

Life Prediction under Creep-Fatigue Interaction with ABAQUS/CAE and fe-safe/TURBOLife tool

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ABSTRACT: The life of a component is nothing but its availability for intended service at specified operating conditions. In the turbomachinery components which are subjected to simultaneous thermal and structural loading the life prediction plays an important role to avoid a catastrophic failure. The purpose of this paper is to investigate the thermo-mechanical fatigue failure of last stage low pressure steam turbine blade and to predict life in hours for crack initiation. The present work primarily focuses on development of a new approach in life prediction under creep-fatigue interaction. The elastic finite element analysis were carried out with ABAQUS/CAE and life prediction calculations are done with fe-safe/TURBOLife tool. A sequential thermal-structural analysis were carried out for steam turbine blade material IN713C. The user defined low cycle fatigue loading with temperature variation is employed for analysis. The material properties involved in fe-safe/TURBOLife are temperature dependent are determined from various experimentations. The life prediction calculations in software tool are done with ductility exhaustion (DE) model.

KEYWORDS: life prediction, last stage low pressure steam turbine blade, creep-fatigue interaction, crack initiation, ABAQUS/CAE, fe-safe/TURBOLife.

I. INTRODUCTION

Now a days mechanical devices are operated at increased operating parameters like temperature, pressure etc. such trend has resulted in starting, growth and interaction of complex damaging processes within the material of these devices. This can lead to failure of component and, consequently of whole structure, thus limit their lifetime. Therefore, an assessment of life is very important to avoid or to prevent catastrophic failure.

Halaszi et al. [1] explained the various damage mechanisms like fatigue damage, creep damage and environmental or oxidation damage. These mechanisms may act independently or can interact depending on various material characteristics like thermal conductivity, thermal expansion coefficient, mechanical properties and operating conditions like maximum and minimum operating temperature etc. A lot of similarity has been observed in low cycle fatigue and thermo-mechanical fatigue.

The predictability of life under thermomechanical fatigue with various materials is studied by Christ [2]. The variation of damage mechanism and cyclic stress-strain behaviour with temperature is also mentioned. In Thermomechanical fatigue during low temperature operation the damage found to be fatigue dominated and with increased temperature it becomes creep dominated.

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II. LITERATURE SURVEY

The prediction methods for thermo-mechanical fatigue life are critically reviewed by Zhuang and Swasson [3]. The few of popular life prediction models are damage summation model, frequency separation model, ductility exhaustion (DE) model, Strain range partitioning model, total strain version of strain-range partitioning model and strain-energy partitioning. Each model has its own merits and demerits.

Ductility exhaustion model is originally derived from the Coffin-Manson relationship between inelastic strain-range ($\Delta\varepsilon_{in}$) and number of cycles to failure (N_f).

Given by;
$$\Delta\varepsilon_{in} N_f^\alpha = D$$

Where α – constant approximately equal to 0.5 at room temperature, may increase up to unity at elevated temperature.

From above expression, the equations for

Creep dominated failure: $\Delta\varepsilon_c N_c = D_c$

And fatigue dominated failure: $\Delta\varepsilon_p N_p = D_p$

Where $\Delta\varepsilon_c$ - Tensile creep strain per cycle, D_c - Low band creep ductility, N_c - Life for creep dominated failure,

$\Delta\varepsilon_p$ - Effective plastic strain, D_p - Fatigue ductility, N_p - Life for fatigue failure.

By simple interactive creep-fatigue damage rule, the lifetime of creep-fatigue can be calculated from;

$$1/N_f = 1/N_c + 1/N_p$$

DE model is simple to use and successfully used to interpret test data. The lifetime indicated by DE model is normally conservative which may be due to effect of oxidation or specimen geometry instability. In fe-safe/TURBOLife the life prediction calculations are done with ductility exhaustion model.

Tulsidas et al. [4] studied a technique to assess low cycle fatigue of steam turbine blade one with linear elastic FEA and fictive were calculated using Neuber's rule, second is based on elastic-plastic FEA. The stresses in linear analysis are much higher than the yield stress of material hence Neuber's formula is used to estimate the plastic stress-strain state. In fe-safe/TURBOLife the fictive stresses will be calculated with the help of Neuber's plasticity method. The critical areas of turbine blade are mentioned in above paper which are air foil base, blade neck and disc hook.

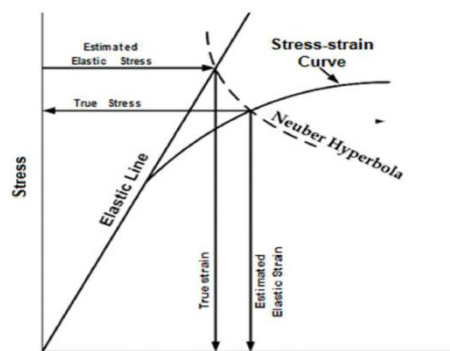


Fig. 1. Neuber's Hyperbola

P. Mestaneck [5] attempted to investigate the low cycle fatigue analysis of the low pressure (LP) steam turbine blade which are cyclically loaded with centrifugal force because of repeated startups of turbine. This study deals with the fatigue analysis of low pressure blade which is used in last stages of large steam turbines. The blade is equipped with fir-tree root assembled in axial groove. The blade is subjected to repeated startups and shutdowns which leads to fatigue in blade. The dynamic forces are neglected since the blade under study was stiff and robust enough to avoid the resonance at lowest multiples rotational frequency. The bending moment induced due to steam pressure is neglected since the change in stresses due to these stresses is less than 0.15%. The whole structure is loaded with rotational speed of 3000 rpm.

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Paper is organized as follows. Section III describes briefly problem definition. After defining the problem, the method of solving the problem is given in Section IV. Section V presents the simulation and life prediction of turbine blade using ABAQUS/CAE and fe-safe/TURBOLife respectively. Finally section VI and VII deals with conclusion and acknowledgement respectively.

III. PROBLEM DEFINITION

Most of steam turbines are subjected to structural and thermal loading which induce a creep-fatigue interaction. In this present work we are trying to develop a new approach to determine life under creep-fatigue interaction. The stress analysis has to be performed using ABAQUS/CAE and life prediction is to be done using fe-Safe/TURBOLife tool.

IV. METHODOLOGY

1. PROCESS LAYOUT

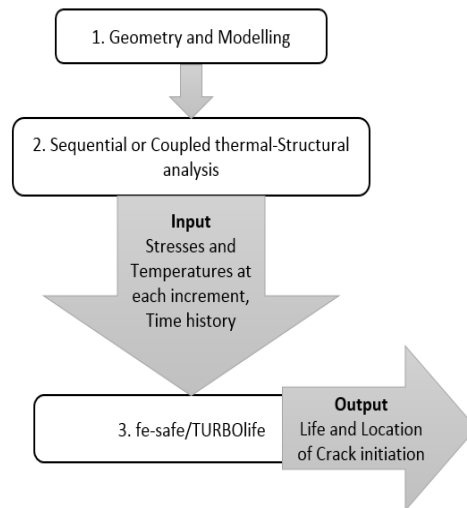


Fig.2. Process layout for life prediction

2. PRELIMINARY DESIGN CONSIDERATIONS

Material: IN713C

Table 1: Material Properties

Temperature (°C)	Specific heat (J/Kg.k)	Thermal conductivity (W/m.k)	Coefficient of thermal expansion (°C)	Young Modulus E (MPa)
204	500	12.2	1.19E-05	203000
427	545	15.4	1.31E-05	193000

Operating speed (N): 3000 rpm
Temperature: 300 °C

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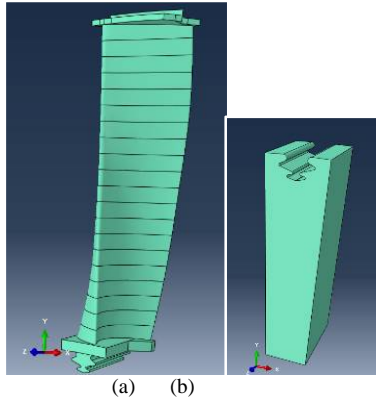


Fig.3. Isometric view of (a) Blade (b) Disc

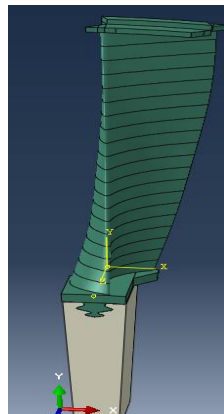


Fig.4. Assembly of Turbine blade

The model of the last stage low pressure steam turbine blade and disc is created using 3Dx platform and then imported to ABAQUS/CAE as shown in Fig.3. (a) And (b) The FE model is created using tetrahedron elements with 115401 elements and 44363 nodes. The contact interactions are created in assembly as shown in Fig.4. In thermal analysis the temperature of 300°C is applied on blade portion. For structural analysis rotational body force of 3000rpm is applied with start-up and shut-down cycle. The cyclic symmetry model is created in order to simulate the bladed disc assembly.



Fig.5. Meshed Turbine blade

V. SIMULATION AND RESULTS

1. FINITE ELEMENT ANALYSIS

Start up and Shut down cycle:

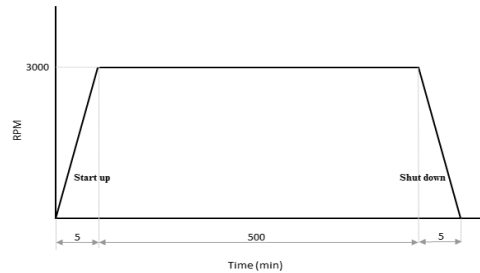


Fig.6. Graph of load V/s time

The loading of turbine blade is described in such a manner that it will generate a creep-fatigue damage interaction. The rapid start-ups and shutdowns will induce a fatigue damage and dwell period will cause fatigue damage. In thermal analysis the temperature of 300°C is applied on blade surface. The von-mises stress for blade portion is found to 1198 MPa which appears at aerofoil root of blade. As the blade part of assembly plays an important role in a successful operation of steam turbine hence we are interested only in stresses in blade part.

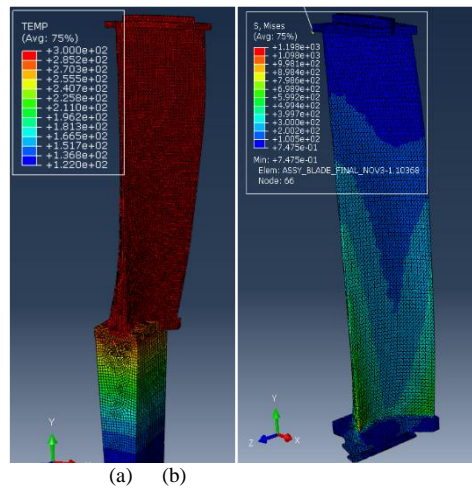


Fig.7. (a) Temperature variation and (b) Von-mises stress for blade

2. LIFE PREDICTION AND LOCATION OF CRACK INITIATION

The output file of finite element analysis is imported to fe-safe/TURBOLife with dimensional homogeneity with analysis unit system. Once the finite element model is imported the loading blocks are defined as shown in Fig. 8. (a). The life prediction model DE is enabled through user interface. The life of turbine blade is predicted with fe-safe/TURBOLife tool and which is found to be 10838 hours and location of crack initiation is at leading edge of blade aerofoil section shown in Fig.9.(a).

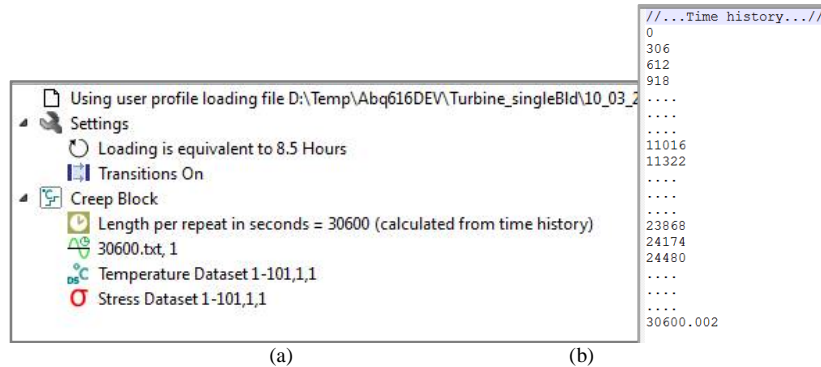


Fig.8. (a) Loading block in fe-safe/TURBOLife and (b) Time History

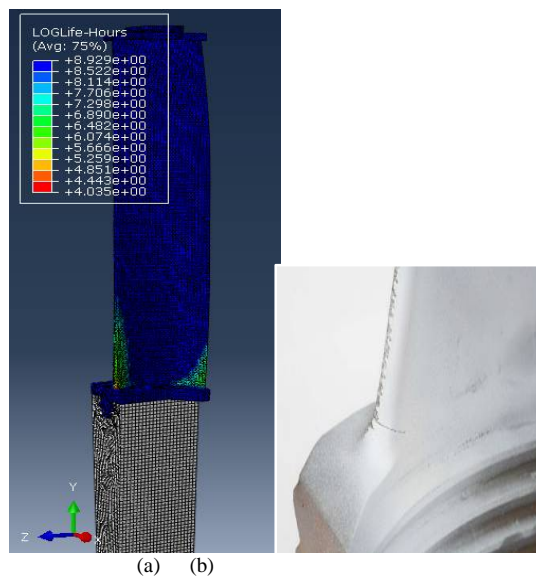


Fig.9. (a) Life and location of crack initiation and (b) Actual location of crack initiation.

VI. CONCLUSION

From above results we have found that the peak stress in analysis are more than the yield strength hence these stresses were Neuberized and life of blade is calculated. The life of turbine blade for crack initiation is found to be 10838 hours which is approximately 1.24 years and along with this we are able to found the location of crack initiation. The location of crack initiation is validated with literature available as shown in fig.9(b).

We have proposed a new methodology to predict the life of component under creep-fatigue interaction which seems to be quite promising. The more precise or accurate results can be obtained with more realistic boundary conditions, loading conditions and material properties.

VII. ACKNOWLEDGMENT

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