Journal of Advances in Science and Technology
Vol. 13, Issue No. 1, (Special Issue) March-2017, ISSN 2230-9659

Structural and Transient Thermal Analysis of Steam Turbine Rotor

Nikhil S. Jumde[1]*, Vivek V. Pande[2]

[1]Asst. Proffesor, Mechanical Department, Shri Sai College of Engineering & Technology, Bhadrawati, M.S, India

[2]Mechanical Department, Ramdeobaba College of Engineering & Management, Nagpur, M.S, India

Abstract – Stresses and temperature distribution in the rotor (300MW) during start-up cycle were evaluated using Finite Element Analysis. Geometry of steam turbine rotor has modeled used CATIAV5R20. In this present work, depending upon flow condition over the rotor, structural and transient thermal analysis has been done using ANSYS 14.5 workbench. And variations of temperature over the rotor at different time step have been observed. Stress distribution was validated by comparing it with yield strength of the material and nature of temperature distribution will be validated by comparing it with actual industrial data. As Creep is one of the most important parameter for life assessment of steam turbine rotor thus result obtained which will be utilized for calculating creep. Remaining life assessment of steam turbine rotor can be obtained.

Keywords: Finite Element Analysis, Rotor, Structural and Thermal Analysis, Life Assessment.

◆

INTRODUCTION

At present, around 40% of Indian power generation capacity is provided by coal based thermal power plant. Being one of the most critical components in power plant, a rotor comprises a high pressure (HP) rotor, an intermediate pressure (IP) rotor, and low pressure (LP) rotor .All rotor shafts are rigidly coupled together. HP and IP rotors are classified as high temperature rotors. Most of those currently in service are manufactured of chromium molybdenum vanadium (CrMoV) material forgings, working under a temperature up to 540°C and pressure 14MPa, causes creep and fatigue interaction which affects turbine life. [1]

During a long service life of the rotor, cracks may develop under the combination of cyclic loading and high operating temperature causes failure of the rotor. This leads to heavy capital loss as well as generation loss. Hence in order to avoid this, there is an increasing desire for the researchers to perform life assessment of steam turbine rotor.

Remaining life assessment offers a possible tool to estimate the remaining useful life and avoid premature scrapping of the parts. It helps to set proper inspection schedule, maintenance procedure and operating procedure. [2] Steam turbine rotor life assessment depends on various factors namely stresses, temperature distribution, material used and operating conditions. [1]

LITERATURE REVIEW

The study of this topic has seldom been addressed by scholars. Despite numerous investigations have modeled structural and transient thermal analysis, most studies have only been addressed by considering sectional view and not a 3-D model.

Xiaoling Zhang (2006) presented the finite element analysis, to determine the stresses, temperature distribution, creep strain, and reference stress of steam turbine rotor for creep rupture. Further he explained the engineering approaches to their remaining life prediction for high temperature components, as well as the most common failure mechanisms of high temperature rotors. R.Vishwanathan (1993) has discussed the purpose and techniques to calculate life assessment for high temperature components and various damage phenomena. Detailed study of various parameters like creep, low cycle fatigue, corrosion, embrittlement etc. which affect the life assessment has also been discussed. S.Barella et al, (2011) investigated the rotor turbine failure of a 60 MW unit of a thermal power plant by several different analysis methods like visual examination, SEM fractography, micro-hardness measurement, and micro structural characterization. They found that mechanical fatigue shall be considered as the unique root cause for failure. Further, they suggested performing ND test on steam turbine to determine the existence of early stage fatigue cracks in steam turbine rotor.

S.Bashetty et al. (2013) has performed the calculation of remaining life assessment for steam turbine rotor by combining the effects of thermal stresses due to temperature variation and stresses due to Pressure load. They particularly focused on the time-dependent inelastic behavior of materials and cyclic loading under non-isothermal conditions and Remnant life assessment of steam turbine rotor. A Caccialupi et al. (1994) performed the finite element analyses on critical main steam valve and discussed various techniques for life assessment such as computer echo tomography. Boresonic. M.Batrani (2006) has discussed utilization of the modern CAE tools like Hyper-mesh, ANSYS and Pro-E etc to model and analyze existing LP rotor and for redesigning it to suit the new efficient modern design of rotor. W. Wiemann (1992) discusses the development of improved 2% CrMovNi rotor steel material, in respect of physical and mechanical properties with other materials. S. R. Holdsworth et al. (2007) described that the crack initiation endurances have been determined for CrMoV rotor steel in uniaxial service cycle thermo-mechanical fatigue (TMF) tests formulated to simulate a range of steam turbine start cycles with a maximum temperature of 565°C.and explained various models by which temperature distribution can be validated experimentally.

From the above literature review it is observed that maximum work is carried out by considering sectional view of the rotor. In this paper 3D geometry of steam turbine rotor was considered to enhance the accuracy of the result.

STRUCTURAL ANALYSIS OF STEAM TURBINE ROTOR

Stress distribution obtained from structural analysis under cold start up condition is used to identify the critical point and location that are most vulnerable to crack initiation, propagation and brittle fracture failure. To find out such critical points on steam turbine rotor structural analysis is carried out .Table 1 shows the specification of turbine of 300MW.

TABLE 1: Specification of Turbine [Steam turbine Operation & Maintenance Instructions Manual 2X300MW]

Vertical	Axis of Turbine
300MW	Rated Power
312MW	Maximum Power
3000RPM	Rated Speed
14.2MPa	Main Steam Pressure
540°C	Main Steam Temperature
650 T/H	Main stream Flow rate
Clockwise	Rotation Direction of Rotor
7213.2 mm	Length of HP IP Rotor
3.72 m	Length of HP Rotor
14MPa	HP I/L Pressure
3.8 MPa	HP O/L Pressure
342.8°C	HP Turbine Exhaust

Selection of material plays a vital role for accurate life assessment process. Selected material should be able to withstand its property till 540°C and above.

The material used for steam turbine rotor is CrMoV steel because of its good creep rupture properties above 540°C, and has a reasonable degree of corrosion resistance in superheated steam. Table 2 shows different properties for selected material.

TABLE 2: Properties of CrMoV rotor steel [www.matweb.com}

7800 kg/m^3	Density(ρ)
199.2 GPa	Young's Modulus of elasticity (E)
0.3	Poisson's ratio (υ)
869 MPa	Yield Strength (S_{yt})
1610 MPa	Ultimate Tensile Strength(S_{ut})
27 w/m-k	Thermal Conductivity (K)
12x10^{-6} m/m-k	Coefficient of thermal Expansion (α)
460 J/kg-k	Specific Heat Capacity

The 2-D and 3-D model of steam turbine rotor (HP-IP) is modeled using CATIA software as shown in fig.1 and fig.2. CATIA stands for Computer Aided Three dimensional Interactive Applications which are graphically user interface that provides a good surface finish to the model.

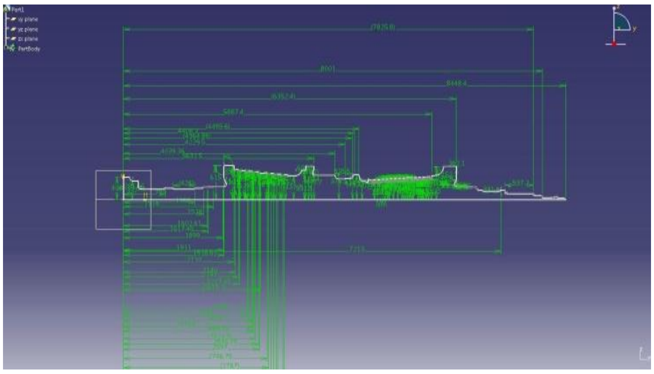

Fig-1: Modeling of HP- IP Rotor.

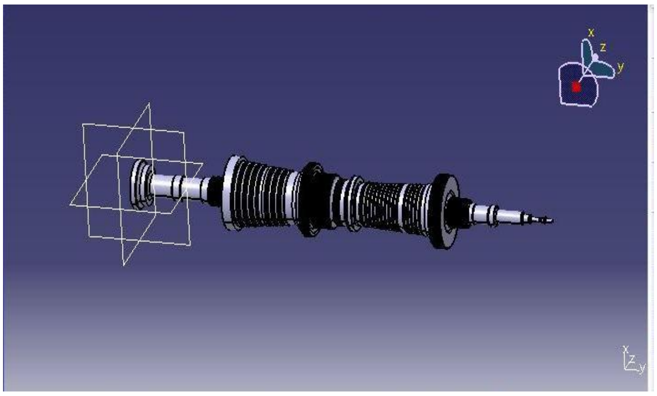

Fig -2: 3D Modeling of HP- IP Rotor.

For analysis purposes, only the HP side of steam turbine rotor is considered since steam enters at HP side first and maximum stresses get induced on HP side as compared to the other portion of the rotor. The 2-D and 3-D model of steam turbine rotor HP side is as shown in fig.3 and fig.4.

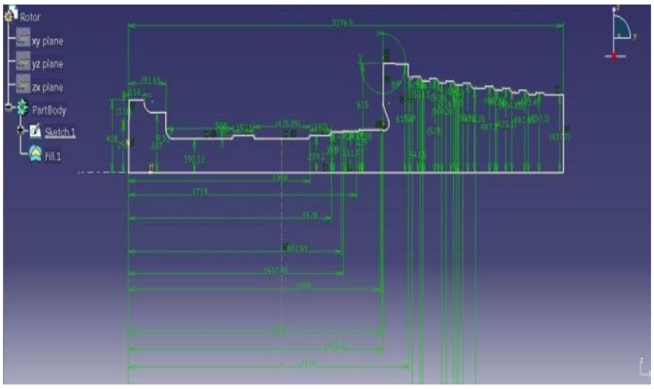

Fig 3: 2-D Model of HP Rotor

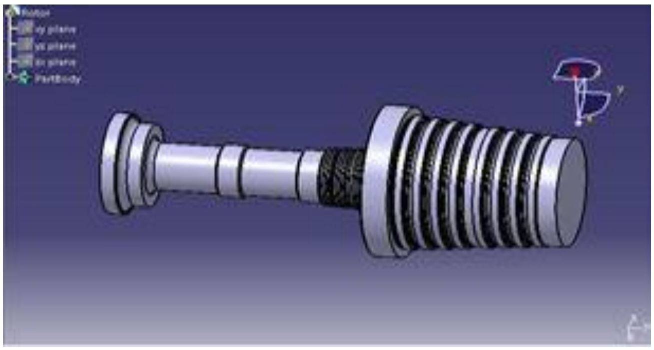

Fig 4 -: 3D Modeling of HP Rotor.

Finite element method is a kind of numerical method which works on the principle of Discretization. Hence, the model is discretized by using triangular 3-D solid element. Fig. 5 shows the meshed model (HP Side) of the rotor.

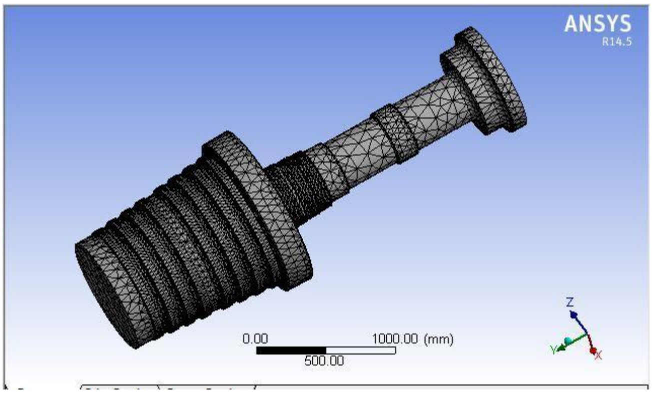

Fig -5: 3-D Meshed Model of HP Side

The specialty of selected elements is that it supports structural and transient thermal analysis. There are total 169219 nodes and 98893 elements in the model. For analysis purposes, IP side of the rotor is fixed and pressure applied over complete surface of the rotor is 14 MPa as shown in fig.6.

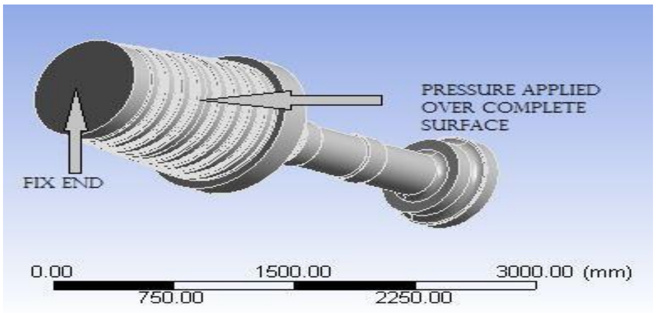

Fig 6-: Boundary Conditions

TRANSIENT THERMAL ANALYSIS

The transient thermal analysis is required to find the temperature distribution on the surface .The analysis is based on plant cold start condition. The initial metal temperature was assumed as 32°C. At the time of synchronization the rotor speed is ramped rapidly from 0 RPM to 3000 RPM. In the meantime, the inlet steam temperature increases and reaches 540°C at full load condition.

For transient thermal analysis, the number of steps for analysis is taken as 5 and sub steps taken as 20 for 33600 seconds in equal interval of time which is programmed to control. The following are the boundary conditions applied to the rotor for transient thermal analysis is as shown in Table 3**.** (Cold start-up data). For analysis purpose convective heat transfer coefficient is calculated.

During actual working process, temperature has reached up to 540°C and this may cause a phase change. But in this analysis phase change is not considered because the chemical composition of material may change.

TABLE 3: Temperature v/s Time Data

TEMPERATURE (°C)	TIME (sec)
35	0
45	7800
250	8400
460	16200
540	24000
540	33600

RESULTS AND DISCUSSION

Structural Analysis

To estimate the crack size, von-Mises stresses and total deformation is calculated using static structural analysis. The von-Mises stresses shown in Fig.7 is 44.75 MPa which is less than yield strength of material (Table 2), which implies that design is safe.

Total deformation of the HP side of steam turbine rotor is 0.30191 mm (Fig.8). It implies CrMoV rotor steel has good toughness property and good anti-corrosive property for high temperature and pressure.

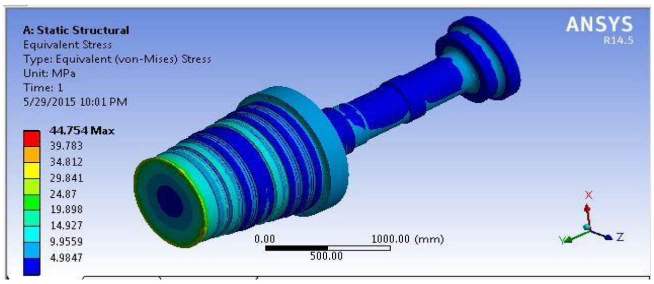

Fig 7 -: Variation of equivalent Stresses on H.P Turbine Rotor

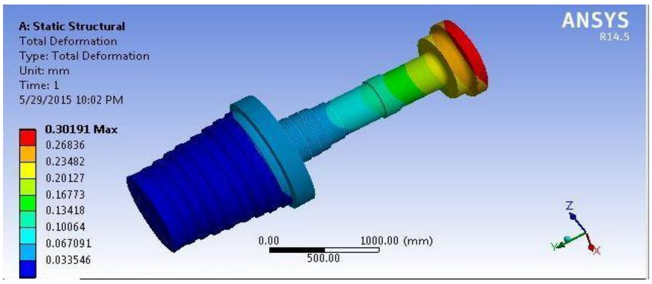

Fig 8 -: Total Deformation on H.P Turbine Rotor

Transient Thermal Analysis

The temperature around the rotor is 32°C and rises to 540°C in 24,000 seconds and then remains constant at 540°C. The temperature distribution across the steam turbine rotor is shown in fig.9, 11, 13, 15 and 17.

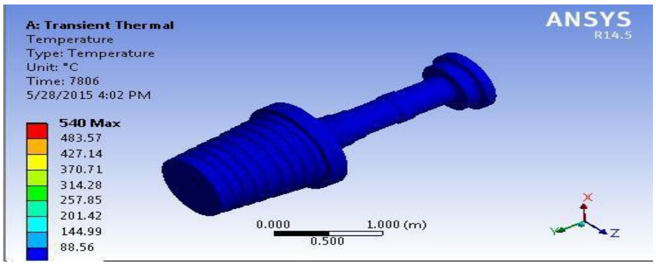

Fig 9 -: Variation of Temperature on H.P Turbine Rotor at 7806 seconds Time Step.

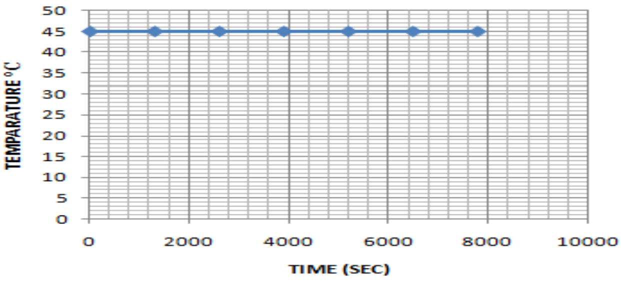

Fig.10: Graph of time v/s temperature at 7806 seconds

The graph (Fig.9) shows that the temperature of the rotor surface is 45°C for first 7806 seconds.

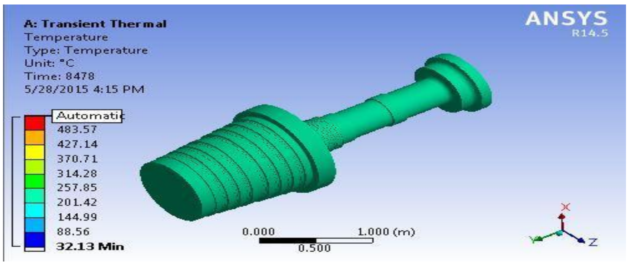

Fig.11:- Variation of Temperature on H.P Turbine Rotor at 8478 seconds Time Step.

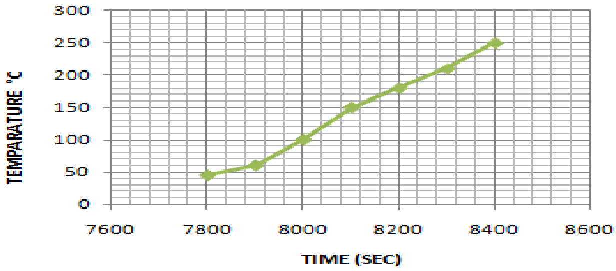

Fig.12: Graph of time v/s temperature at 8478 seconds.

The graph (Fig.12) shows that temperature of the rotor raises from the 45°C to 250°C in time interval of 672 seconds only.

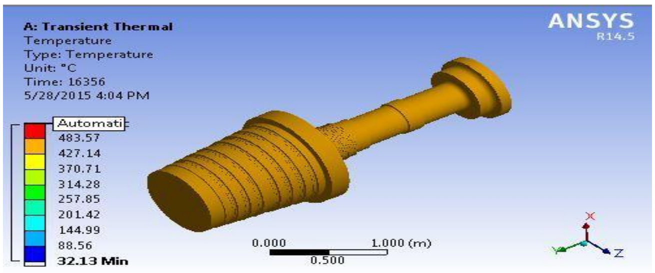

Fig 13:-Variation of Temperature on H.P Turbine Rotor at 16356 seconds Time Step.

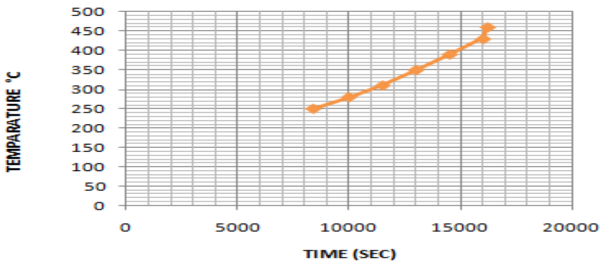

Fig.14: Graph of time v/s temperature at 16356 seconds

The graph (Fig.14) shows that temperature of the rotor surface rises from 250°C to 460°C that takes longer time i.e. 7878 seconds.

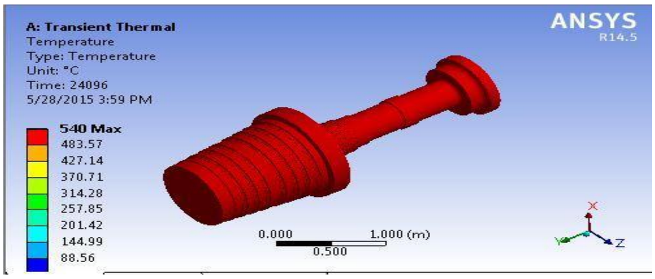

Fig 15:-Variation of Temperature on H.P Turbine Rotor at 24096 seconds Time Step.

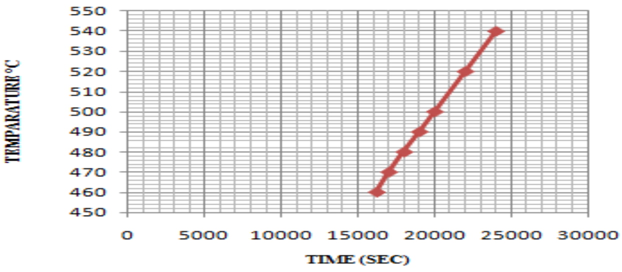

Fig 16: Graph of time v/s temperature at 24096seconds

The graph (Fig.16) shows that temperature of the rotor rises from 460°C to 540°C and takes more time i.e. 7740 seconds.

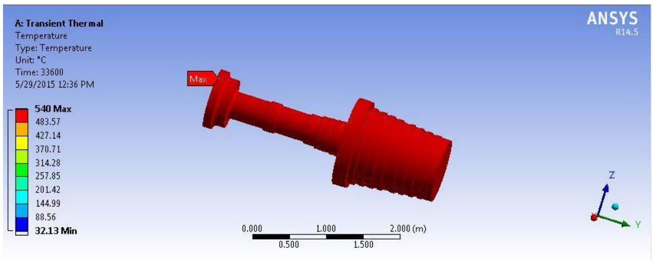

Fig 17:- Variation of Temperature on H.P Turbine Rotor at 33600 seconds Time Step.

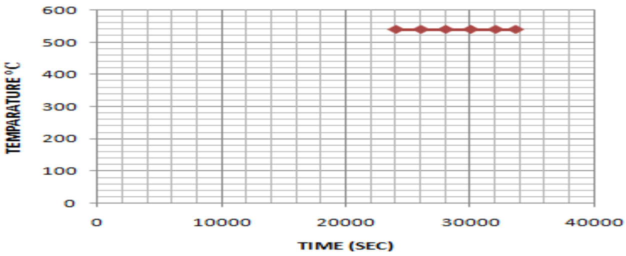

Fig 18: Graph of time v/s temperature at 33600 seconds

It is observed from the graph (Fig.18) that the temperature achieved after 24000 seconds is 540°C and remains same for the next 9504 seconds. During running of steam turbine rotor, the temperature rises at the rotor center much slower than at the surface, which causes a relatively high temperature difference.

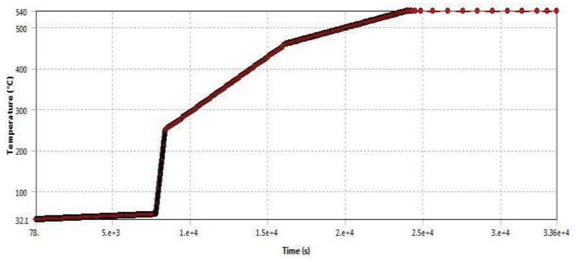

Fig. 19: Temperature distribution graph

From fig. 19, it can be seen that temperature at bore of rotor reaches higher value than that of rest of the rotor where crack begins to propagate. The crack size can be calculated by using R6 code –software developed by British energy for assessing the integrity of structural containing defects**.** [1] Cracks located near the rotor axis could grow to a critical size causing brittle fracture failure. At the rotor surface, the operating temperature is high. Hence creep interaction is the primary damage mechanism that could limit rotors safe working life.

CONCLUSIONS

The structural analysis is carried out for rotor by using FE software. It is found that the maximum stress obtained from analysis is less than yield strength. Hence the design is safe.

Similarly the transient state analysis is carried out to determine the temperature distribution and with respect to change in time. It is observed that the temperature varies from room temperature to 540 °C during 24000 seconds and remains same for remaining time i. e. 9600 sec (33600 sec -24000 sec). The temperature distribution can be validated experimentally by using following models- (a) Manson-Coffin model (b) CDM model (c) Miner's LDA model (d) SEM Fractography. [11]

REFERENCES

[1] Xiaoling Zhang, "High Temperature Rotors: Failure Mechanisms and Remnant Life Assessment," 2006 ASME Pressure Vessels and Piping Conference, PVP 2, Vancouver, BC, Canada, July 23–27,(2006)

[2] R.Viswanathan, Damage mechanisms and life assessment of high temperature components, (1993) second edition ASM international

[3] S.barella, M.Bellogini, M.Boniardi, S Cencera," Failure analysis of steam turbine rotor, "Engineering Failure Analysis. 2011 18 1511-1519. (2011) Elsevier Ltd

[4] Steam turbine Operation & Maintenance Instructions Manual 2X300MW

[5] Shrikanth Bashetty, Parthasarathy Garre, "Coupled Thermal-Structural Analysis of a Turbine Rotor using Ansys for finding out remnant life," The International Journal of Science and Technology (ISSN 2321-919X).

[6] Y Maruthi Prasad, A K Shukla and Amitava Roy, "Analysis of transient thermal cycling for life assessment of steam turbine rotors, "Journal of Scientific & Industrial Research. Feb (2007).

[7] A. Caccialupi, R Crudeli, G P Fazio, F.Porro, M.Santoro, M.Zannoni, Approach to Reduial Life assessment of large steam turbine component. International .journal Pressure & piping. 59 1994(241-258).

[8] Jeffrey R.Cheski, et al Siemens, A large steam turbine retrofit design and operation history. Power-Gen International Conference, Las Vegas, NV. December 6, 2005

[9] Vivek V. Pande, G.R.Nikhade, S.K.Nath, Finite Element Analysis of Steam Turbine Casing. Third International Conference on Industrial Engineering, SVNIT Surat (IND). Nov 2015

[10] S.R. Holdsworth, E. Mazza, L. Bindaa, L. Ripamonti, Development of thermal fatigue damage in 1 CrMoV rotor steel. Nuclear Engineering and Design 237 (2007) 2292-230, Elsevier

[11] Maneesh Batrani BHEL Haridwar, Hypermesh an effective 3-D CAE Tool in Designing of complex steam turbine low pressure casing 2006, IEEE

[12] www.matweb.com

Corresponding Author

Nikhil S. Jumde*

Asst.Proffesor, Mechanical Department, Shri Sai College of Engineering & Technology, Bhadrawati-442902, M.S, India

E-Mail – nsjumde@gmail.com