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CREEP FATIGUE INTERACTION STUDY IN A STEAM TURBINE SHAFT – ASSESSMENT OF LIFE CONSUMED

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ABSTRACT

Power plant turbine hot parts are subjected to high temperature fatigue, and creep loading. The fatigue damage accumulation caused from both fatigue and creep mechanisms and their interactions lead to the failure of components. In this paper authors present a case study of predicting the fatigue hot spot in a turbine shaft of a 220 MW steam turbine. In this study the fatigue-creep interactions were studied to obtain hot spot accurately. Objective of the work is to develop a computational model for the turbine shaft, to predict the hot spots and number of cycles for crack initiation. Such a model would be used for reliability and risk analysis for remaining life assessment and life extension.

Damage hot spots and the flaw size (defect) were available from NDT. Crack initiation and growth had happened in between the maintenance intervals. First step towards remaining life assessment was to model the damage accumulated and life consumed. A part of such study regarding damage accumulated is presented here. A detailed thermo-mechanical finite element model with rate dependent thermo-plasticity is generated. A commercially available software ABAQUS is used for this purpose. Damage model was generated using creep and fatigue modeling and an interaction model. For this purpose a commercially available damage software for fatigue life and durability analysis, FESAFE / Turbolife was used.

Model predictions of the fatigue hot spot was seen to correlate exactly with the NDT test flaw location. Crack initiation cycles predicted were also correlating with plant observations.

Keywords: Creep, fatigue, remaining life assessment, (RLA), damage assessment, turbine shaft.

1.0 INTRODUCTION

Creep and fatigue damage can occur separately and interactively during plant operation. Fatigue damage is primarily related to the magnitude of load and load cycles. Creep damage is primarily related to steady load levels and operating temperature. During the transient events in the operation of a turbine, thermal stresses occur causing high fatigue loading. At the same time, turbine system experiences creep loading as result of high temperatures. Combination of creep and fatigue loading over a period of time puts stresses on the turbine system, eventually leading to crack initiation and growth that can limit life. Determining the damage caused by creep and fatigue is very important for the reliability and durability assessment of the steam (or gas) turbine hot parts.

A 220 MW steam turbine is studied here. The IP Shaft was made out of 30-Cr Mo Ni V 511 rotating at 3000 RPM. Table 1 shows the Operating conditions of the plant.

Table 1: Operating conditions

IP Rotor		
Stages	**Pressure (MPa)**	**Temperature(°C)**
Inlet	2.50	535
1	2.19	515
2	1.87	500
3	1.56	460
4	1.25	420
5	1.05	390
6	0.86	360
7	0.66	320
8	0.54	300
9	0.41	290
10	0.28	240
11	0.14	183
Exhaust	0.14	183

This plant had undergone a service life of 30 Years, against a design life of 36 years. The usage cycle was Cold starts: 19, Warm starts: 81, Hot starts: 67

A challenge in the remaining life assessment and life extension studies in Indian plants is the lack of sufficient information and availability of basic design details. The basic requirement is to generate a 3D CAD model for any analysis. For a majority of plants, the design drawings are not available. The time available during the maintenance interval is too short to create a 3D CAD model. Figure 1 shows a schematic flow chart of remaining life assessment project cycle.

2.0 CREEP FATIGUE INTERACTION ANALYSIS

For the estimation of damage from numerical techniques, following parameters plays an important role.

- Loading definition (hot start, cold start warm start, operating pressure)
- Materials definition & Damage mechanism Algorithms chosen (Cyclic hardening curve, Creep ductility as a function of creep strain rate for the creep damage calculations, A creep damage and fatigue damage interaction diagram etc)

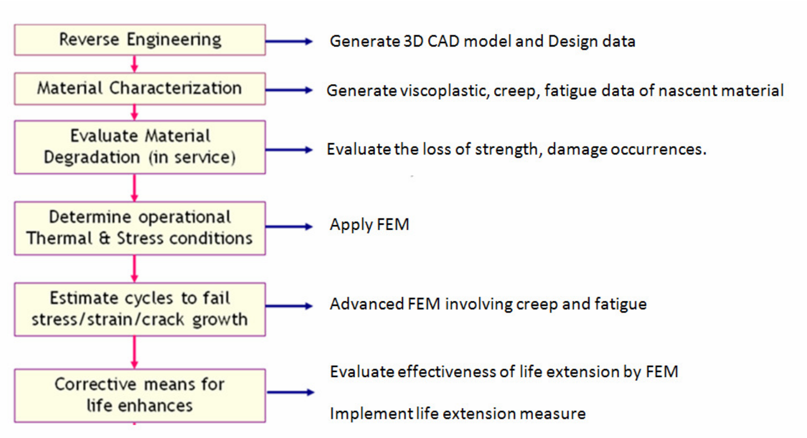

Figure 1: Flow chart for RLA.

3.0 TURBINE SHAFT CREEP FATIGUE ANALYSIS

The shaft was analyzed for thermo mechanical loads arising due to operating conditions as given in Table 1. Coupled thermo mechanical analysis using ABAQUS was performed; temperature, stress and strain results were taken for further creep & fatigue analysis. Figure 2 shows a FE model of the shaft.

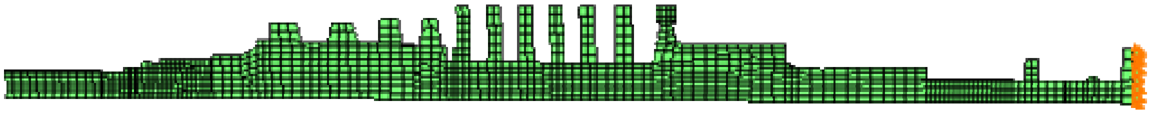

Figure 2: FE model of turbine shaft

The following sections outline the procedure for performing an analysis using fe-safe/TURBOlife.

fe-safe/TURBOlife performs creep-fatigue crack initiation calculations for engineering components under thermo-mechanical loading. fe-safe /Turbolife has ductility exhaustion and strain range partitioning methods for calculating creep damage.

3.1 Ductility Exhaustion (DE)

Stress analysis for the component is performed elastically by finite element analysis to describe the load cycle or a sequence of load cycles. Plasticity and relaxation methods are then used to calculate plastic strain and creep strain at a node for the load sequence and construct the stress-strain history. Individual cycles and unmatched half cycles are identified. Fatigue endurance is calculated using a strain-life approach and creep life is calculated using a creep ductility exhaustion method. Creep fatigue interaction is accounted for by means of a creep-fatigue interaction diagram.

3.2 Strain Range Partitioning (SRP)

This method is based on work by Manson, Halford and Hirschberg [1]. It is aimed at separating a strain cycle into its strain component behaviors and then evaluating the damage attributable to each. The strain components are creep and plasticity.

3.3 Creep-Fatigue Interaction Diagram

To account for the significant additional damage due to the interaction of creep damage and fatigue damage, the interaction diagram is often used. The form of the interaction diagram is shown in Figure 3 [2,3,4 and 5].

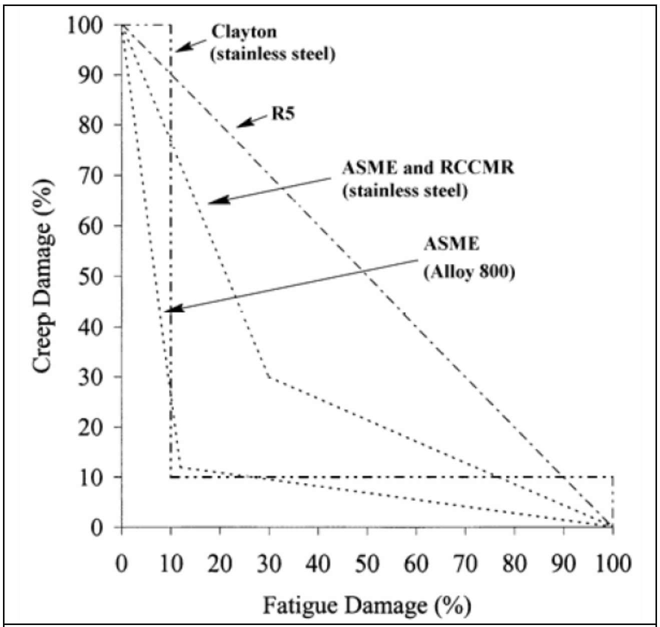

Figure 3 : Creep-Fatigue Interaction Diagrams

Cracking will occur when the fatigue damage-creep damage coordinates are outside the envelope (dotted lines) with respect to the interaction model chosen. Various forms of the interaction envelope have been proposed R5, RCC-MR, ASME and Clayton.

Table 2: Calculation basis of various methods.

METHOD	CREEP DAMAGE	FATIGUE DAMAGE	CALCULATION METHOD
RCC-MR	Time fraction	Strain life	Approximate elastic methods
ASME	Time fraction	Strain life	Approximate elastic methods
R5	Strain fraction	Strain life	Approximate elastic methods
Clayton	Strain fraction	Strain life	Detailed inelastic analysis

4.0 RESULTS AND DISCUSSION

Figure 4, shows the temperature distribution in the turbine shaft. Temperature dependent thermal properties are used for this analysis. Figure 5 shows the temperature-time plot at point 1 on the shaft. Figure 6 shows stress developed due to thermo-mechanical loads in the shaft. Stress hot spots indicating stress concentration is visualized in Figure 6.

Detailed fatigue and creep analysis and creep-fatigue interaction study of steam turbine shaft was performed for plant service and operating conditions. Figure 7 shows damage site predicted. It can be seen that the damage hot spot is different from stress hot spot. This is amply explained by the modern metal fatigue theory [6]. Figure 7 also shows the actual failure in the physical shaft. Correlation of the predicted and plat observed hot spot is visualized.

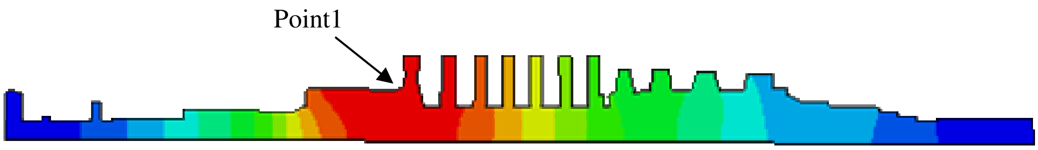

Figure 4: Temperature distribution in the shaft

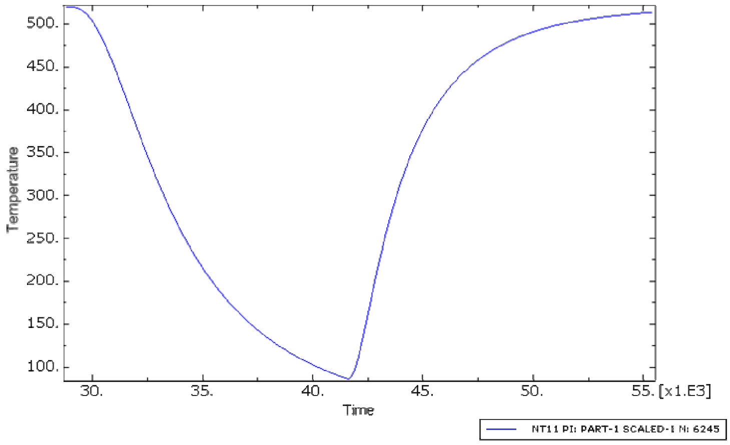

Figure 5: Temperature variation with time at high temperature location shown

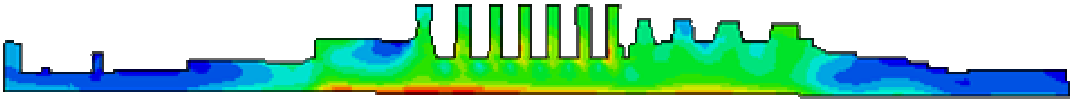

Figure 6: Stress due to thermal expansion of shaft

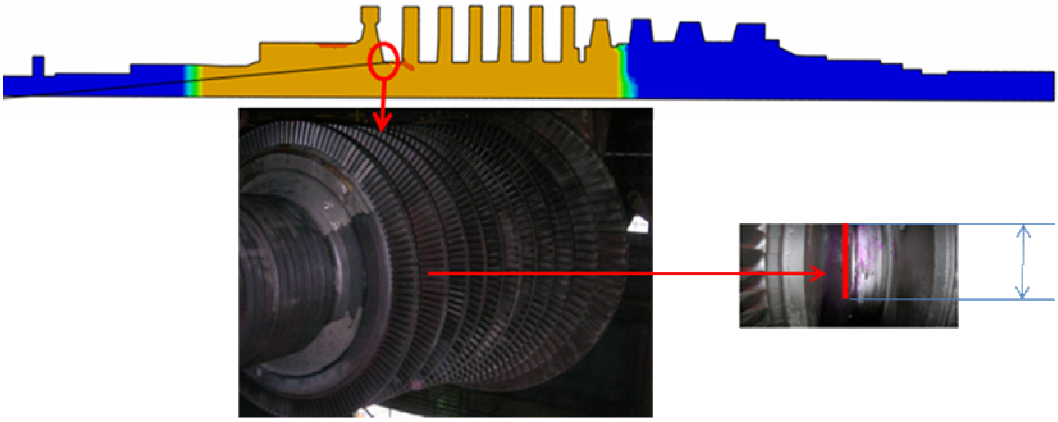

Figure 7: Failure hot spot

5.0 CONCLUSIONS

Damage sites and flaw sizing was done by NDT. The hot spot predicted by FEM analysis and fatigue damage simulation was found to match exactly with the NDT observed hot spot. This was done by accounting for the creep and thermos-mechanical fatigue damage interactions.

Further investigations were carried out to assess the remaining life. The analysis showed that the crack initiated much earlier to the designed life of due to higher number of hot, warm and cold startups.

Computer simulation and analysis based remaining life extension studies are useful to predict the damage. Users should take appropriate care to impose right material model in such efforts. With such carefully calibrated model, one can develop a science based approach to assess the risk and reliability in remaining life extension studies off turbine hot parts.

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