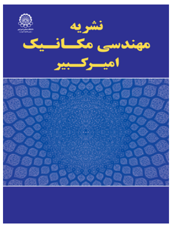

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Developing a CDM Based Model for Creep-Fatigue Life Assessment of a Gas Turbine Blade

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ABSTRACT: The aim of this research is to propose a procedure for predicting the creep-fatigue life of gas turbine blade. Components in gas turbine hot section such combustion chamber and turbine get damaged under effect of thermomechanical loadings. These damages developed via fatigue and creep together, thus it is necessary to identify their interaction with each other. Chaboche's elasto-viscoplastic model which is an appropriate model for simulating the behavior of nickel alloys is used. Damage evolution rules for fatigue and creep which introduced by Chaboche and Kachanov, respectively, added to viscoplastic model and implemented in ABAQUS by developing an appropriate UMAT. After verification of developed subroutine, the creep-fatigue life of a rotor blade in last stage of a low-pressure turbine was assessed. The predicted life has presented in three ways as (1) the operating hours, (2) the number of starts and (3) the equivalent operation hours which are the common ways of announcing gas turbines life. Comparison the obtained results with common gas turbine lifetimes represents the capability and practicality of proposed model.

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1- Introduction

Gas turbines subjected to various mechanical and thermal damages due to their functionality. Recognizing these damages and their effects on each part are vital steps in a life assessment process. The turbine is the most complicated part in a gas turbine in terms of applied loadings and damages are inducing by them such as fatigue damages due to rotational loadings, creep damages by high temperature and the other damages such as fretting due to vibrations and erosion and hot corrosion due to gas collision. The major damage might be the combination of the low cycle fatigue and creep called thermomechanical damage.

Since 1975 [1] with the observation of creep-fatigue effects on metallic materials, thermomechanical damage has calculated in two different methods. In the first one, the interaction of creep and fatigue has neglected and their damages have independently considered, then at the end of process they add together. The predicted lifetime in this method is usually higher than actual life. These limitations lead researchers to propose new models in thermomechanical life assessment. In second method by utilization of damage parameter introduced by Kachanov [2] in 1986, creep and fatigue damages have calculated simultaneously and add together to consider their interaction during loading time. In the context of this method Chaboche [3] has introduced his elastic viscoplastic model for simulation of the behavior of nickel alloys in 1989 and represents equations for calculating creep and fatigue damages in 2001 [4]. Other researchers such as Kim et al. [5], Shi et al. [6] and Wang et al. [7] also using this method in the process of gas turbine life assessment.

In the present study, a rotor blade which was made by Waspaloy and from the last stage of a heavy-industrial gas turbine has been studied. The blade subjected to thermomechanical loading, then damage has calculated for various operation times and predicted lifetimes have reported in two forms of operation hours and numbers of starts and shutdowns. This work is superior to previous researches in two areas, first in modeling a 3-Dimensional (3D) part which has all the stress components in it unlike others that studied standard sample models and second is calculating Equivalent Operation Hour (EOH) parameter for each analysis which is official term of reporting gas turbines lifetime in power generation plants. These issues have been neglected in majority of previous studies.

2- Methodology

In order to simulate a creep-fatigue analysis and calculate their respective damages two kinds of equations are required. The first equation is the constative equation that represents behavior of the alloy under creep-fatigue conditions. To aim this goal Chaboche's elasto-viscoplastic model has been employed. The main equations of the developed model have been shown as Eqs. (1) to (3):

$$\dot{\varepsilon} = \dot{\varepsilon}^{e} + \dot{\varepsilon}^{I} \tag{1}$$

$$\dot{\varepsilon}^{I} = \frac{3}{2}\dot{p}\,\frac{S'-X'}{J\left(S'-X'\right)} \tag{2}$$

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Table 1. Turbine characteristics

Operation Time	Damage (per cycle)	Lifetime (hrs.)	Lifetime (cycle)
10 min.	0.00004338	3842	23052
30 min.	0.00005843	7641	15283
1 hour	0.00013894	7197	7197
5 hour	0.00049429	10115	2023

Table 2. Turbine characteristics

Operation Time	No. of Starts & Shutdown	EOH (hrs.)
1 hour	1	1.42
5 hour	1	23.51
5 hour	5	32.73
5 hour	30	433.12

$$\dot{p} = \left\langle \frac{\frac{|S'-X'|}{1-D} - R - k}{Z} \right\rangle^{n} \tag{3}$$

which $\dot{\varepsilon}$ is strain rate, $\dot{\varepsilon}^{e}$ and $\dot{\varepsilon}^{I}$ represents elastic and inelastic strain rate, P is plastic parameter, S is deviant stress tensor and X and R represents isotropic and kinematic hardenings respectively and k is yield stress and n and Z are viscous parameters.

The second kinds of equations are damage evolution formulas that calculate creep and fatigue damage during analysis. These equations have been shown as Eqs. (4) to (6):

$$dD = dD_c + dD_f \tag{4}$$

$$dD_c = \left(\frac{\sigma}{A}\right)^{r} (1-D)^{-k}\, dt \tag{5}$$

$$dD_f = \left[1-(1-D)^{\beta+1}\right]^{\alpha(\sigma_{\max},\bar{\sigma})} \left[\frac{\sigma_{\max}-\bar{\sigma}}{M(\bar{\sigma})(1-D)}\right]^{\beta} dN \tag{6}$$

These six equations have been introduced to ABAQUS finite element software in the framework of UMAT subroutine to simulate the thermomechanical analysis of nickel-based alloys. Loading consists of a Start Operation Shutdown (SOS) cycle with various operation times that applied as pressure on internal surface of blade plus a rotational constant speed and a constant temperature. The damage of each cycle is accumulated up to end cycle.

3- Results and Discussion

Damages that produced during a cycle for each operation time have been shown in Table 1. Predicted lifetime for 1-hour case is about 7200 cycle with one-hour duration for each cycle; lead to 7200 hours blade lifetime. By reducing operation time to 10 minutes, it can be seen the number of cycles increases while the lifetime in form of hours decreases. It reflects the effects of fatigue in compression of creep in life assessment process that means short time intervals and several starts-shutdowns operations, decrease turbine life drastically.

It is noted that the obtained results can be shown in the concept of EOH that equates damages caused by starts and shutdowns causing fatigue, with damages due to operating time, causing creep mechanism to create a basic condition. EOH parameters for some cases have shown in Table 2.

It can be seen that EOH in the first case with one hour operate and one-time start and shutdown, is equal to 1.42 EOH, means the damage caused by a one-time start and shutdown is equal to 0.42 hour of operation in normal condition. The second case shows the damage produced by 5 hours of operation is nearly 20 times greater than 1 hour and compression between second, third and fourth cases shows the effect of increasing starts and shutdowns on EOH. Again, it can be concluded that shorter operating times leading higher number of starts and shutdowns, will greatly reduce the useful life of a gas turbine.

4- Conclusions

In the present work, a method based on continuum damage mechanics was presented for gas turbine life assessment. The developed method employing Chaboche's elasto-viscoplastic model to simulate fatigue and creep damages of nickel-based alloys. to consider creep-fatigue interaction during the loading, all of procedure were inserted into Abaqus solver via a UMAT subroutine. The obtained results of developed code show that with decreasing the operating time, the number of SOS cycles has increased while the total lifetime of turbine decreasing. In other hand, it can be concluded that shorter operating times leading higher number of starts and shutdowns, but will greatly reduce the total life of turbine. The EOH parameter was calculated for various investigated cases to highlight the effect of starts and shutdown on gas turbine lifetime. In addition the results show that in five hours operating with one start and shutdown the EOH is equal 23.51 hours and it can be increased to 32.73 hours with 5 starts and shutdowns. Comparison these results with common gas turbines lifetimes represent the capability and practicality of the proposed model.

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