or stress location. The HP turbine blade design is good enough to with stand the centrifugal force. Here weak or stress location of blade occurs in T root of blade. But the maximum stress = 560MPa obtained from Ansys is less than the allowable limit (yield strength of 900MPa). So the design is safe.

VI.FUTURE SCOPES

In This project has attempted to investigate the stress region and maximum stress of the steam turbine blade. The goal of the research was to find out the maximum stresses in the HP turbine blade equipped with the T root and to determine the weak or stress location. The design and analysis of turbine blade involves creation of turbine blade solid model using Creo-4.0 (2016) & ANSYS 17.1 software is used for F.E. modeling & processing.

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